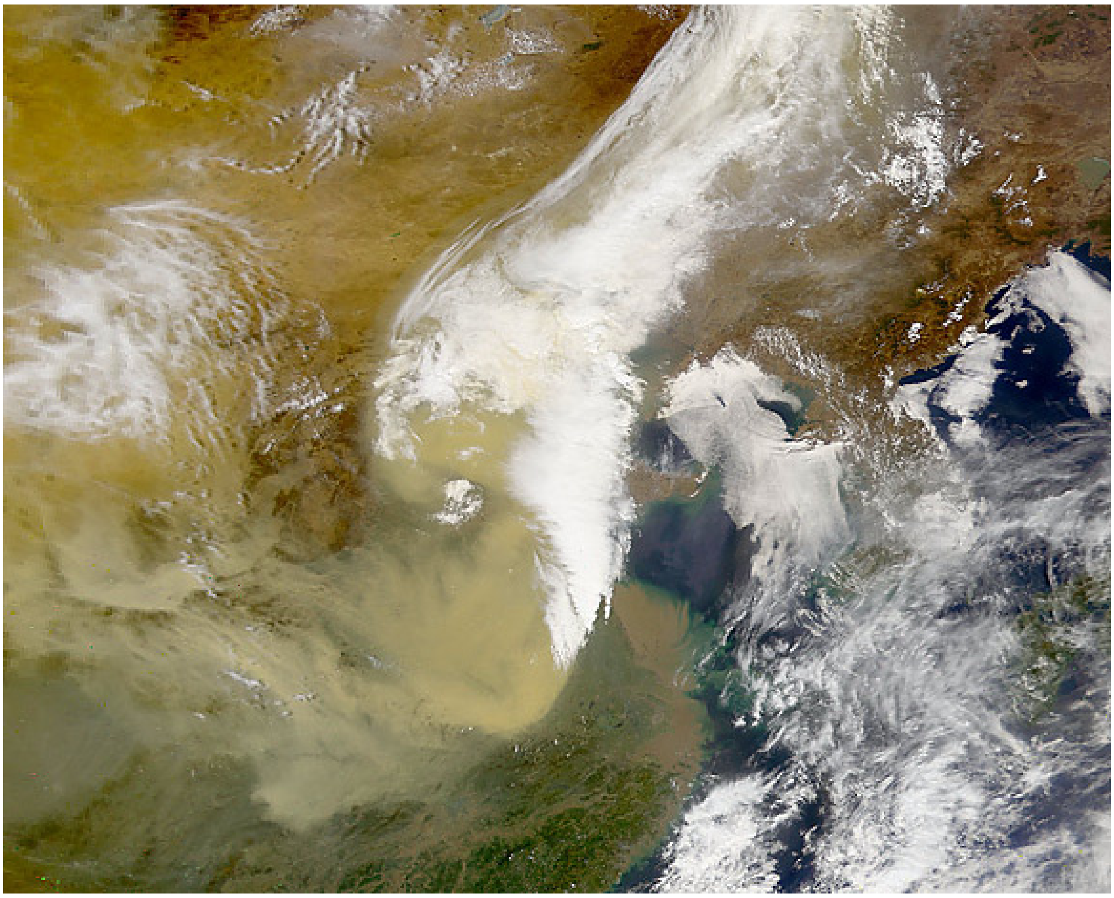
GLOBAL ALARM: DUST AND SANDSTORMS FROM THE WORLD'S DRYLANDS



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"These SeaWiFS images show the development of a large dust storm in China and its interaction with a meteorological system that carried the dust far out into the Pacific Ocean. In the first image, from April 16, 1998, the bright yellowish-brown cloud near the coast is the center of the storm, being pushed by a frontal system. In the subsequent images from April 20-24, the atmospheric circulation around a low-pressure system entrains the dust from the storm and carries it over the North Pacific Ocean. On April 25, dust from this event reached the West Coast of North America."

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http://eosdata.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/asian_dust.html

Additional copies of this publication are available upon written request from the Asia RCU of the UNCCD, United Nations Building, Rajadamnern Avenue, Bangkok 10200, Thailand.

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Yang Youlin	*Victor R. Squires*	*Lu Qi*
Bangkok	*Adelaide*	*Beijing*

Bangkok, August 2001

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PREFACE

INTRODUCTION

After the devastating dust storms that swept across Northern China in 2000, there was much interest in examining and analyzing experiences with dust storm mitigation, prevention, forecasting and control. There was a need to document the nature, extent, causal factors associated with the severe sand and dust storms experienced in China itself and which threatened the lives and livelihoods of millions of people. Due to the long-range transport of sediments impacting the neighbouring countries, especially those downwind of the source, there was much interest in getting international cooperation so that the collective wisdom of experts from many countries could be distilled in this monograph.

What emerged from the writings collected here was that desertification - land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities, is the result of processes that are complex and variable. Desertification is characterized by a cycle of natural and socio-economic causes and effects.

Sand and dust storms are both a symptom and cause of desertification. They are often an early warning that things are going wrong. Once they progress from slight to serious and severe categories they contribute to the spread of desertification through the transport and deposition of sediments that can destroy crops, habitation and infrastructure and render areas uninhabitable.

Combating sand and dust storms demands political, social, biological, economic, educational and engineering approaches as well as the physical effort that has dominated efforts in the past.

Past policy in many countries has been shown to exacerbate the problem and efforts are now being made to reverse past mistakes and set things in train to develop and maintain more sustainable land-use. Lessons learned from the big disasters in North America during the so-called Dust Bowl era of the 1930s and the more recent adoption of participatory approaches in many other countries, may well see a reversal of the recent trends toward more frequent and more severe dust storms, that not only affect local communities but are impinging and impacting on peoples in urban centres. Apart from the inconvenience and the disruption to transport and communications, there is also the increased risk of health-related problems (respiratory diseases, etc).

There are enormous costs in terms of direct damage to life and property but also in terms of income foregone. Development of robust and sophisticated tools to enable economic analysis of the real costs of dust storms is a high priority. Decision-makers need to know, based on cost-benefit analysis, how to respond to the perceived threats.

A number of decision-making problems arise as we try to balance the costs of early action against delayed or no action. One way to deal with this problem of uncertainty is to adopt the precautionary principle *"when there are threats of serious or irreversible damage, lack of full scientific uncertainty should not be used as a reason for postponing such measures."* Clearly there is need for more research into the economic aspects including a robust methodology for assessing *"damage cost"* and more work needs to be done on the important questions of monitoring, prediction and forecasting of dust storms.

Because the impact is on people, the human tragedy needs to fully understood. Drylands occupy half of the world's land surface. They are home to about 1 billion people and therefore warrant a lot of attention from national governments and from the broader international community. From the point of view of the UN family of agencies there are many cross cutting issues involved: food security, poverty alleviation, health and welfare and sustainable development. The recognition that the world's drylands are regions under threat has now taken hold. Many countries are signatories to the UN Convention to Combat Desertification (UNCCD) and many have prepared their National Action Plans. Efforts to arrest and reverse land degradation will have a beneficial effect on the mitigation of dust storms and improve the welfare of the people.

This publication aims at providing the reader with analysis of the factors contributing to dust and sandstorms and provides, via the various detailed case studies, examples of how the menace can be brought under control through a series of measures, ranging from mechanical interventions and bio-remediation to policy change and legislative back up.

SCOPE AND CONTENT

The collection of essays and case studies presented here have been selected to meet the following objectives:

1. To identify more precisely the physics and mechanics of dust storms and the entrainment and transport of sediments.
2. To present reviews of success stories from various countries and regions to demonstrate that measures can be effective in mitigating the effects of dust-related events and to counter the threat of severe and disastrous sand and dust storms.
3. To draw lessons from the experiences gained in designing strategies and programmes for sustainable land-use in the worst affected regions, where climatic and human-induced factors combine to promote frequent and severe dust storm events.

THE BOOK HAS SEVERAL MAJOR THEMES

Human-induced change is by far the most significant factor in the alarming increase in some regions in the scourge of dust storms. Past policies on land-use and the promotion of farming systems that were unsustainable were the root cause of most disasters. Climatic factors, including some evidence of global climate change, make the task of mitigation and prevention more difficult. Distinguishing natural causes from human intervention as factors in accelerated wind erosion is a major task for scientists and land managers.

The challenge for policy makers is to put in place instruments that will reinforce the beneficial aspects of land-use change, assist the reversal of past errors and generally assist the welfare of the people.

THE BOOK IS ORGANIZED INTO SIX PARTS

In *Part I*, the physics, mechanics and processes of dust and sandstorms are examined. *Part II* analyses the experiences in North America (Canada and the US) during and after the Dust Bowl era of the 1930s and also looks at the current situation as weather patterns favourable to dust storm activity return from time to time. *Part III* contrasts the situation on two continents, Australia and Africa, and compares the response to the spread of desertification in each. *Part IV* focuses on the several case studies from Asia and gives insights into the serious and possibly irreversible consequences of large-scale implementation of policies and land-use practices that were fatally flawed. *Part V* zeroes in on China's experiences and particularly analyses several calamitous dust storms that wreaked havoc over vast areas of China and beyond. Detailed case studies are provided of the legacy of destruction in one sub-region where a combination of a harsh and unforgiving environment came into collision with an inflexible set of policy decisions that have proven to be misguided and unsustainable. Finally, *Part VI* looks at the important question of how to forecast, mitigate and prevent dust storms. The role of monitoring and modeling is considered here.

Yang Youlin	Victor R. Squires	Lu Qi
Bangkok	*Adelaide*	*Beijing*

Bangkok, August 2001

FOREWORD

Drylands, the focus of the articles in this volume, cover about 43% of the world's land surface. They are characterized by low and variable rainfall and, on many of them, heavy pressure from human impacts. It is for this very reason that the UNCCD was framed and why over 170 countries are signatories to the Convention. The work of the UNCCD is to counter the problems outlined here and to arrest the spread of desertification.

One of the manifestations of desertification that is commonly experienced in the cities and towns of dryland countries is the visitation by dust and sandstorms. Often these dust-related phenomena are the trigger for government action as citizens of the cities and towns pressure their governments to act.

Sand and dust storms are natural events that occur widely around the world, especially in the subtropical latitudes and dry Savannah's. They are most common in the mid-latitude drylands. However, the major dust storms occur where anthropogenic land disturbance occurs in drylands under conditions of severe drought. Major storms occur when prolonged drought causes the soil surface to lose moisture and there are strong winds.

Land management, or lack of it, is also a contributing factor in most cases of dust-related events. Anthropogenic changes in land cover can be reversed by attention to re-vegetation and other remedial measures. The evidence from the work reported in this volume is that frequency and severity of dust storms can be reduced to almost negligible proportions through attention to proper management practices.

The fact that most of the articles in this volume are from Chinese scientists is particularly appropriate, since China is one of the countries severely plagued by desertification. With up to 58% of the country's land area being classified as arid or semi-arid, nearly one-third of China's land suffers from the effects of desertification.

The effects of desertification in China are mainly in the form of encroachment on arable land, destruction of forest ecosystems, and worsening sandstorms that blow across large areas of the northern and western regions. The damage that desertification causes in China each year is estimated to amount to USD 6.5 billion, which accounts for 16% of the overall damage of worldwide desertification.

Desertification occurs primarily in the form of encroachment on arable land but rangelands are also under threat. For instance, in China since the 1950s, expanding deserts have taken a toll of nearly 0.7 million hectares of cultivated land, 2.35 million hectares of rangeland, and 6.4 million hectares of forests, woodlands, and shrublands. At present, as many as 2.6 million km^2 of land in China is already desertified; each year an estimated 3,000 km^2 of land turns into deserts, compared to an annual expansion rate of 1,560 km^2 in the 1970s and 2,100 km^2 in the 1980s. A considerable number of villages have been lost to expanding deserts. It is estimated that some 24,000 villages, 1,400 kilometres of railway lines, 30,000 kilometres of highways, and 50,000 kilometres of canals and waterways are subject to constant threats of desertification

Dust-laden blasts have buried villages before blowing into cities and suffocating urban residents. While incremental ecological destruction leads, inevitably, to desertification, the pace of desertification has been accelerating due to rapid population growth and unsustainable human activities such as excessive land conversion, overgrazing, over-logging, and irrational utilization of water resources.

The good news, however, is that measures can be taken as the case studies from China, Australia, the USA, and elsewhere demonstrate.

The mission of the CCD is precisely to assist governments to reverse trends of land degradation in those countries where desertification is a problem. The lessons learned from the experiences collected in this volume are therefore greatly welcomed by the Secretariat of the CCD. It is my hope that the outcome following the publication of this volume will benefit not only dryland inhabitants but be of value to dryland administrators and policy makers everywhere.

Hama Arba Diallo
Executive Secretary
UNCCD

MESSAGE FROM THE EXECUTIVE SECRETARY ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (ESCAP)

One of the manifestations of desertification in the world's drylands is the increased frequency and severity of dust storms. This is especially so in North East Asia where populations are receiving frequent reminders of the problem being encountered. Dust is often transported over great distances (thousands of kilometres) and expresses itself in ways that are highly visible.

Asia is a vast region, home to more than half of the world's population and one of the world's regions most adversely affected by desertification. Here, the full interplay of human-induced environmental change and the often harsh and unpredictable climate is being experienced. No region has such a delicate balance between the number of people and the capacity to have food security. No region has undergone such upheaval, social and economic, in the past century.

Dust is both a symptom of serious land degradation, and also a problem in its own right. The economic costs to infrastructure, transport communications and to human health are significant. Yet the human tragedy of crops and animals sacrificed, homes damaged and lives lost bring home the true nature and extent of the problem.

The measures needed to forecast the likelihood of damaging dust related events, the setting up of monitoring systems and mitigating their effects are an urgent priority for governments throughout the drylands. This is especially so when it is noted that the people most affected by sand-dust storms are the rural poor.

ESCAP's mission is to respond to such environmental threats. ESCAP as the hosting agency of Asia Regional Coordinating Unit of the UNCCD has a special interest in the problems outlined in this publication. Since 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.

The lessons to be learned from experiences in several contrasting geographic regions of the world should be especially valuable in framing the action plans of the various countries in Asia and the Pacific. The opportunity presented by the compilation of this publication is therefore welcomed by ESCAP.

Dr. Kim Hak-Su
Executive Secretary

MESSAGE FROM THE EXECUTIVE DIRECTOR
UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)

The processes of land degradation are complex and variable, a cycle of natural and socioeconomic cause and effect. Deforestation, degraded rangelands, exhausted cultivated fields, salinized irrigated land, depleted groundwater resources, all have terrible consequences for many poverty-stricken people living in the drylands. With little or no capital or decision-making control over their resources and with scant political support, many have had few available options but to mine their resources or to migrate during times of stress.

Land degradation is about people. People cause and suffer from it. Unsustainable land management practices caused by either inadequate techniques or increasing population pressure will enhance degradation of land especially in susceptible drylands. Around 40% of the land surface are drylands and thus prone to the land degradation process. About 65% of all arable land has lost some of its biological and physical functions.

UNEP, being one of two United Nations agencies headquartered in Africa, has witnessed the consequences first hand. Environmental refugees, who flee the miserable conditions created by the vicious cycle of unfertile land, droughts, decreasing production and subsequent over-use of land, are the first victims of desertification. More than 40% of Africa's population lives in the susceptible drylands. Equivalent numbers account for Asia and South America. Desertification affects the lives of one-sixth of the world's population.

This volume in particular deals with a scourge of many dryland regions – *devastating dust storms.* These are both a symptom and a cause of further desertification. Dust storms affect the ecological and economic foundation of whole regions and are in turn affected by climatic changes, weather patterns, policy decisions and individual actions at the grassroots level.

The lessons learned from the experiences in Africa, Asia, particularly China and North America demonstrate that there are ways and means of mitigating the worst impact of the recurrent dust storms. Governments and individuals in North America have invested billions of dollars to minimize loss of productive agricultural lands after the *"Dust Bowl"* of the 1930s. How can the poorest citizens of the poorest countries be expected to sustain themselves without similar investments? How can they respond to mounting pressures of population growth, land degradation and migration without losing their livelihood and human dignity?

UNEP from the very beginning, has been closely associated with the UN Convention to Combat Desertification which focuses attention to the needs of the people in the drylands, and aims to ensure that they receive the support they need to maintain sustainable livelihoods on their lands. Part of this support must be to assist with education of the local people (officials and land users alike) about sustainable management of arid and semi-arid lands, soil conservation and about inter generational equity. To this end, UNEP will continue to provide the necessary support to the Convention and affected governments, within the means at its disposal.

It is equally essential to enlist the support of the wider international community to accelerate the pace and magnitude of action. It is our sincere hope that readers to this volume will be encouraged to learn more from the experience of others and that policy makers will be heartened by the knowledge that concrete achievements and a more sustainable and secure future for the inhabitants of the world's drylands can be replicated – many times over.

Dr. Klaus Topfer
Executive Director

PART I

PHYSICS, MECHANICS AND PROCESSES OF DUST AND SANDSTORMS

Field observations and wind tunnel laboratory research have helped to explain the physical process of sand and dust blowing under the force of wind and moving over the land surface in arid and semi-arid zones. When the wind force reaches the threshold value, the sand and dust particles are transported from the surface and start to move.

Soil erosion by wind has two broad dimensions: transport and accumulation. Studies on sand-dust storms cover both aspects, because each is damaging in its own way and each contributes to the problem of desertification in the world's drylands.

The literature dealing with wind erosion and dust-sandstorms amounts to tens of thousands of articles, research papers and books. The two articles in this section introduce the essential issues.

Chapter One

DUST AND SANDSTORMS: AN EARLY WARNING OF IMPENDING DISASTER

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Key Words: coping strategies, traditional technologies, land-use, policy, drought, socio-economics, Dust Bowl, entrainment, transport, dunes, dust storm, sandstorm, early warning, disaster

SYNOPSIS

Drylands occupy more than 40% of the world's land surface. They are home to about 1 billion people. Dust storms are a symptom of poor land management and a constant reminder of the interaction between people, the land they use and the climate. When land management is inappropriate as a result of government policies or because the traditional technologies are no longer able to cope with burgeoning populations and the shrinking resource base, wind erosion will occur. This chapter considers the relationship between weather, climate and dust storms and examines the mechanisms by which dust and sand are transported. The regional transport of dust in the atmosphere is also considered.

KEY POINTS

1. *True deserts are rarely the source of dust storms because of the way in which particles are entrained and transported. The desert margins are more often the principal source of damaging dust storms that periodically (or regularly) sweep across the landscape wreaking havoc as they roll by.*

2. *The mechanism of transporting sediments (sand, dust, and organic matter) by the action of wind has been well studied and is understood. The challenge is to create a situation on the ground where entrainment and transport is unlikely.*

3. *The socio-economic aspects (human dimension) of dryland degradation need to be given more attention. The emphasis should be on the people who use the land, not only on the land they use.*

1. INTRODUCTION

Sand and dust storms are natural events that occur widely around the world in arid and semi-arid regions, especially in subtropical latitudes. The vast distribution and existence of desert landscapes (*see Figure 1*) indicates that these regions are a very important source of dust storms in historical time but in more recent times the action of humans has created another source on the desert margins in semi-arid areas that previously were stable. The major dust storms occur where anthropogenic land disturbances exist in drylands under severe drought. Several areas of the world are contributing to large-scale storms. These areas correspond to areas undergoing accelerated desertification.

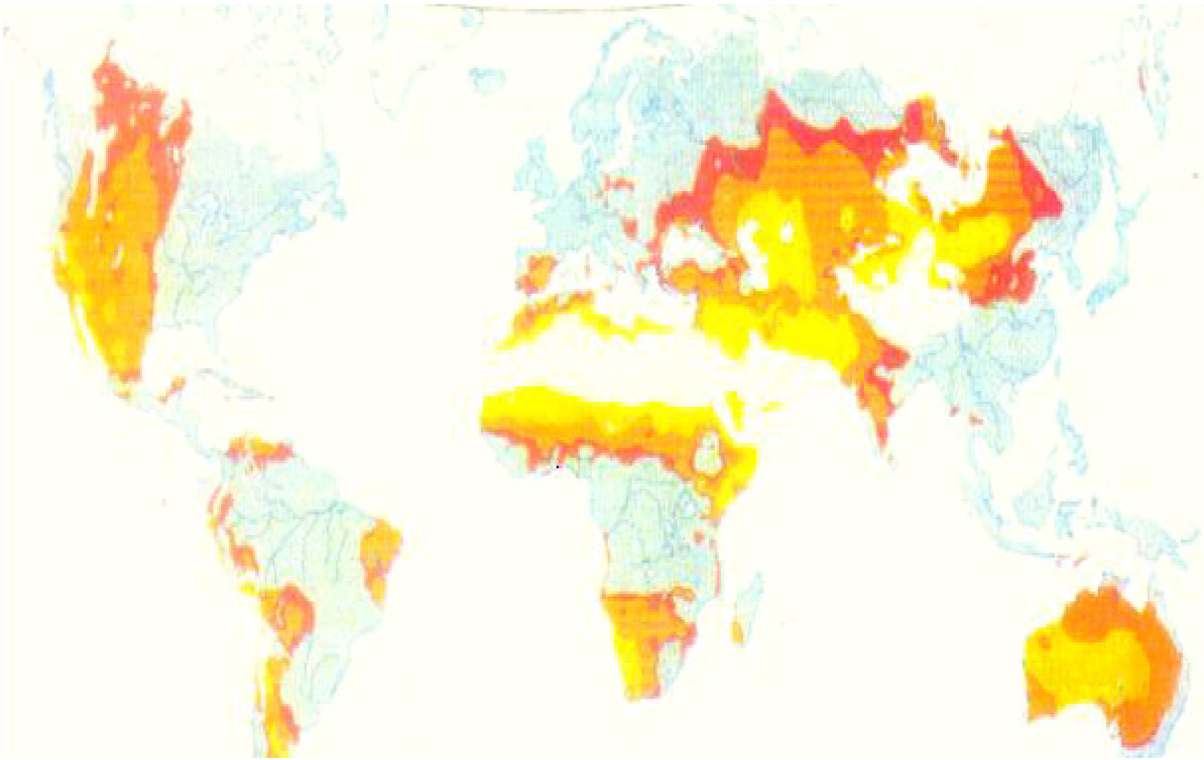


Figure 1: Vast distribution and existence of desert landscapes

Yaalon (1996) has indicated that North Africa is a source of dust for southern European dust deposition. Mattson and Nilsen (1996) indicate that the Sahara region is the main source of aeolian dust in the world. Dust is transported westwards over the Atlantic Ocean and Sahara region and northwards over several cycles of transport and deposition. Pease et.al. (1998) suggests that arid and semi-arid regions around the Arabian Sea are one of the principal sources of global dust. India, Pakistan, Iran and the Arabian Peninsular contribute to Arabian Sea dust deposition (*Figure 2*). Dust from China contributes to sediment in the Pacific (*see cover*).

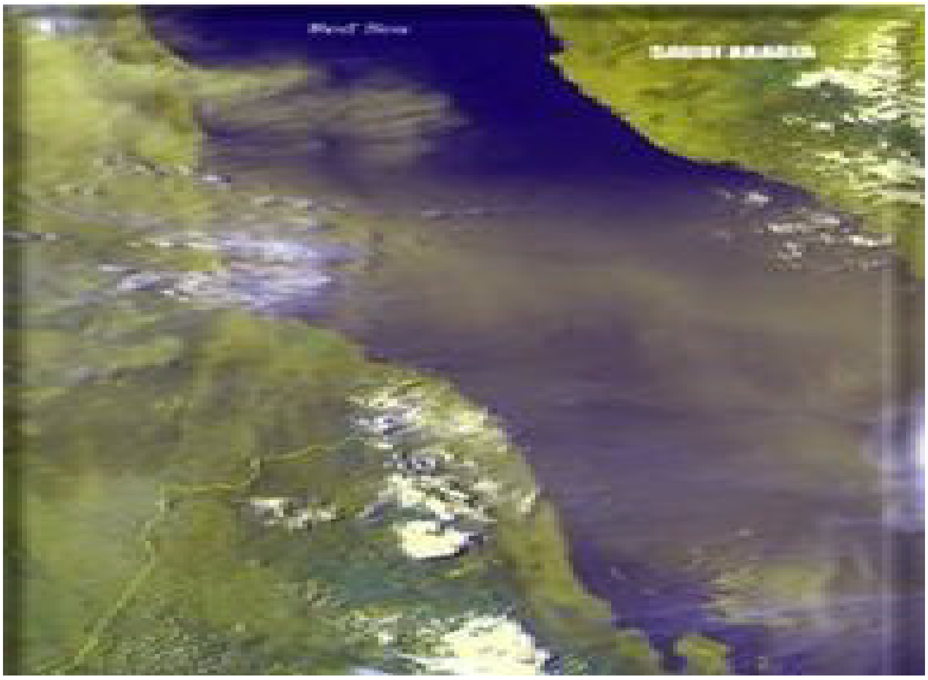


Figure 2: Satellite image of dust over the Red Sea. Saudi Arabia on the right of the image

2. SAND AND DUST STORMS – TERMINOLOGY

Conventionally, *"sand"* describes soil particles in an approximate size range of 0.6-1 mm, while *"dust"* describes particles <0.6 mm. In practice only those dust particles below 0.1 mm can be carried by suspension (see below) and be manifested in a dust storm. Thus dust storms are a product of mass transportation of soil particles by wind. Dust storms are typically a form of dry deposition. Often the fine fraction that is richer in nutrients and organic matter is entrained into the air upon which dust particles become condensation nuclei. These small particles may be deposited subsequently as a wet deposition through rain or snow.

The transport, suspension and deposition of dust particles in the atmosphere mainly manifest itself as a dust storm. Major storms occur when prolonged drought causes the soil surface to lose moisture and there is a co-occurrence of strong winds.

3. HOW DOES DUST BECOME AIRBORNE?

Field observations and wind tunnel laboratory research allow us to understand the physical process. Consider a surface made up of separate particles that are held in place by their own weight and some inter-particle bonding. At a low speed wind, there will be no indication of motion, but when the wind force reaches the threshold value a number of particles will begin to vibrate. Increasing the wind speed still further, a number of particles will be ejected from the surface into the airflow. When these injected particles impact back on the surface, more particles are ejected, thus starting a chain reaction. Once ejected, these particles move in one of three modes of transport depending on particle size, shape and density of the particle. These three modes are designated *suspension*, *saltation* and *creep*. Its size and density determine movement pattern of sand-dust particles (*Table 1*).

The *suspension mode* involving dust particles of less than 0.1 mm in diameter and clay particles of 0.002 mm in diameter are small in size and light in density. These fine dust particles may be transported at altitudes of up to 6 km and move over distances of up to 6,000 km. These red-coloured and alkalized dust particles are 0.1 mm in diameter and suspended high in the atmosphere and contribute to general loss of visibility, but do not manifest as a real dust storm. The research results of the Geology Faculty of Oxford University in the UK show that

Great Britain has suffered dust storm disasters 17 times since 1900. About 10 million tons of dust particles has been transported and brought to Great Britain from the Sahara Desert during a single dust storm.

Saltating particles (i.e. those between 0.01-0.5 mm in diameter) leave the surface, but are too large to be suspended. The remaining particles (i.e. above 0.5 mm) are transported in the creep mode. These particles are too large to be ejected from the surface and are therefore rolled along by the wind and impacting particles. Coarse sands of 0.5-1.0 mm in diameter move along in a rolling movement. Medium-sized sands of 0.25-0.5 mm in diameter encroach in the form of a jumping movement. As these particles impact upon the land surface, they initiate movement of other particles. About 50-80% of all soil being transported is carried in this mode. Due to the nature of this mode the heights carried are rarely more than 30 cm and the distance traveled rarely exceeds a few metres.

Sand particles, transported by saltation and by creep will accumulate to form new sand dunes when they are blown out, graded and transported for a distance (*Figure 3*). Sands of 2.0 mm in diameter will be left on land surface when fine materials are blown away (*Figure 4*).

Table 1: Movement of soil particles under a wind force of 15 metres/second*

Particle size (mm)	Period of suspension (time)	Comment/description
0.1	0.3-3.0 seconds	Fine sand
0.01	0.83-8.3 seconds	Dust. Can go up to 700 m high
0.001	0.95-9.5 years	Fine clay can go up to 77 km high

*The threshold wind velocity (15 cm above ground surface) that can lift up and transport dust grains of 0.05-0.1 mm in diameter is 3.5-4.0 m/s. Data from (Qian Ning, 1983).

Figure 3: Sand and small gravel remains after the finer particles, including organic matter, have been blown away. The wind is constantly moving the sediments, leaving a typical windswept surface

Figure 4: Sand dunes form when sand is moved along by the wind (*see text*)

4. INTERACTIONS BETWEEN CLIMATE, WEATHER[1] AND DUST STORMS

Reference has already been made to the role of prolonged drought in exacerbating the severity and frequency of dust storms. This is due to several causes. The most obvious are the reduction of plant cover and the drying of the soil. Bare, dry soil is more susceptible to the actions of the wind. Plant cover reduces wind velocity at the soil surface and moisture improves cohesion between individual soil particles. However, the major effect of prolonged drought seems to be to force land-users to take greater risk and impose greater pressure on an already stressed environment.

One important aspect of the discussion about drought is the difference between aridity and drought. Coughlan and Lee (1978) state:

> "Aridity implies a high probability of rainfall for a given period below a low threshold. Drought implies a low probability of rainfall for a given period below a relatively low threshold."

Drought can be thought of as a meteorological phenomenon but it is more than that. The whole question of drought perception is a vexed one and the implications for governments and for individuals in learning to live with drought are quite profound.

Drought is defined by meteorologists as a period of rainfall in the lowest decile (Gibbs and Maher, 1978). This means that droughts occur in all climatic regions with the same frequency i.e. 10% of the time. This definition says little about the severity or duration of the drought. If droughts are perceived to occur more frequently than 10% of the time then it is because land management is inappropriate for the climatic variability so that the land is under stress in periods with rainfall well above the tenth decile; i.e. management is inappropriate for the normal climatic variability. It is not the climate that is at fault, but human perception of the land as being better than it is.

[1] Weather refers to the environmental conditions being experienced on a day-to-day (even hour-by-hour) basis, but climate is the pattern of these occurrences over a long time period. Weather can be conducive to the advent of dust storms on some days or at certain times of a given day.

Many people associate desertification with droughts. While it is true that land degradation commonly proceeds more rapidly during drought, the real causes of desertification are:

i. Inappropriate land management both during droughts and between droughts.
ii. Management which does not take cognizance of the normal climatic variability .
iii. The inherent capabilities and limitations of the land.

In effect, drought (however defined) is one of the risks associated with human occupation of arid lands characterized by a variable and largely unpredictable climate. Drought (especially severe drought) is often regarded as an abnormal event. But in fact it is a natural recurring feature of all arid environments. It is often said that the climate in a particular region is *"characterized by frequent droughts"* but this is nonsense and furthermore it is dangerous to think it, because it tends to reduce human responsibility for land degradation.

From a practical viewpoint drought is intrinsically related to climatic zones and the resistance of plants to water shortage. Thus, establishing whether there is, or is not, a drought in progress is less meaningful for arid zones since the prospects of it remaining dry are significantly higher than in more abundant rainfall zones.

In low rainfall regions, the amplitude of rainfall variation is relatively greater than in higher rainfall regions (i.e. rainfall in the lowest decile is relatively much lower than average or higher deciles) and individual periods in the lowest decile are longer. These are factors that need to be taken into account in land management systems; especially where cropping and herding are the major land-uses.

For example, an analysis of drought in Australia shows that the likely pattern of drought across the Australian continent (7,600,00 km^2) in any 100-year period can be summarized as:

i. 21 years are likely to be free of major droughts.
ii. 62 years will have a drought that covers less than 20% of the continent.
iii. 15 years will have drought covering 20-40% of the continent.
iv. 2 years will have drought covering more than 40% of the continent.

These figures give some idea of the return periods, but not the severity of those periods.

Droughts are normal components of climate variability, though their effects are seriously worsened by human factors such as population growth that forces people into drier and drier regions and inappropriate cropping and herding practices. The impacts of drought are likely to become ever more severe as a result of development processes and population increases.

Drought is a time of crisis, for the land, its animals and its people. It is a critical testing time for sustainability of land management systems and will often determine whether the enterprise will survive and whether the productivity of the land on which it depends will be maintained. The crisis can be averted or diminished with careful planning and management. No two droughts are the same and the responses to them need to differ because the nature, extent and degree of risks are constantly changing. This means that to best cope with drought, management must be closely attuned to climatic conditions, land resource conditions, financial and forage reserves, and prevailing economic conditions in the affected region or country.

The practical problems of dealing with drought are that we do not know when it starts, and we do not know how long it will last. Unlike other natural disasters such as cyclones and wildfires, drought (at least at the outset) has no obvious physical presence. It is this insidious nature which has made drought management so complex.

Droughts often stimulate sequences of actions and reactions leading to long-term land degradation. Droughts may also trigger local food shortages, speculation, hoarding, forced liquidation of livestock at depressed prices, social conflicts and many other disasters associated with famines that may catastrophically affect numerous groups and strata of local populations. In some instances however, droughts may contribute to the emergence of social strategies that enhance sustainable land productivity while protecting local livelihoods. The lessons learned from those countries/regions that have experienced severe drought and its attendant land degradation problems need to be more widely disseminated and put into practice in today's situation (*see Chapter 2*).

The majority of dryland human populations struggle daily with persistent and almost universal poverty in their struggle to scrape a living from a harsh environment where periodic drought is a common phenomenon, soil fertility is low, and productivity is very low. In addition, traditional technologies have not kept up with the present rate of population growth and increased demands for food, fuel and shelter. The end results are poverty, hunger and malnutrition (*Table 2*). Unable to survive with scarce land and water resources, these poor populations are often forced to become environmental refugees that migrate to neighboring lands and urban centers in search of relief, employment and refuge (*see Chapter 6*).

Traditional coping strategies are frequently unable to deal with accelerated land degradation associated with over-use of diminishing resources in a fragile environment. Abuse of a natural resource base by its traditional users is seldom due to carelessness or ignorance, but results from survival mechanisms under harsh conditions. Droughts often stimulate sequences of actions and reactions leading to long-term land degradation.

5. IMPACTS OF DUST STORMS – PHYSICAL AND ENVIRONMENTAL

The environmental impacts from dust storms are wide ranging, impacting on source, transport and deposition environments.

6. SOURCE ENVIRONMENTS

The impact on source environments is primarily a consequence of soil loss. During dust storm generation, nutrients, organic matter and thus soil fertility are exported out of the source ecosystem. Consequently there is a loss of agricultural productivity.

6.1. Transportation environments

During dust transportation, many young plants are lost to the sand blasting nature of the process at ground level, resulting in a loss of productivity. However, major dust storms have most of their impact within the atmosphere. The most noticeable effect is the reduction of visibility. This is of course dependent on the severity of the dust event (*see Chapter 7*). It could range from a slight haze to a major dust cloud. In the worst cases, visibility can be reduced to only a few metres. This loss of visibility can be a major hazard to aircraft and in some cases to motorists (*see Chapter 12*).

Dust particles are thought to exert a radiative influence on climate directly through reflection and absorption of solar radiation and indirectly through modifying the optical properties and longevity of clouds (*see Chapters 2 and 8*). Depending on their properties and in what part of the atmosphere they are found, dust particles can reflect sunlight back into space and cause cooling in two ways. Directly, they reflect sunlight back into space, thus reducing the amount of energy reaching the surface. Indirectly, they act as condensation nuclei, resulting in cloud formation (Pease et al, 1998). Cloud formation raises the albedo of the globe, causing more solar radiation to be reflected back into space.

However, dust particles can also cause an indirect heating effect of the atmosphere through cloud formation. Clouds act as an *"atmospheric blanket,"* trapping long wave radiation within the atmosphere that is emitted from the earth. Thus, dust storms have local, national and international implications concerning global warming, and land degradation. They also impact human health.

6.2. Deposition environments

Mineral dust, it has been suggested, has an important role to play in the supply of nutrients and micronutrients to the oceans and to terrestrial ecosystems. Iron in the minerals composing this desert dust is a vital nutrient in oceanic regions that are deficient in iron. Further, more research has shown that the canopy of much of Central and South American rainforest derives much of its nutrient supply from dust transported over the Atlantic from the Sahara region of North Africa. Sahara dust occasionally reaches the State of Florida in the US, causing a high-altitude haziness that obscures the sun. Dust from China's deserts is transported to the waters near Hawaii in the south Pacific. As the dust settles in the waters around Hawaii, the primary productivity of the plankton in the water column increases (NOAA, 1999). This research suggests that dust transport processes form an integral part of the global ecosystem.

Yet, nutrient deposition can have negative effects. Many arid region rivers and lakes have been slowly eutrophied by ongoing dust deposition. As the dust cloud moves downwind it inevitably passes through populated areas, contributing to urban air pollution. As the dust settles over a populated area and people breath in these tiny dust particles, those with asthma and other respiratory disorders will suffer. Dust particles have been shown to cause a wide range of respiratory disorders including chronic bronchitis and lower respiratory illness. More sinister are the health related problems in areas where the dust is salt laden or is contaminated by *toxins (see the Aral Sea experience reported in Chapter 8*).

7. SOCIAL AND ECONOMIC IMPACTS OF LAND DEGRADATION

The human aspects are related to both population pressure and land-use technologies that are not sustainable, as they have not developed alongside the rapid population growth that is being witnessed in the Third World but whose negative effects hit the drylands most. The best known of these land-use technologies is the fallow system that in earlier times involved the resting of exhausted land long enough to allow fertility recovery through secondary revegetation. This original time span has been shortened and is almost non-existent now as a result of land pressure, especially in the African drylands (*see Chapter 6*). Clearing of vegetation, rapid abandonment of exhausted cropland, expansion of cropping into more and marginal land set up a vicious cycle that is hard to break. *Figure 9* is a flow chart showing the typical sequence contributing to this cycle of poverty.

As much as the inherent ecological fragility of the drylands, coupled with recurrent droughts, increase the degree of susceptibility to human-related land degradation processes, so do the latter affect the impact of drought through the weakening of the resilience of the system and the ability to return to equilibrium. Devastating dust storms are a common symptom of the rapidly deteriorating ecological situation (*see Chapter 8*).

Land degradation through loss of vegetation and soil cover contributes to global climate change by increasing land surface albedo, increasing the potential and decreasing the actual evapo-transpiration rate, changing the ground surface energy budget and adjoining air temperature, and adding dust and carbon dioxide to the atmosphere.

Impacts of land degradation on the natural resource base with direct effect on human populations include:

i. Reduction of perennial and annual livestock forage in rangelands.
ii. Reduction of available fuelwood material.
iii. Reduced biodiversity.
iv. Reduced water availability due to a drop in the water table.
v. Sand encroachment on productive land, human settlements and infrastructure.
vi. Increased flooding as a result of sedimentation of water bodies.
vii. Reductions of yield or crop failure in irrigated or rainfed farmland.

All these factors may ultimately lead to disruption, in various degrees, of human life due to deteriorating life-support systems that are expressed by:

i. Increase in the spread of poverty and hunger due to loss of land resources and consequent inability to provide sufficient food and shelter to growing populations, leading to a reduction in the nutritional and health status of the affected populations, especially the young and the elderly.
ii. Migration in search of relief and refuge as a result of economic and political stress as populations struggle to survive on the diminished water and land resources.
iii. An influx of environmental refugees that puts enormous pressure on the physical environment, economy and stability of societies in the immediate neighborhood, often exacerbating political differences and in some cases civil strife.

The solution to desertification, if there is to be one, is to shift the emphasis from the land to the people. Desertification control should be about the people who use the land not only the land they use.

As the case studies presented in this volume show, there are many regions where dust storms and drifting sand are real problems faced on a day to day basis by local populations and by government land management specialists and advisors. Experience in the Dust bowl of North America should be both a warning and a source of comfort. Faulty land-use practices, poor farming/herding methods and inappropriate government policies can lead to an acceleration of land degradation in drylands (*Figures 5 and 6*). The good news is that something can be done if the problem is properly analyzed and if there is a serious attempt to mobilize all the stakeholders in finding a solution. The solution may well be to relocate people and abandon attempts to crop or graze the badly degraded areas. The National Action Plans of each signatory to the UNCCD should reflect all options and develop a programme with verifiable targets and an agreed time frame that is known to the public.

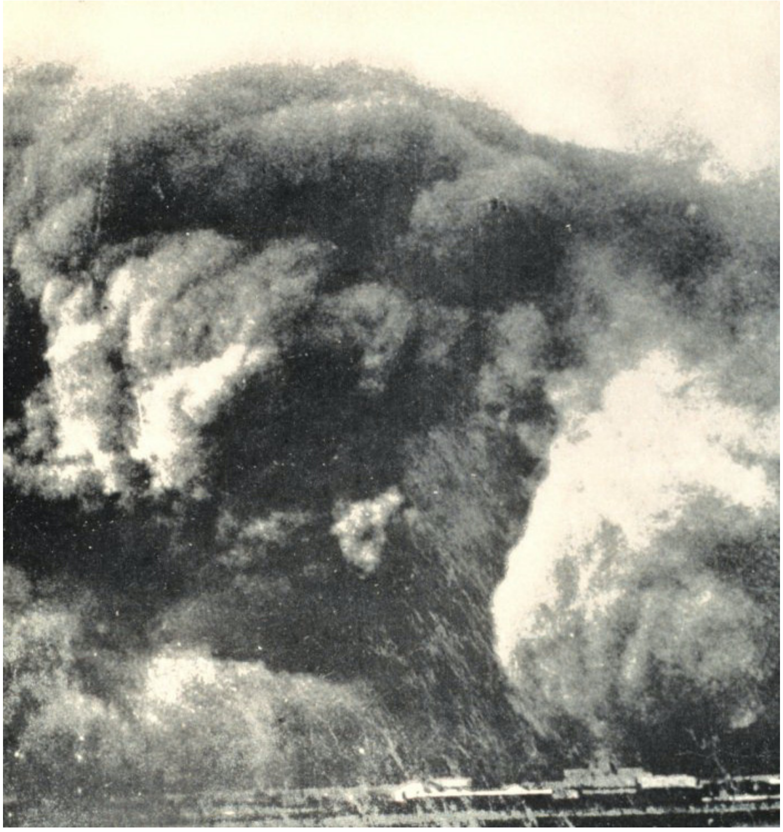


Figure 5: Black blizzards like the one experienced in North America during the Dust Bowl era can develop when poor land management, short sighted policies and drought combine

Figure 6: Dust storms have a serious impact on people's wealth, health and spirit. They can destroy whole communities and impose high economic costs on a region or a nation

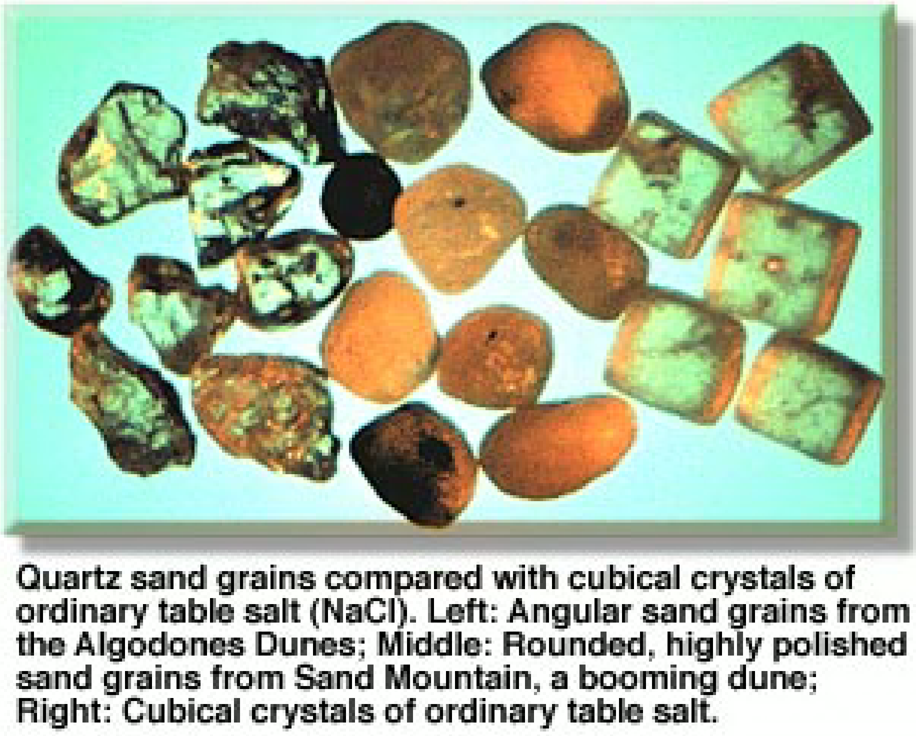


Figure 7: Sand grains are not all the same. The size and density will determine the behavior of sand particles when subjected to wind

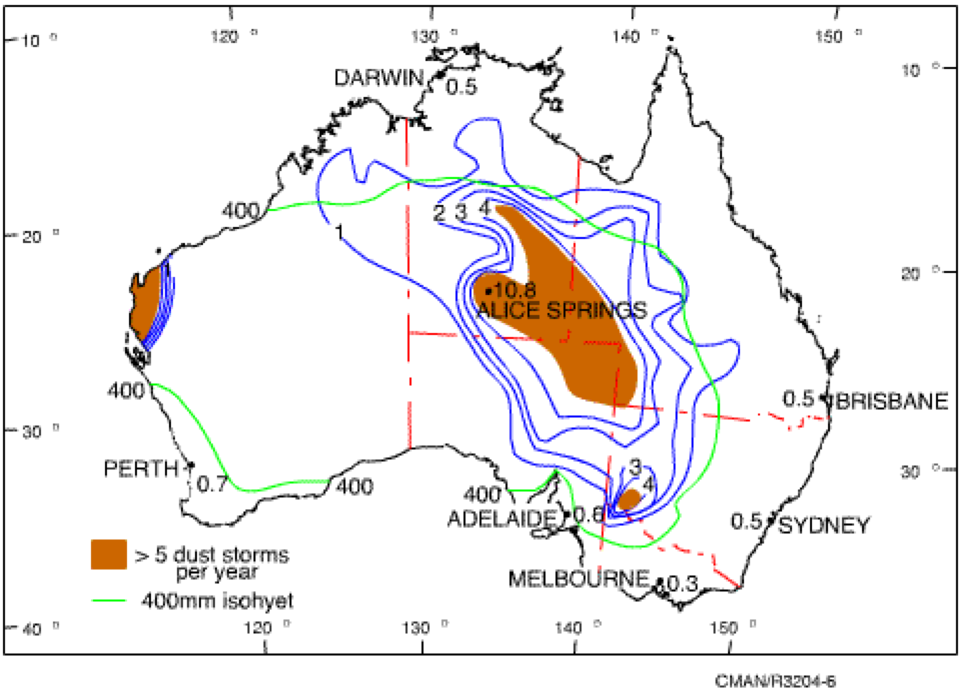
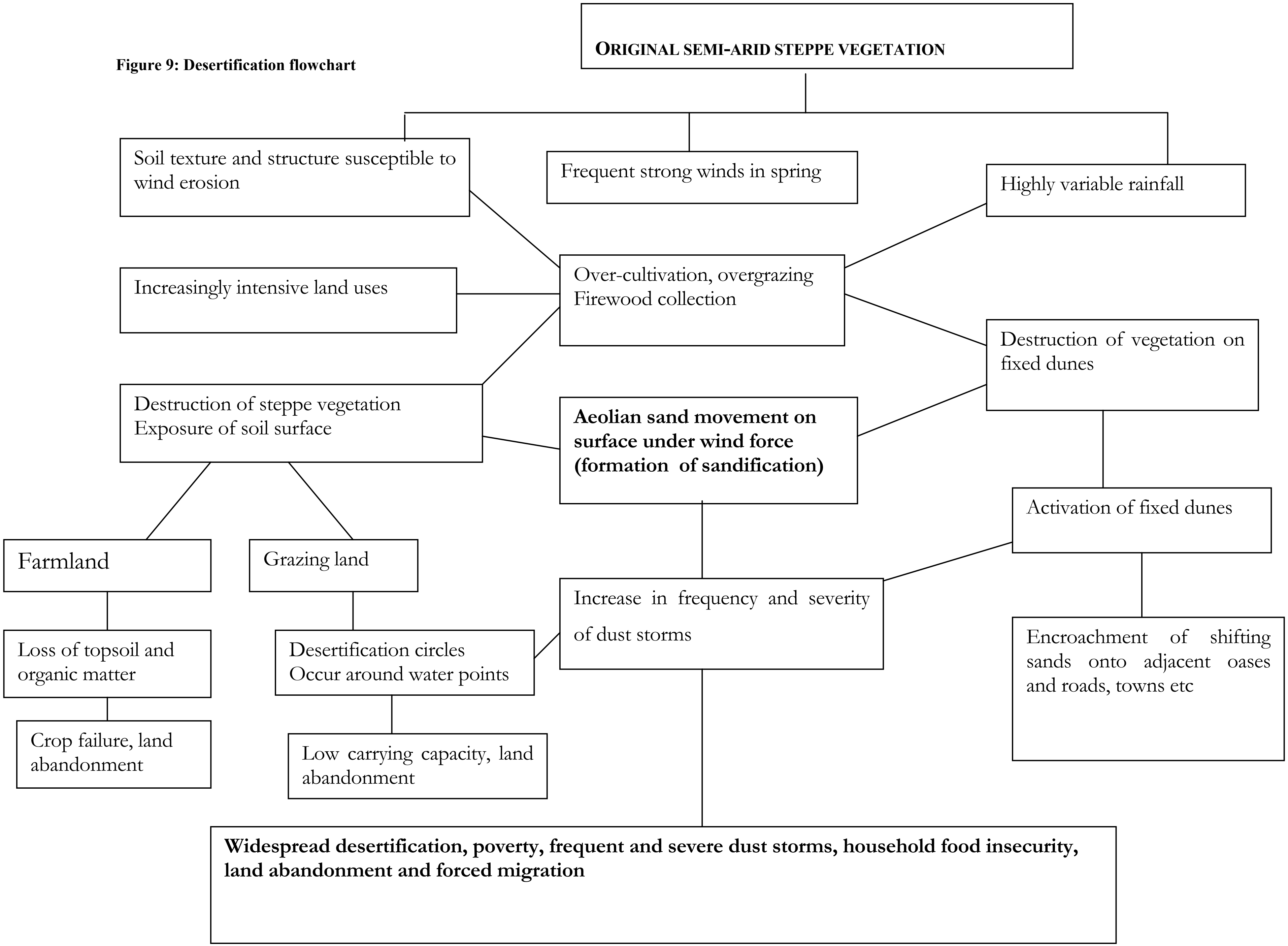


Figure 8: Frequency and distribution of dust storms in Australia (Data from Middleton, 1984)

Table 2: Some common manifestations of desertification

ECONOMIC MANIFESTATIONS	ECOLOGICAL MANIFESTATIONS	SOCIAL MANIFESTATIONS
Economic loss in cash	Loss of diversity in terms of wildlife, plants, and ecosystems	Migration of population off affected areas
Decreased crop yields	Loss of inland lakes	Rural poverty
Loss of farmland due to desertification	Loss of topsoil in terms of organic matter, N, P, and K nutrients	Influx of ecological refugees into urban areas
Loss of rangeland due to desertification	Decreased ground water level, increasing salinity of water	
Decreased grazing capacity in terms of the number of livestock	Increased frequency of sandstorms and associated loss of human life and livestock	
Abandoned farmland		
Abandoned rangeland		
Drifting sand affects railway lines and highways		
Increase in suspended load raises river heights and increases flood problems		

Figure 9: Desertification flowchart



8. REFERENCES

Coughlan, M.J. and Lee, D. H. *The assessment of drought risk in Northern Australia. "Natural Hazards Management in North Australia"* Aust. Nat. University, Canberra; 1978.

Gibbs, W.J. and Maher, J.V. *Rainfall deciles as drought indicators*. Bulletin no. 8 Bureau of Meteorology, Australia; 1978.

Mattson, J.O. and Nilsen, J. *The transport of Saharan dust to southern Europe: a scenario*. Journal of Arid Environments; 1996; 32: 111- 119.

NOAA; As reported on the web-site on 09-12-99 (http://www.noaa.gov/); 1999.

Pease, P., Vatche, P., Tchakerian, N. and Tindale, N.; *Aerosols over the Arabian Sea: geochemistry and source areas for aeolian desert dust. Journal of Arid Environments*; 1998; 39: 477-496.

Yaalon, D. *Comments on the source, transportation and deposition of Saharan Dust to Southern Europe*. Journal of Arid Environments; 1996; (36): 193-196.

Chapter Two

PROGRESS OF RESEARCH ON UNDERSTANDING SAND AND DUST STORMS IN THE WORLD

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Key words: seasonality, periodicity, frequency, severity, satellite imagery, optical qualities, weather, particulates, trace elements, air pressure, forecasting, monitoring, research

SYNOPSIS

Sand-dust storm is the generic term for sand and dust storms. Sand-dust storms are hazardous weather events often associated with extreme calamity. The occurrence and development of sand-dust storms is either an important process of the acceleration of land desertification, or to a certain extent a consequence of the spreading of desertification. Strategies for preventing sand transport and reducing sandstorm disasters can be developed from an analysis of the causal factors in the formation of sandstorms.

This paper reviews the relevant recent research and studies on sandstorms in China and abroad. It intends to raise awareness of the severity of sandstorms and its impacts, to promote detailed studies on sandstorms and to enlarge the effective channels for exploring strategic measures against sand-dust storms.

KEY POINTS

1. *Desertification is one of the major global environmental issues and constitutes one of the three modern frontier research topics closely related to global climate change and biodiversity. It is well known that desertification is a consequence of natural factors (mainly climatic elements) and human elements. As one of the manifestations of desertification, sand-dust storms are both an important process of acceleration of desertification and a consequence of land desertification. Therefore, further integrated and systematic studies of sand-dust storms will promote understanding of the dynamics and mechanics of the desertification processes.*

2. *Sand-dust storms are hazardous weather events often associated with extreme calamity. They occur most commonly in desert and adjacent areas. Since the 1920s and 1930s, institutions abroad have started their studies on the spatial and temporal distribution, formation, causes and structure of sand-dust storms, and*

sand-dust storm disaster monitoring and controlling strategy. Since the 1970s, China started research on sand-dust storms but the attention given to it increased after a major dust storm in May 1993.

3. *On May 5th 1993, a unique strong sand-dust storm took place in Northwest China and serious attention from both research institutions and government was paid to the issue ever since. Emphasis was on promotion of further studies of sand-dust storms. In September 1993, the "First National Seminar on Sand-Dust Storm Weather" was sponsored in Lanzhou, the capital of Northwest Gansu Province. On November 29th 1993, the State Commission of Science and Technology convened a Reporting Meeting and the research programmes of sand-dust storms and dust storms were incorporated into the "Tackle Key Problem Programmes" of the State's Eighth Five-Year Plan of Science and Technology.*

4. *Since 1994, the State Natural Science Fund has financed more research programmes on sand-dust storms and some scientific agencies of provincial governments have also allocated budgets for carrying out research topics on sand-dust storms and dust storms. Particularly since the spring season of 2000, due to the rapid increase in the number of sand-dust storms and dust devils, alarm bells began to ring and nationwide concerns were expressed about the deterioration of the eco-environment. Attention is now being paid to the serious issue of sand-dust storms. Therefore, the central government of China and its agencies (like the Ministry of Science and Technology and others) strengthened the research capability to carry out further studies and approaches to control sand-dust storms.*

5. *This paper reviews the relevant recent research and studies on sandstorms in China and abroad. It intends to raise awareness of the severity of sandstorms and its impacts, to promote detailed studies on sandstorms and to enlarge the effective channels for exploring strategic measures against sand-dust storms.*

1. FUNDAMENTAL CHARACTERISTICS AND HAZARDS OF SAND-DUST STORMS

1.1. Definition, terminology and classification

Sand-dust storm is the generic term for sand and dust storms. It is a serious phenomena of wind and sand which brings sand particles and dust silts into the sky and turns the air turbid (horizon visibility is less than 1 km). Sandstorm refers to the strong sand-carrying windstorm at force 8 (Beaufort scale) that blows up great quantities of sand particles from the surface into the air. Dust storm refers to the strong dust-carrying windstorm that blows up great quantities of dust and other fine grains into the atmosphere (Zhao Xingliang, 1993).

Terminologically, different countries or regions term sand-dust storm differently; for instance, in the Northwest region of India, the convection sand-dust storm that occurs in the season preceding the monsoon is named *Andhi*. It is called *Haboob* (Joseph et al., 1980) in Africa and Arabic countries. It is titled *"phantom"* in some regions: namely it means *"devil"* (Wolfson et al., 1986).

In general, two indicators, wind velocity and visibility, are adopted to classify the grade of intensity of sand-dust storms. For instance, Joseph has classified the sand-dust storms occurring in the Northwest part of India into three grades. Namely, the feeble sand-dust storm develops when wind velocity is at force 6 (Beaufort) degree and visibility varies between 500-1,000 m. The secondary strong sand-dust storm will occur when wind velocity is at force 8 and visibility varies 200-500 m. Strong sand-dust storms will take place when wind velocity is at force 9 and visibility is <200 metres. In China, a sand-dust storm is defined similarly to the above. The only difference is that the category of strong sand-dust storms is defined again into two grades, namely strong sand-dust storms and serious-strong sand-dust storms. When wind velocity is 50 metres per second (m/s) and visibility is <200 metres, the sandstorm is called a strong sand-dust storm. When wind velocity is 25 m/s and visibility is 0-50 metres, the sandstorm is termed a serious sand-dust storm (some regions name it Black windstorm or Black Devil) (Xu Guochang et al, 1979).

1.2. Statistic features of spatial and temporal distribution

1.2.1. Spatial Distribution

As consequences of land desertification, sand-dust storms frequently occur in four regions throughout the world: Central Asia, North America, Central Africa, the Sahel and Australia (Yan Hong, 1993). Sand-dust storms occurring in China belong to one part of the Central Asia Sandstorm region, mainly in Northern China. General characteristics of sandstorms in China are that sandstorms prevail in Northwest China and Northeast China, more frequent in plain (or basin) areas than in mountain areas and occurring much more in desert or at desert fringes than other districts. Most sandstorms are concentrated in two large regions. One is the Taklimakan Desert in Tarim Basin where there are two sub-centre areas from Maigaiti to Keping via Bachu and average sandstorm frequency is 20-38.8 days annually. The other sub-centre area is from Sache to Qiemo via Hetian and average sandstorm frequency is 25-35 days annually.

Another large region with frequent sandstorms is the vast area from the eastern edge of the Baidan Jilin Desert to the Kubqi Desert via the Tengger Desert, the Ulan Buh Desert and Mu Us Sandy Land. Its boundary in the southern part is the Hexi Corridor in West Gansu Province (*see Chapter 11*). This vast belt is a region with frequent sand-dust storms in Northwest China and its centre is located in Minqin County at the southern fringe of the Tengger Desert, with average annual frequency of sand-dust storms being 37.7 days. The second largest area with frequent cases of sand-dust storms is situated in Hangjin County in the northern part of the Kubqi Desert and Dingbian County in the southern part of Mu Us Sandy Land, with annual frequency of sand-dust storms averaging 27 and 25.9 days respectively (Wang Shigong et al, 1995). Statistic analysis of case studies of strong and serious-strong sandstorms and dust devils in Northwest China (He Huixia et al, 1993) has indicated that the most serious sandstorm in Northwest China originates potentially from the vast belt areas from the Turpan and Hami regions in the west and extends to the Great Bay Area of the Yellow River crossing the thousand kilometres long Hexi Corridor of Gansu Province and the Alxa Plateau in West Inner Mongolia. In addition, there are three local sandstorm occurring and prevailing areas in Northwest China. They are the Kelamayi Region of North Xinjiang, the Hetian Region of South Xinjiang and the Northwest part of Qinghai Province.

1.2.2. Temporal change

According to the measurements of deep-sea lithologic core and glacial cover sediments, sandstorms occurred before the end of the Cretaceous period, dating back 70 million years ago. In light of the local chronicles, sandstorms had occurred in Wuwei of Gansu province in 351 AD and some collapsed houses and human and animal casualties had been recorded.

Over long-term geological history, periodic changes of sandstorms were significantly indicated and sandstorms were closely related to climate change in geological periods and the growth and decline of land surface sand materials. Meeting with warm and wet climate, vegetation on land surface grew dense and eco-environment conditions were favorable and the frequency of sandstorm occurrence was low. On the contrary, in the cold and dry climate period, the frequency of sandstorm occurrence was high (Xia Xuncheng et al, 1996). Since the early 1950s, the detailed records of modern sandstorms began.

In Northwest China, the frequency of sandstorms during the last five decades is characterized by the following facts: the frequency of sandstorms in the 1950s was highest and a slight decline of frequency took place in the first half of the 1960s, with maximum reduction particularly in 1967 and 1968. It increased slightly again in the 1970s and dropped down in the 1980s. Since the early 1990s, a certain increase occurred and a remarkable growth of sandstorm frequency again took place. There is a certain difference of sandstorm frequency in various arid climate zones. The situations in extreme arid zones, central arid zones and semi-arid zones are fundamentally similar to the general situation of entire Northwest China. Yet there is a significant difference in the arid zone in the northern part of Xinjiang, namely, it was constantly at a negative anomaly since the later 1950s to early 1970 and was constantly at a positive anomaly since the later 1970s to the end of the 1980s. Sand and dust storms occur mainly in spring season, which covers half of the total frequency of sandstorms (particularly the serious-strong sandstorm occurring in spring season). The summer season is the next in line, and autumn (winter season in Xinjiang) is the season with minimum frequency of sandstorms. In terms of months in which sandstorms occur, April is the dangerous month with high frequency, March and May are lower and September (December and January in Xinjiang) is the month with minimum frequency (Wang Shigong et al, 1996). Liu Jingtao et al (1998) have studied the situation in central and western Inner Mongolia and analysis shows that the frequency of sandstorms in April is maximum and sandstorms in the spring season (March to May) occupy 73% of the total cases of sandstorm.[2]

Sand-dust storms are also characterized by their significant daily change. Wang Shigong et al (1995) analyzed the daily change of the frequency of sandstorms in April 1994 in Northwest China and their results show that most sandstorms took place mainly in the period from afternoon toward evening, occupying 65.4% of the total number of sandstorms. The sandstorms occurring in the period from early morning to midday occupy only 34.6% of the total frequency. In the Hexi Corridor of West Gansu Province, most dust storms or black devils occurred during the period from 12:00-22:00 o'clock (Fu Youzhi, 1994).

1.3. Variation characteristics of meteorological factors

The peak of serious sand or dust storms moves quickly eastward as a black wall from the west (or southeastward from the northwest). The weather conditions change severely before or after the transit of windstorms and sand-dust storms. Before the transit of sandstorms, the temperature is very high, air pressure is very low, weather is fine and wind velocity is low. When the sand-dust storms occur, strong wind sweep across, sand and dust flies upward, air pressure ascends immediately and air temperature drops suddenly. On April 22nd, 1977, a black windstorm took place in the Hexi Corridor of West Gansu Province. It was recorded that ten minutes later, after the sandstorm in Zhangye, air pressure rapidly increased 2.8 hpa (hectopascals[3]), temperature declined 6.8°, wind direction changed northwestward and west from east wind and mean wind

[2] In Mexico City, the most frequent cases of sandstorms took place in March (that normally receives less than 13 mm of rainfall in three months) and minimum frequency took place in September (Jauregui, 1989). In Northwest India, sand-dust storms occur mainly in April-June and this fact coincides with the reality frequency of sandstorms in Xinjiang of China.

[3] Hectopascals: a measure of pressure

velocity increased up to 20 m/s, while maximum wind speed exceeded 30 m/s (Xu Guochang, et al, 1979). On May 5th 1995, a serious black sand-dust storm originated from Jinchang City in West Gansu Province. It was recorded that the air pressure heightened suddenly to 3.1 hpa in a span of ten minutes in Jinchang. In Yongchang City neighboring Jinchang, the air pressure increased 2 hpa in two minutes and the air pressure curve was manifested by phenomena of *"air pressure nose"* after jump reductions of air pressure (Chen Minglian, et al, 1993).

Joseph (1980) studied the convection sandstorm of *"Andhi"* in Northwest India and results show that visibility can be reduced quickly from 1,000 metres to 200 metres, and even 100 metres, while a strong sandstorm or dust storm sweeps across. Wind velocity can be increased up to 20 m/s from 4 m/s. Air temperature can be reduced about 5° and relative humidity can increase 10% or more. On May 20th 1976, a sandstorm took place in India and the visibility at New Delhi Airport was reduced to 280 metres from 4,000 metres in a span of two minutes. Air temperature declined from 38-25°, relative humidity increased rapidly from 31-70% and wind speed was 73-80 km/hr. Research (McNaughton, 1987) on the spring sandstorm/dust storms in the Arabian Gulf and adjacent Gulf countries indicates that the above-mentioned meteorological factors possess similar variation characteristics.

1.4. Satellite image and optical characteristics

Zheng Xinjiang et al (1995) studied and interpreted the images of sandstorm weather, and research results show that the serious-strong sandstorm of May 5th 1993 in Northwest China was clearly indicated on the NOAA images. Sandstorms occurred in the gray-white areas between cloud masses and peak cloud belts. The reflection of light was characterized by the well-distributed top structure of sandstorm occurring areas and some stripes can be seen along with the wind direction. These stripes were light gray and some shadows of high clouds were visible. There was a big difference between rate of reflection of light at the top peak of sandstorms and the rate of reflection of light on land surface. The rate of reflection of light on land surface was lowered nearly 15% and the rate of reflection of light on the top windstorm peak was reached 24%. The reflection of light of cloud masses was highest reaching 51%. On the infrared images, significant differences of temperatures between sandstorms, cloud masses and land surface are visible. Here, the temperature of clouds is minimum and centralized around -54°, the temperature of sandstorm areas is secondary and centralized around -3° and the temperature of land surface is at a maximum and reaches +39°. According to the characteristics of temperature and air data, it can be determined that the peak of the serious-strong sandstorm on May 5th 1993 in Northwest China was as high as 2,100 metres above ground.

Xu Xihui (1997) studied the characteristics of satellite images of sandstorm weather in desert regions (Taklimakan Desert) and her research shows that, on the visible satellite images, there were water bodies and rain-traces on the land surface and the rate of reflection of light of forest coverage is minimum and manifested in black colour. The rates of reflection of light of crops, forages and desert steppe vegetation are manifested in dark gray or gray colours. In arid climate zone deserts, due to the scarcity of vegetation, the rate of reflection of light is high and manifested in gray or light gray colours. The rate of reflection of light of clouds and alpine snow is highest and manifested in gray-white or white colours. The feather-shaped masses formed by sand or dust storms are similar to the low clouds and coloured in gray-white. The only difference between the sandstorms and low clouds is that the boundary of low clouds is clear and its shape is uncertain or undulating, impacted by agitation. The boundary of sandstorms is unclear and its shape is well-distributed feather-like and dispersed and scattered under the cloud masses and it is easier to be classified with the cloud masses. The distribution of feather-like sandstorms is due to topographic orientation and its borderline often coincides with the margin of the basin. Yang Dongzheng, et al (1991) interpreted the satellite images of sandstorm occurrences in the Beijing region in April 1988 and his analysis shows that the sandstorm developing area is coloured in light gray on the satellite images.

Jiang Jixi, et al (1995, 1997) analyzed the causes of the serious-strong sandstorm that occurred from afternoon to nighttime on May 5th 1993 in Gansu and Ningxia, by utilizing the GMS-4 digital stretch infrared data, and concluded that the Medium Convection System (MCS) of the head section of the medium-strong cold front and the squall line formed during the serious-strong sandstorm, can be interpreted by using satellite image data. The resolution of the Meteorological Satellite is high, yet all the weather systems with different (space-time) spatial and temporal scales, from planet to weather scale, medium scale and windstorm convection body scale, can be seen on one sheet of image. Even the dynamic and thermal processes, which occur and develop in the weather system, can be revealed. Therefore, the combined use of satellite image data and normal data will help increase the recognition of the occurrence and development mechanism of sandstorm weather systems and the characteristics of the structure for improving the capacity and ability for long-term and short-term prediction and warning.

Sand-dust storms, particularly the black dust devil, possess unique optical characteristics. For instance, the black dust devil that occurred on May 5th 1993 in Northwest China, according to witness records of the meteorological station of Jinchang City of West Gansu province, was a 300-400 metres high sandstorm wall, observed when the black dust devil moved closer and its shape changed to that of a mushroom cloud similar to an atomic bomb explosion, manifested in revolving sand-dust masses. The upper part was coloured in yellow, the middle part was coloured in red and the lower part was coloured in black. Wang et al (1993) has explained this phenomenon from the point of view of optics. They pointed out that sunshine is composed of red, orange, yellow, green, blue, indigo and purple colours and its wavelength decreases progressively (0.75-0.4 μ). When sunshine passes the atmospheric stratum, the fine particles in the top stratum of the atmosphere can scatter some of the purple light of the sunshine. Consequently, the sky in the atmospheric stratum is purple coloured. Again, as the sunshine passes the middle and lower atmosphere, fine dust particles in these strata can scatter some blue light in the sunshine, because the diameter of fine dust particles is similar to the blue light waves. Therefore, the sky in this stratum is sky-blue coloured. In the sand-dust wall, the up-lifting force produced by the rising air current is powerful. The sand grains at the lower stratum of the sand-dust wall are coarse particles, the sand particles in the middle stratum are the next in size and those in the upper stratum are mainly suspension dusts. Because suspension dusts can scatter the yellow light in the sunshine, we can see the upper part of sand-dust wall is yellow coloured. When the sunshine passes through the middle stratum of the sand-dust wall, the fairly coarse particles can scatter the red light in the sunshine and thus we see the middle stratum of the sand-dust wall is red coloured. When sunshine passes the whole atmosphere and the upper and middle parts of the sand-dust wall, then all the seven lights of the sunshine have been completely scattered, refracted or blocked up and this is why we always see the bottom of the sand-dust wall as black coloured.

Qiu Jinheng et al (1994) conducted synthetic measurement of the three sand-dust storm weather processes in the Beijing region that occurred in April 1988 by using laser radar and photometer. His result shows that the optical thickness of aerosol of atmospheric column in Beijing varied between 0.11 and 0.25 and average value was 0.18 before the occurrence of sand-dust storms. But when the sand-dust storm occurred, the average value of the optical thickness was as high as 5.27 and the latter was twenty times as high as the former. The sand-dust storm was very serious during 8:00-11:00 on April 11th 1988: the sky was fully yellow coloured and the optical thickness of aerosol of atmospheric column varied between 8-15. Mainly high-altitude inputs and great quantity of sand particles and dusts blown up from land surface caused this characteristic. An experiment on the interrelationship between land surface and air current in the Heihe River region was carried out and field measurements of aerosol of sand-dust were conducted. The experiment concluded that the scattering light coefficient of aerosol or optical thickness of sand-dust in April is much high than that in October. The sand particle and dust of 0.1-1.0 μ are the main grains to block the light.

1.5. Physical chemistry and radiation characteristics of aerosol of sand-dust

During sand-dust storm weather process, the concentration of various elements of sand particles and dust are quite different. Yang Dongzheng, et al (1995) measured the various elements of sand-dust particles of the sandstorm that occurred on April 9^{th}-12^{th} 1988 in the Beijing region. The analysis results show that the element concentration exceeding >500 ppm contains Al, Fe, K, Mg, S, P, Ti, Na. The element concentration exceeding 100-500 ppm contains Mn, Ba, and V. The element concentration exceeded 1-100 ppm includes Zn, Ni, Pb, Cr, Co, and Cd. They also conducted measurements of element concentrations of sand-dust particles in two sandstorms that occurred in April 1990 and analysis results show that the majority of elements in aerosol of sand-dust are the elements from the crust of the earth and are mainly found in big-sized grains (d>2.1 mm). Some artificial pollutant elements are mainly found in the small-sized particles (d<2.1 mm). As a consequence, the elements in aerosol of sand-dust originated from natural sources. The characteristics of rich concentration and physical chemical nature of sand-dust elements are closely related to the sources of sand-dust. According to the measurement of sand-dust elements of the sandstorm that occurred in April 1988, the value of rich elements factors (mean value) possesses the following characteristics: 1) EF (Ti) is higher than EF (Fe) in the same element; 2) only one element S has its EF value exceeding 10. The EF (Ti) and EF (Fe) of sand-dust are 39.45 and 15.52 respectively; 3) the EF value of the rest of the elements are less than 10 and mostly close to 1.

Legrand, et al (1988) studied the characteristics of the radiation of sand-dust in the Sahara Desert and their research shows that dust haze, through the impact of radiation process, cuts down the heating effect on land surface during the daytime and slows down the cooling effect near ground surface during the nighttime.

Shen Shaohua and Chen Shoujun (1993) studied, by using numerical value modes, the compelling effect of the effective radiation on the peak system while sand-dust storm are occurring and developing. Their research shows that radiation heating of sand-dust storms causes occurrences of peaks at low atmospheric strata during the daytime, and that radiation cooling of sand-dust storm causes disappearance of the peak at low atmospheric strata during the nighttime. This fact coincides with results of ground measurements and observations. They pointed out that, when they analyzed the occurring process of the peak under the radiation of sand-dust storms, the peak occurrence during daytime was mainly caused by a combination of non-heat insulation heating and horizontal speed transfiguration field. The perpendicular speed field causes an inferior effect on the occurrence of the peak and it accelerates the disappearance of the peak. At nighttime, the key factor accelerating the disappearance of the peak at low atmospheric strata is the non-heat insulation heating process. The level-flow at horizontal temperature gradient does not cause any effects on the occurrence or disappearance of the peak. When the sand-dust accumulation takes place, the peak front intensity and gradient under the radiation compelling will be correspondingly deducted.

Wen Jun (1995) conducted measurements and observations on the aerosol of sand-dust which affects the input and output of radiation on land surface. His research and analysis show that the weakening effect of aerosol of sand-dust on solar radiation takes place at a low atmospheric stratum below 3000 metres. Under the background condition, the weakening effect can be achieved up 25.0-58.0 W/m^2 and the weakening effect will be more significant while the sand-dust storm is breaking out. The aerosol of sand-dust plays a significant radiation-heating role for the low atmospheric stratum below 3000 metres. The maximum heating rate at low atmospheres in October and April are 1.12 k/d and 2.27 k/d respectively. According to mode calculation, under the condition of sand-dust weather, the maximum heating rates of aerosol of sand-dust are 2.59 k/d, 5.12 k/d and 11.30 k/d when the optical thicknesses are at 0.49, 1.42 and 2.12, in 540.5-m positions.

Ackerman and Hyosang Chung (1992) conducted studies on the effect of accumulating dust to radiation effectiveness of local energy input and output. Their research shows that, in the sky above the ocean, the existence of dust increases short-wave radiation volume at the top atmospheric stratum up to 40-90 $w.m^{-2}$ while the sky was clear. On contrary, long-wave radiation on the top atmospheric stratum will be decreased by 5-20 $w.m^{-2}$. Sand-dust will cause certain impacts on the heating rate of the atmosphere and the input and output of radiation energy on the surface of the earth and, as one of the aerosol in desert region, it is an important local climatic variation. Wei Li, et al (1998) carried out analysis of the data of ten times AVHRR passing the testing areas in the Heihe region in March-May 1991 and interpretation of the data of turbidity of the atmosphere at the same period. Their efforts show that the sand-dust in the atmosphere can cause increases of the backward scattering of the ground-atmosphere system, namely increase the refraction rate of the planet. The impact on the long-wave radiation that shoots from the ground-atmosphere system can be indicated mainly through the impact on surface temperature.

1.6. Calamity of sand-dust storms and their impacts on the environment

Sand-dust storms, especially serious-strong sand or dust storms are hazardous weather with extreme calamity. When it occurs, sand-dust storms can move forward like an overwhelming tide and strong winds take along drifting sands to bury farmlands, denude steppe, attack human settlements, reduce the temperature, pollute the atmosphere, blow out top soil, hurt animals and destroy mining and communication facilities. These hazards bring about frost freeze to crops and result in a loss of production. They accelerate the process of land desertification and cause serious environment pollution and huge destruction to ecology and living environment. The hazardous consequences severely threaten the safety of transportation and electricity supplies and contributes unforeseen casualty to people's life and property.[4]

It was estimated that the direct economic loss caused by the serious-strong sand-dust storm that occurred on May 5th 1993 was 560 million RMB Yuan and 1.1 million sq. km of territory, occupying 11.5% of the total land area of China, was threatened by this sand-dust storm. About 12 million people of 72 counties of 18 prefectures and cities of the four Northwest provinces were affected. According to the statistics, 85 people were killed, 31 people were lost and 264 people were wounded, with the majority of the death and missed people being children. Hundred of thousands of animals were killed and lost during this serious sand-dust storm. Hundred of thousands of ha of arable land, fruit plantations and seedlings were un-vegetated. Hundreds of greenhouses and plastic sheds for cash crops were destroyed. Steppe and grazing lands were seriously denuded. Infrastructure facilities, highway, railway and electricity supplies were seriously ruined. In addition, this sand-dust storm, through denudation, erosion, blow out, sand transport and accumulation, has brought about critical destruction of desert plants and ecological environment in Northwest China, promoting the desertification process in the affected areas, and its indirect economic loss is hard to assess (Wang Shigong, et al, 1995).

[4] In the Sahelian region at the south edge of the Sahara desert in Africa, from the early 1970s to the middle of 1980s, due to prolong drought, rangeland and savanna were degraded, agricultural lands were desertified, sand-dust storms occurred, desertification processes accelerated, and wind and sand disasters intensified. It was estimated that hundreds of thousands of African villagers and farmers became destitute and homeless, and that their livelihood was pathetic. China is also one of the countries suffering from sand-dust storms, particularly Northwest China faces strong or serious-strong sand-dust storm attack almost every year.

During the recent decade, the frequency of sand-dust storms has increased year by year and the situation of overloading land resources cannot be improved in a short period of time. Along with global warming, constraints of shortage of water resources become as intense as ever. As consequence, sand-dust storms will bring about more harmful calamities to human beings.

The process of sand-dust storm weather is a huge mobile source of pollution and it can increase silt pollutants in the atmosphere significantly, where sandstorms or dust devils blow up. Yang Dongzheng, et al (1991) made measurements of physical and chemical characteristics of sand-dust of the sandstorm that occurred in the Beijing region on April 9-12th 1988. The analysis results show that the mean value of the total suspension particles (TSP) was 5.118 mg/m^3 and it was 15.7 times higher than that under normal weather conditions. Scientists of the Changsha Institute of Labour Protection have done measurements of sand and dust of the sandstorm that took place on May 5th 1993 in Jinchang City of Gansu Province. Their analysis shows that the TSP was 1016 mg/m^3 outside a room and 80 mg/m^3 inside a room, which exceeded by more than 40 times the criteria that stipulate and result in severe air pollution.

In addition, sand transports will produce positive effects. According to Swap et al (1992), it is indicated that each sand-dust storm in the Sahara Desert can blow up 480,000 tonnes of sand and dust into the Northeast part of the Amazon Valley. The annual sand transport is approximately 13 million tonnes, meaning sand-dust storms have brought about an accumulation of 190 kg of sand and dust particles per ha every year in the region. It was estimated that, along with the accumulation of sand-dust, 1-4 kg of phosphate has been transported and accumulated per ha per year. It can be assumed that the rate of production of the rain forest in the Amazon depends on the phosphorous and other elements transported along with sand-dust storms from the Sahara. The output, increase and decrease of the area of rain forest in the Amazon are directly related to the enlargement and cut down of the area of the Sahara Desert and the sand transport capacity.

Furthermore, sand-dust is partially alkali itself and can restrain certain harm from acid rain during its transportation in the affected area. Japanese scientists' research indicated that yellow sands and dust from Northwest China are the major component of coagulation tubercles cooling clouds in the sky of Japan and play an important role in precipitation in Japan. At the same time, ice crystals of yellow sand are alkali and play an active role in the neutralization of emerging of acid rain in Japan (Qu Zhang et al, 1994).

2. ANALYSIS ON THE ROOT CAUSES OF SAND-DUST STORMS

2.1. Macroscopic condition

Research (Xia Xuncheng, et al, 1996; Qian Zheng, et al, 1997) shows that the formation of sand-dust storms is determined by the following three basic conditions:

1) Wind is the motive power of the formation of sand-dust storms.
2) Sand composition on land surface is the material foundation. For instance the excessive opening-up of rangeland in the Western part of the USA has accelerated the desertification process, opened more sand sources and caused frequent occurrences of sand-dust storms. The same disaster phenomenon took place in Kazakhstan and former USSR Siberia in the 1950s: a large amount of wasteland was blindly opened up and

vast sandy land areas were exposed to strong wind erosion and serious sand-dust storms frequently occurred causing hazardous impacts.

3) Unstable atmospheric condition is the local heating power condition. Most sand-dust storms took place during the period from afternoon to evening. This fact shows the importance of the unstable atmospheric status.

Wang Shigong, et al (1995) carried out systematic analysis on the macroscopic weather and climatic conditions causing sand-dust storms and the condition of the underlying surface. He concluded that sand-dust storms occurred and developed mainly in spring and early summer seasons because of the following five reasons:

1) Underlying surface and unusual topographic conditions of abundant sand source.
2) Long time aridity and freezing weather in winter months and loose topsoil after defrosting weather in spring season.
3) Position of rapid stream axis in high altitude in spring is an important reason causing strong wind in northern regions.
4) The instability of atmospheric stratification in spring is increased and convections easily emerge in afternoon and this condition is advantageous to the under-blow of atmospheric dynamic power.
5) Spring is the season with frequent cold fronts in the northern region and strong winds behind cold fronts is one of the most important elements causing sand-dust storms.

2.2. Main circulation trends and affected systems

Sand-dust storms are a consequence of various factors. Particularly, the occurrence and development of serious-strong sand-dust storms are related to the matching reaction of advantageous circulation conditions and weather systems under the circumstance of macroscopic climate and underlying surface conditions.

An analysis of various weather conditions of sand-dust storms in Arizona, USA during the period 1965-80 concluded that the following systems could easily cause the occurrence of sand-dust storms: 1) frontal systems; 2) thunder storm and convection; 3) torrid turbulence; and 4) cut-off of low pressure at top stratum.

Swap, et al (1992) indicated that sand-dust originating from the Sahara Desert passes through torrid Atlantic Ocean to the Amazon Basin over large-scale circulation. In the central Amazon basin, matching the main precipitation system in the rainy season, the low-pressure centre of the precipitation system produces motive power and vertically blows up sand-dust to the sky causing suddenly paroxysmal sand-dust storms. Precipitation is generally composed of thunderstorms, which are formed in several kilometres long horizontal scale and several days' time scale. Along with these main precipitation systems, sand-dust storms are intermittently transported to the Amazon Basin. As a consequence, development of thunderstorms can provide energy to sand-dust storms. Although not all precipitation processes are associated with cases of sand-dust storms in the Amazon Basin, the phenomenon of all sand-dust storms associated with precipitation was observed in the mentioned basin.

Pauley, et al (1996) studied one sandstorm event along the California Valley and it was concluded that sandstorms are closely related to torrents in high skies, secondary circulation of peak fronts and the boundary stratum process. Dynamic power is transported downward with great quantity at the upper convection stratum to form the peak. Then the dynamic power accumulates at the low altitude of convection, the development of the boundary stratum process is promoted, and wind force on land surface is reinforced. High wind velocity on ground plays an important role in the occurrence of sand-dust storms.

Jiang Jixi, et al (1997) studied and observed seven serious-strong sand-dust storms and concluded that the occurrence of serious-strong sand-dust storms can be divided into three types:

1) Serious-strong sand-dust storms caused by prefrontal squall lines. This is one of the most important parts of strong sand-dust storms in Northwest China and the north of Northern China.
2) Sand-dust storms caused by strong convection clouds at tail peak. This kind of sand-dust storm is particularly strong in intensity, but its threatening scope is limited.
3) Strong sand-dust storms caused by strong convection clouds at the frontal peak. The frequency of occurrence of this kind of sand-dust storm is fairly rare, but its threatening scope is very vast. Hu Yingqiao and Yasushi Mitsuta (1996) conducted research on the relationship between developments of squall lines or squall lines at the strong cold front and the breakout of the black dust devil. It was concluded that when a strong cold front passes through the sky, the squall line at the cold front is transported to the ground surface, heated by strong solar radiation, and with the area atmospheric condition being unstable, the squall line is further developed and results in a black dust devil.

We conclude, through integrated analysis of domestic and international, particularly the large-scale serious and strong sand-dust storms in the Northwest China, that main circulation conditions and weather systems easily cause sand-dust storms containing:

2.2.1. Adjustment of longitude and latitude circulation

The occurrence and development of large-scale sand-dust storms in Northwest China is always followed by a one-time large-scale circulation adjustment, namely, when the longitude circulation is adjusted to latitude circulation, cold air from Siberia moves rapidly from northwest to southeast in China. If it is just in the spring season with scarce rainfall and prolonged drought, the lower stratum of the convection stratum is fiercely unstable, and sand-dust storm weather on a large scale is then the result.

2.2.2. Cold front activity

Spring is the season when cold front activity is most frequent in the Northwest China. A very strong pressure gradient is brought about after the transit of each strong cold front, and twinkles at wind velocity of 20-30 m/s will consequently take place. Sand-dust storms will often be brought about in the region where the twinkle wind prevails. Sand-dust storms that occurred in the northeast part of Peninsular Arabia, namely in Iraq and Kuwait, were concentrated and took place during the daytime in the summer season. The cold front transit was accompanied by strong wind and sand-dust storms resulted. In the Peninsular region, wind speed is usually accelerated in daytime and weakened in nighttime (Wolfson, N. and Matson, 1986).

2.2.3. East wind torrents at lower altitudes

During the early days before the appearance of sand-dust storms, large degrees of temperature raising often took place at lower altitudes in the east part of the Qinghai-Tibet Plateau. This fact urged the development of low eddy in the northeast of the Plateau. If development of high pressure took place at the same time in the southeastern part of the Mongolian Plateau, the eastern wind torrent would possibly be formed in the lower sky along the Hexi Corridor in the North of the Plateau and this is the important condition causing large-scale sand-dust storms in the Baidan Jilin Desert, the Tengger Desert, the Hexi corridor of West Gansu and the western part of Great Bay of the Yellow River.

2.2.4. Meso-scale system

By analyzing several serious sand-dust storms that occurred in Northwest China since the 1980s and the early 1990s, the central areas of serious-strong sand-dust storms were always interrelated to the meso-scale lower pressure and the meso-scale squall line. This fact shows that the meso-scale system plays an important role in the occurrence and development of strong and serious-strong sand-dust storms. In addition, Qu Zhang, et al (1994) concluded from their research that although sand-dust storms were associated with strong wind at force 7, some winds, without transport of sand-dust particles, were even stronger than those prevailing under sand-dust impacts were. Moreover, the fact is that mean annual sand-dust days are less than windy days and the fierce instability of convections at the lower convection stratum is the most important condition to *"blow up sand to cause dust storms."*

Joseph et al (1980) studied convection sand-dust storms (termed *Andhi* in the northwest part of India) that occurred in the season before the monsoon season and his research shows that the majority of local sand-dust storms are also related to the meso-scale system. For instance, on May 13th 1973, the observed sand-dust storm around New Delhi Airport was related to the meso-scale squall line system at wind speeds of 84 km/hr. On May 20th 1976, a similar sand-dust storm was caused by strong a windstorm system at wind speeds of 73-80 km/hr. Sand-dust storms that occur in Gulf of Arabia region are usually the result of meso-scale thunder storm systems (McNaughton, 1987). Therefore, although the topography, underlying surface, large-scale circulation background and weather system are essential conditions favoring sand-dust storms, under the above-mentioned conditions, the meso-scale system plays an extremely direct role in the occurrence of sand-dust storms. In addition, the sand-dust storms that appear in the Persian Gulf and the Gulf of Arabia regions are usually related to thunder storm activities (McNaughton, 1987).

2.3. Remote correlation between sand-dust storms in the Hexi Corridor of West Gansu Province and sea temperature of the Central and East Pacific Ocean

Shang Kezheng, et al (1998) studied the tele-connections between sand-dust storms in the Hexi Corridor of West Gansu and ocean temperatures in the middle of the Equator and the Eastern Pacific Ocean, and their analysis shows:

1) The number of sand-dust storms in the Hexi Corridor in spring season correlates to the negative correlation of ocean temperature factors in the autumn and winter seasons of previous two years. Time factors too long ago or recent are fairly weak in correlation. This means that when the ocean temperatures in the middle and eastern parts of the Pacific Ocean in spring and autumn in certain years are higher (lower), the number of sand-dust storms threatening the Hexi Corridor will be partially fewer (frequent) in the spring two years later. The number of sand-dust storms in the Hexi Corridor in summer season correlates to ocean temperature factors in spring and summer seasons two years before. Namely, when the ocean temperature of the east Pacific Ocean in spring and summer in a certain year is higher (lower), the number of sand-dust storms in the Hexi Corridor will be partially fewer (frequent) in the summer season two years later.

2) In terms of each month during the spring season, the correlation between the number of sand-dust storms in the Hexi Corridor and the years' early ocean temperature factors in March is approximately identical. In April, it is rather well correlated to the negative correlation of ocean temperature factors two years' before. In May, it intervenes among spring and summer seasons.

3) By using the anomaly of ocean surface temperatures in the middle of the Equator and the eastern Pacific Ocean in early years and the given correlated prediction, the number of sand-dust storms in the Hexi Corridor in spring can be well forecasted.

In general, the occurrence and development of sand-dust storms is a consequence of joint functions under circumstances of specific topography, sand-dust sources and various scale weather conditions.

3. NUMERICAL VALUE OF SAND-DUST STORMS AND STUDIES ON SAND TRANSPORT

Sand-dust storms, particularly serious-strong sand-dust storms, are a consequence of interactions of macro-scale, meso-scale and micro-scale weather conditions, unusual topography and underlying surface conditions. In order to study physical mechanism of the formation of sand-dust storm, the numerical value simulation should be adopted as one of the important measures.

By using the meso-scale mode, Cautenet et al (1992) conducted numerical value simulation observations on impacts of heating power of sand-dust storms that originated from the Sahara Desert in Niamay, the capital of Niger. His result is satisfactory and the sand-dust contents and radiation characteristics in the atmosphere are the most significant parameters.

Slobldan (1996) has conducted a three-dimension space numerical value simulation on the distance transport of sand-dust that took place in July 1985 in the Western Mediterranean Sea. He is the first researcher that divided the sand-dust transport process into two phases, namely the shifting phase of sand-dust on land surface and the lifting-up phase of sand-dust by rapid current. In his observation, severe vertical mixture, flank diffusion, horizontal and perpendicular movement and the accumulation process of sand-dust in the atmosphere have been simulated and the result of sand-dust transport simulation is extraordinarily similar to satellite observation.

Shen Shaohua and Chen Shoujun (1993) studied, by utilizing two-dimension and three-dimension numerical value simulation respectively, the front-genesis process reinforced by sand-dust radiation and the impacts of isolated sand-dust radiation effectiveness on front circulation while sand-dust storms spread and develop. His research shows that the impact of sand-dust radiation on weather systems is very important. During the daytime, sand-dust radiation heating causes front-genesis at lower atmospheric strata and produces powerful a lifting-up movement. Due to the continuous heating of sand-dust, an instability consequently appears in the middle stratum of the atmosphere and the first rate entropy mixture layer is finally formed in the middle stratum of the atmosphere. The horizontal speed following the front movement direction is characterized by significant convergence (divergence). The high altitude torrent vertical to the front direction is weakened and the low altitude torrent is accelerated. During the nighttime, radiation cooling of sand-dust storms results in the disappearance of the front at low atmospheric strata. The vertical speed field is mainly a sinking movement and the horizontal speed field also takes place to corresponding changes.

Isolated radiation heating (cooling) of sand-dust storms forces a significant perpendicular circle along the large-scale prevailing wind direction at an approximated height of 1,000 metres. In daytime, this perpendicular circulation circle is very thick and the lifting-up branch is comparatively strong while the sinking branch is fairly weak. In nighttime, the perpendicular circulation circle reverses and thins. There is obviously an existence of horizontal shearing change around the sand-dust spreading area and it accelerates horizontal change and convergence of rapid currents. The response of horizontal wind fields to sand-dust radiation is different at different heights. Cheng Lingsheng and Ma Yan (1996) conducted a meso-scale numerical value simulation on the root causes and sand transport of the black sandstorm that occurred on May 5th 1993 in Northwest China. Their research shows that the two-dimension numerical value mode simulated the lifting-up blowout and horizontal transport. The three-dimension numerical value mode simulated the horizontal and vertical distributions of sand-dust and the simulation result on low pressure and high pressure ridges ahead and behind the cold front is better.

Cheng Lingsheng and Ma Yan (1996), by improved MM4 and high resolution Planet Boundary Layer (PBL) parameters and a 40 km fine net control experiment, basically simulated the structure and variation of the Black sandstorm on May 5th 1993. Simulation results show that the black sandstorm is concomitant to the strong vortex of the meso-scale inside the PBL at its beginning stage of development. It is concomitant to vertical eddy-pillar inside the convection stratum. The lower (upper) part of the eddy-pillar extending to the convection top stratum is a vortex eddy pillar (reverse vortex) that is concomitant to the strong convergence (divergence) inside (outside) flow at lower (high) altitudes.

Song Zhenxing and Cheng Linsheng (1997), by using meso-scale numerical simulation data of the Black Sandstorm on May 5th 1993, have conducted numerical diagnosis and analysis on the contribution of effective potential energy and wet stir energy in the process of the Black Sandstorm on May 5th 1993 on the basis of wet stir energy formulation of moist barocline atmosphere. The analysis shows that the huge amount of released effective potential energy of agitating wet energy inside the planet boundary layer (PBL) is the main source of energy brought about by rapid occurrence and development of the sand-dust storm on May 5th 1993. The emergence of the mentioned energy is not only related to the powerful vertical slash of the wind in the wet inclined atmosphere, but also related to the powerful heating and strong convection instability of the underlying surface inside the PBL. The agitating wet energy source decreases rapidly above the PBL and the agitating energy in the black sandstorm area is basically negative; namely it is the energy convergence.

Zhang Xiaoling, et al (1997) conducted diagnosis and analysis of the vortex origin causing the occurrence and development of the meso-scale whirlpool during the black sandstorm weather on May 5th 1993 by utilizing MM4 high-resolution data. The results of the diagnosis and analysis indicate that the development of the black sandstorm on May 5th 1993 was directly related to the occurrence and development of the meso-scale air vortex eddy. The occurrence, development and formation and variation of the vertical pillar structure coincide with the vertical structure and variation of the meso-scale vortex formation. It was concluded that the dynamic mechanism of such rapid development of the meso-scale vortex is determined by total vortex origin. The classification of total vortex sources of the atmosphere shows that the agitating vortex that is related to powerful wave agitating air current makes the biggest contribution to the total vortex sources. The contribution of the non-linear interacted vortex between large-scale and meso-scale systems is second biggest. The contribution of the time average vortex related to topographic compelling is the minimum.

Chen Weimin, et al (1996) simulated, by utilizing the improved PSU/NCAR meso-scale numerical value mode (MM4 Standard edition), the variation and distribution of sea-plane air pressure during processes of large-scale suspension floating dust and sandstorm weather that occurred from 5th to 11th April 1994 in Northwest China. Normal observation data was applied at the initial stage. Special attention was paid to the meso-scale low pressure in Zhangye and Dunhuang of the Hexi Corridor in Western Gansu and the Qaidam Basin in Qinghai. At the same time, the strong eastern wind in the Hexi Corridor of Western Gansu prevails among the Zhangye middle-low pressure, and the Mongolian cold high pressure has also been simulated. The result of the sensitive experiment shows that dry physical processes of the atmosphere mainly restrict the formation and development of middle-low pressure of sand-dust storms. Yet the heating power, dynamic process and compelling outside source of unusual topography play important roles.

Genthon (1992) studied the characteristics of desert sandstorms and aerosol of the ocean salt of Antarctica by using the atmospheric circulation mode. His research indicates that the quotation of parameterization programmes of simple aerosol into climatic forecast modes gained solution from the observation value of desert sandstorms and ocean salt of the Antarctic, reflecting the interaction between climate and aerosol in the past and at present. The most interesting result is that the vertical structure of aerosol distribution is a very important parameter of the numerical value simulation and the stability of the planet boundary layer greatly affects the vertical distribution of closer-ground aerosol.

The aerosol of sand-dust storms that emerged during the process of sand-dust storm weather can be transported to remote regions through atmospheric circulation and bring about impacts on the weather and climate there. Iwasaka, et al (1979) carried out research on the process of sandstorms that occurred on April 14-15th 1979 in Northwest China. Their results indicated that the horizontal scope of sand-dust clouds was approximately 1.36×10^6 km^2 and the total quantity of sand-dust particles was at least $1.63\text{x}10^6$ tonnes. Results of radar observations showed that the sand-dust clouds were composed of two layers, with the upper layer of the cloud being 6 km and bottom layer being 2 km. Analysis of locus of sand-dust clouds demonstrated that the upper layer of the sand-dust cloud originated from the Taklimakan Sand Desert of China and the bottom layer sand-dust cloud originated from the Gobi Desert and the Yellow River valley in Northwest China. These facts show that sand-dust weather processes in Northwest China have an important impact on the weather and climate in Japan.

The Sahara Desert and its adjacent arid zones are the one of the four sand-dust areas in the world. Sand-dust storms that originated from the Sahara and its neighbouring arid areas can be transported to the American Continent via the Atlantic Ocean by tropical eastern wind air currents. According to Swap's (1992) research, the sand-dust of the Sahara Desert was transported to the Amazon Plain of Brazil and approximately 4.8×10^5 tonnes of dust particles was brought to the northeastern part of the Amazon Plain during a one time sand-dust storm that occurred in the Sahara Desert. The annual transport and accumulation was 1.3×10^7 tonnes, namely 190 kg of dust particles accumulated annually on one ha of land. Through analysis of aluminum in 4 μ aerosol in Barbados in Latin America, Ellis Jr. et al (1995) concluded that 55% of aluminum particle samples originated from North Africa. Franzen, et al (1995) made analyzed sand-dust storm processes that occurred in central and southern Europe and the north of Scandinavia in March 1991, which originated from the Sahara Desert, and they concluded that the sand-dust of the Sahara Desert was transported and accumulated in the northern region of Germany. The affected area of the sand-dust storm process of this sand-dust storm in March 1991 was at least 3.2×105 km^2 and dust accumulation in the above-mentioned region was estimated to be as much as 5.0×10^4.

4. STUDY OF STRATEGIES AND PROJECT ARRANGEMENTS FOR PREVENTING AND REDUCING SAND-DUST STORM DISASTERS

Sand-dust storms, particularly when developed into black sandstorms, are hazardous weather events with serious calamity and bring about critical harm to local people's life, property and agricultural and industrial productions. Sandstorms accelerate the desertification process in affected regions. Although the occurrence and development of sand-dust storms cannot be completely controlled through human ability at the moment, as long as further studies and efforts are conducted to explore objective regularity of the occurrence and development of sand-dust storms, the casualty and economic loss caused by sand-dust storms, particularly the black sandstorms, can be reduced to a minimum extent, by utilizing appropriate modern science and technology and by popularizing valuable experience and know-how to fight against desertification and sand-dust storms, through researchers and people working in the field combating the issues. In recent years, relevant research has been carried out in China (Xia Xuncheng, et al, 1996), as follows (*see also Chapter 14*).

4.1. Study on emergency protection measures of human life property

Sand-dust storms particularly black sandstorms, move violently along with strong roaring winds and suffocating dust-laden blasts. Black sandstorms darken the sky and conceal the sun while yellow sand blows and devil winds sweep across the area. Sandstorms are a terrible disaster easily causing injuries, deaths and property loss. Relevant studies have raised some effective measures for preventing children from dropping into water bodies, avoiding broken walls and collapsed cliff, safeguarding domestic fowl and animals, cutting off electricity supplies and controlling fires.

4.2. Withdrawing crop cultivation for revegetation and other eco-environment improvement projects

In light of the implementation of the China Western Region Development Strategy and Acceleration of Central-Western Region Progress, the central government of China, from 2000, is going to facilitate Ten New National Projects in the China Western Region. Among the total, the National Project for Withdrawing Dry Farming for Revegetating Forest and Grasses and Ecology Restoration in the Central-Western Region is one of the ten initiative arrangements. It is planned that, from 2000, demonstrations and pilot interventions for withdrawing dry farming to restore forest and grasses are arranged in the Yunnan and Sichuan provinces at the upper reach of the Yangtze River and Shaanxi, Gansu and more than 10 other provinces in the middle and upper reaches of the Yellow River. The target of the plan is to withdraw 343,000 ha of dry farming land and to plant 432,000 ha of forest and grasses through artificial means. This initiative will play an important role in controlling the occurrence, the development and calamity of sand-dust storms on a large scale.

4.3. Study on the establishment of protective oasis shelterbelts

According to the actuality of the situation in Northern (especially in Northwest China), the following protective networks and green tree belts have been implemented.

1) Sandbreaks and grass-shrub kulun for preventing natural psammophyte from destruction at the oasis fringes, for instance the *"Three North Regions Shelterbelts Construction Project"* since the late 1970s.

2) Enclosure of degraded land and protection of natural desert forests to control the occurrence and development of sand-dust storms.
3) Establishment of windbreaks and sandbreaks around oasis to control and reduce shifting sand disasters and threats of black sandstorms.
4) Adoption of engineering approaches to stabilize shifting sands and revegetate mobile dunes at the oasis fringe.
5) Plantation of protective farmland shelterbelts at the marginal areas and oasis edges to avoid soil erosion of sandy land surface and preventing farmland from blowing-out sand-dust storms. Such plantations can partly improve the microclimate of the protected farmland.
6) Popularization of optimum agricultural cultivation skills to prevent or reduce the extent of wind erosion and sand accumulation. For instance, adoption of soil transformation, reinforcement of the roughness of land surfaces to reduce denudation and optimum introduction of varieties and inter-cropping systems.

4.4. Wind-sand control in arid and semi-arid zones in the north part of the Loess Plateau

The arid and semi-arid zones in the northern part of the Loess Plateau are characterized by extremely abundant material sources for causing sand-dust storms. Furthermore, most land surface is exposed to frequent prevailing winds and human disruption in the long winter months. The sand-dust storm calamity is critical and wind-sand impacts are serious in the mentioned loess plateau. In respect to these severe conditions, the following measures have been taken in recent years.

1) Measures for controlling wind erosion were adopted in the dry-farming areas where excessive reclamation of wasteland and mismanagement of drylands have been practiced during the 1950s to the 1970s. For instance, crop residues were kept on the land surface after harvest to reduce soil erosion and bush-shrub seedlings were re-planted to decrease wind blowout and denudation. An effective measure has been formulated to withdraw dry farming and revegetate degraded lands in dryland areas.

2) Rejection of wasteland opening-up and rotation cropping were encouraged while practicing enclosure and protection of fodder-farm/steppe/rangeland and rational grazing systems or optimum carrying capacity. Promotion of rangeland management, animal husbandry development and rotation fence installation constituted a series of effective measures improving natural steppe vegetation. Vegetative cover in the mentioned loess plateau has increased and the potential dynamics to control wind and sand disasters has been strengthened.

4.5. Preventive approach for stabilizing shifting sands by plantation in inter-dune areas

In the inter-dune or lower-lying areas, artificial plantation of seedling trees and shrubs was done directly on mobile dunes. Man-made vertical wheat straw barriers were planted on shifting sands and then as a second step, psammophyte was transplanted on the straw checkerboards and air seeding was initiated to sow sand-holding varieties. This approach has effectively reduced the acceleration of desertification and turned mobile dunes into fixed sand mounds.

4.6. Control of sand disasters along traffic lines and adjacent industry and mining facilities

In Northwest China, mining fields, communication and transportation facilities, newly emerging rural and urban towns, water resources and hydro-stations, electric power, petroleum and gas exploitation are impacted by hazards and threats of sand-dust storms, particularly the damages caused by the serious sand-dust storms or black sandstorms. In recent decades, some successful research and technical engineering efforts have been conducted in many sections along railway lines in Northwest China and these efforts have not only guaranteed unblocked operation of the railway, but have also limited the occurrence and development of local sandstorms. Both economic and eco-environmental benefits are satisfied.

5. CONCLUSION

Research efforts on sand-dust storms over the last five decades, done on many aspects and in various countries, have gained a series of valuable results. These results have served decision-makers and governmental agencies as important scientific evidence for formulating policies and determining measures to control the issues of sand-dust storms and land desertification. These results set a substantial foundation for further studies on the issues in the future. However, along with the continuous rapid growth of human population and the intensification of global change, the contradiction between limited resources (especially water resources) and environmental conditions and the fast increase of human requirements becomes outstanding day by day. The natural eco-environmental situation in certain regions will gradually worsen if more effective efforts and approaches are not adopted as soon as possible. It is estimated that the occurrence and development of sand-dust storms will be more frequent than in previous decades in the world's dryland regions. As a consequence, the possibility of intense sand-dust storms will be crucial, the threatening scale will be widened and issues that need to be studied will be more complicated. The research on sand-dust storms is yet facing challenges and long-term efforts are needed for future strategy.

6. REFERENCES

Ackerman, Steven A. and Hyosang Chung. 1992, Radiative Effects of Airborne Dust on Regional Energy Budgets at the Top of the Atmosphere. *J. Appl. Meteor.*, 223-233.

Cautenet, G., et al. 1992, Thermal Impact of Saharan Dust over Land. Part I: Simulation. *J. Appl. Meteor.*, 166-180.

Chen Min-lian, Guo Qing-tai, Xu Jian-fen, et al. 1993, Research and Discussion on the Black Storm. *Journal of Gansu Meteorology*, 11 (3): 16-27.

Chen Wei-min, Wang Qiang, Niu Zhi-min, et al. 1996, The Numerical Simulation of Meso-scale Lower Pressure of "4.5" Dust Storm in Northwest China. *Journal of Desert Research*, 16 (2): 140-144.

Cheng Lin-sheng, Ma Yan. 1996 Numerical Experiments of Developing Construction and Different Model's Resolution on the "93.5" Black Storm. *Quarterly Journal of Applied Meteorology*, 7 (4): 386-395.

Ellis JR, W.G. and J. T. Merrill. 1995, Trajectories for Saharan Dust Transported to Barbados Using Stokes' Law to Describe Gravitational Settling. *Journal of Applied Meteorology*, 34: 1,716-1,726.

Franzen, L. G. et al. 1995, The Saharan dust episode of South and Central Europe, and northern Scandinavia March. 1991. *Weather*, 50 (9): 313-318.

Fu You-zhi, Liu Kun-xun, Ding Rong, et al. 1994, The Causative Factors and Forecasting of the Black Storm in Hexi Corridor. *Journal of Meteorology*, 20 (12): 50-53.

Genthon, C. 1992, Simulations of desert dust and sea-salt aerosols in Antarctica with a general circulation model of the atmosphere. *Tellus*, 44B, 4: 371-389.

He Hui-xia, Qian Zheng-an, Qu Zhang. 1993, Example Registers of Partly Strong Sand-dust Storms in Northwest China. *Journal of Atmospheric Information*, 30 (4): 14-18.

Hu Yin-qiao, Yasushi Mitsuta. 1996, Development of the Strong Dust Storm and Dry Squall Line – A Mechanism Analysis on Generating Black Storm. *Plateau Meteorology*, 15 (2): 178-185.

Iwasaka, Y. et al. 1983, The transport and spatial scale of Asian dust storm Clouds: a case study of the dust-storm event of April 1979. *Tellus*, 35B, 3: 189-196.

Jauregui E. 1989, *The dust storms of Mexico City*. Inter. J. Climatol, 9 (2): 169-180.

Jiang Ji-xi, Xiang Xu-kang, et al. 1997, *A Study on the Short-range forecasting Method for Strong Sandstorm Taking Satellite Cloudness Imagery Data as the Dominant Factor.* Studies on Sand-dust Storms in China. Press of Meteorology.

Jiang Ji-xi. 1995, A Study of Formation for "Black Storm" Using GMS-4 Imagery. *Quarterly Journal of Applied Meteorology*, 6 (2): 177-184.

Joseph, P.V., Raipal, D.K. and Deka, S.N. 1980, "Andhi," the convective dust storms of Northwest India. *Mausam*, 31, 431-442.

Legrand, M. et al. 1988, Satellite Detection of Saharan Dust: Optimized Imaging during Nighttime. *Journal of Climate*, 1 (3): 256-264.

Liu Jing-tao, Zheng Ming-qian. 1998, The Climatic Characteristics of Black Storm in the Northern Part of North China. *Journal of Meteorology*, 24 (2): 39-44.

McNaughton, D. L. 1987, Possible connection between anomalous anticyclones and sandstorms. *Weather*, 42 (1): 8-13.

Pauley, Patricia M., Baker, Nancy L. and Barker, Edward H. 1996, *An Observational Study of the "Interstate 5" Dust Storm Case*; Bulletin of the American Meteorological Society, 77 (4), 693-720.

Qian Zheng-an, He Hui-xia, Qu Zhang, et al. 1997, Classified Standard, Example Registers and Statistical Characteristics of Sand-dust Storms in Northwest China. *Studies on Sand-dust Storms in China*. Press of Meteorology.

Qiu Jin-heng, Sun Jin-hui. 1994, Optically Remote Sensing of the Dust Storm and Result Analysis. *Scientia Atmospherica Sinica*, 18 (1): 1-10.

Qu Zhang, Xu Bao-yu, He Hui-xia. 1994, Some Enlightenment from A Sandstorm Occurred in Northwest China. *Arid land geography*, 17 (1): 63-67.

Shang Ke-zheng, Sun Li-hui, Wang Shi-gong, et al. 1998, The Tele-connections of Sand-dust Storms over Hexi Corridor in Gansu Province and Sea Surface Temperature in Area of Middle and Eastern Pacific Ocean near Equator. *Journal of Desert Research*, 18 (3): 239-243.

Shen Shao-hua, Chen Shou-jun. 1993, The Analysis of Fronto-genesis Process Forced by Dust Radiative Heating. *Acta Meteorologica Sinica*, 51 (4): 425-433.

Shen Shao-hua, Chen Shou-jun. 1993, The Numerical Simulation of Fronto-genesis Process Forced by Dust Radiative Heating. *Acta Meteorologica Sinica*, 51 (3): 283-294.

Slobldan N., Srdjan. 1996, A Model for Long-Range Transport of Desert Dust. *Monthly Weather Review*, 2,537-2,544.

Song Zhen-xin, Cheng Lin-sheng. 1997, Diagnostic Analysis of the Perturbation Sources on the "93.5" Black Storm. *Journal of Lanzhou University*, 33 (4): 116-122.

Swap, R. et al. 1992, Saharan dust in the Amazon Basin. *Tellus*, 44B, 2: 133-149.

Tanaka, Toyoaki. 1974, Ice-crystallization process of cloud, Ice crystal core, *Journal of Meteorology*, (122): 689-737.

Wang Shi-gong, Dong Guang-rong, Yang De-bao, et al. 1996, A Study on Sandstorms over the Desert Region in North China. *Journal of Natural Disasters*, 5 (2): 86-94.

Wang Shi-gong, Yang De-bao, Jin Jiong et al. 1995, Study on the Formative Causes and Countermeasures of the Catastrophic Sandstorm Occurred in Northwest China. *Journal of Desert Research*, 15 (1): 19-30.

Wang Shi-gong, Yang De-bao, Jin Jiong, et al. 1995, Analyses of Time-space Distribution and Formative causes of Sandstorms Occurred in Northwest China. The Proceeding of the Second Academic Conference of Young Scientists of Chinese Association for Science and Technology. *Press of Sciences and Technology of China*, 364-370.

Wang Shi-gong, Yang De-bao, Meng Mei-zhi, et al. 1993, Analyses of Structure Characteristics and Formative Causes of the “5.5” Black Storm. *Journal of Gansu Me*teorology, 11(3): 28-31.

Wang Shi-gong, Yang De-bao, Zhou Yu-su, et al. 1995, Analysis on the Formative Causes of Sand-dust Storms in the Northwest China during 3-12 April 1994. *Journal of Desert Research*, 15 (4): 332-338.

Wei Li, Wen June, Shen Zhi-bao. 1998, The Radiative Characteristics of Atmospheric Dust Observed from Satellite. *Plateau Meteorology*, 17 (4): 347-355.

Wolfson, N. and Matson, M. 1986, Satellite observations of a phantom in the desert. *Weather*, 41 (2): 57-60.

Xia Xun-cheng, Yang Gen-sheng, et al. 1996, Disasters of Sand-dust Storms and Their Prevention and Control in Northwest China. *Press of Environmental Sciences of China, Beijing*.

Xu Guo-chang, et al. 1979, Analysis of the “4.22” Much Stronger Sand-dust Storm in Gansu Province. *Acta Meteorologica Sinica*, 37 (4): 26-35.

Xu Xi-hui. 1997, Analysis and Study on Cloudiness Feature of Sandstorms over Talimu Basin. Studies on Sand-dust Storms in China. *Press of Meteorology*.

Yan Hong. 1993, A Nationwide Meeting Summary of Discussing Sand-dust Storm Weathers Occurred in China. *Journal of Gansu Meteorology*, 11 (3): 6-11.

Yang Dongzhen et al. 1991, A case study on Sandstorm. *Acta Meteorologica Sinica*, 5 (2): 150-155.

Yang Dong-zhen, Wang Chao, Wen Yu-pu, et al. 1995, An Analysis of Two Sandstorms in Spring 1990. *Quarterly Journal of Applied Meteorology*, 6 (1): 18-26.

Zhang Xiao-ling, Cheng Lin-sheng. 1997, Diagnosis of Vorticity Source for the Genesis and Development of Meso-scale Vortex during “93.5” Black Storm. *Journal of Lanzhou University*, 33 (4): 123-131.

Zhao Xing-liang. 1993, Damages and Countermeasures of Catastrophic Sandstorm Occurred in Gansu Province. *Journal of Desert Research*, 13 (3): 1-7.

Zheng Xin-jiang, Liu Cheng, Cui Xiao-ping, et al. 1995, Cloudiness Features of Two Kinds of Dust Devil weather in China. *Journal of Met*eorology, 21 (2): 27-31.

Chapter Three

BLACK WINDSTORM IN NORTHWEST CHINA: A CASE STUDY OF THE STRONG SAND-DUST STORM ON MAY 5TH 1993

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SYNOPSIS

China is one of the countries where calamitous sand-dust storms are on the increase. The link between widespread desertification and the increase in the frequency and severity of dust storms has prompted more study of the causes and mechanics of such wind-related events. Of necessity it requires an inter-disciplinary approach because meteorologists, geomorphologists, ecologists and soil scientists need to work together.

A major sand-dust storm on May 5th 1993 caused serious economic loss and was as hazardous as a disaster caused by an earthquake. According to ground observation and investigation made by the expert group of the Ministry of Forestry, a total of 85 people died, 31 people were lost and 264 people were injured (most of these victims were children). Agriculture and animal husbandry were mostly severely hurt. In total 373,000 ha of crops were destroyed. 16,300 ha of fruit trees were damaged. Thousands of greenhouses and plastic mulching sheds were broken. 120,000 heads of animals died or were irrecoverably lost. The fundamental agricultural installations and grassland service facilities were ruined. More than 1,000 km of irrigation channels was buried by sand accumulation. Many water resource back-up facilities, such as reservoirs, dams, catchments, underground canals and flood control installations were filled up with sand silts. About 6,021 communication poles and electricity grids were pushed down and electricity transports and communication services in some regions were stopped for several days. Some sections of railway and highway were interrupted due to deflation and sand accumulation.

This chapter describes in detail 1) the time, location and characteristics of the sand-dust storm on May 5th 1993 (hereafter called the 5.5 Sand-dust storm); 2) evaluation of hazards and economic loss caused by the 5.5 sand-dust storm; 3) analysis of the root causes of sand-dust storms and its processes; 4) and the present situation in the affected regions.

KEY POINTS

1. *China, especially northwest China, is one of world's regions most susceptible to widespread and disastrous sand-dust storms. There are reasons for this, many of them due to the natural conditions (climate, topography, soils and vegetation) but there are also strong influences from human activities.*
2. *Analysis of the sand-dust storm on May 5th 1993 tells us a lot about the mechanics and dynamics of such a wind-related event and of the consequences for human life and property as well as for the ecosystem.*
3. *The root causes are complex and involve an interaction between natural factors, weather, climate, geomorphology, edaphics and vegetation and the impacts of human use under high population pressure and unbridled economic development in an era when potential environmental consequences were disregarded in favour of economic advancement.*

1. FACTS ABOUT THE 5.5 SAND-DUST STORM

On May 5th 1993 (hereinafter referred to as the 5.5. storm), a strong sand-dust storm of an intensity seldom seen in history occurred in Northwest China. This sand-dust storm (of a type called *"Black windstorm"*) brought about violent terror and extreme destruction and caused disastrous loss to people's life and property. All walks of life in China paid great attention to this calamity.

1.1. Space-time characteristics

The 5.5 sand-dust storm originated from the northern part of Xinjiang and gradually died out in the eastern part of Ningxia. It swept across Urumqi, Turpan, Hami of Xinjiang Uygur Autonomous Region, Jiuquan, Zhangye, Jinchang, Wuwei, Gulang, Jingtai in Gansu Province, Ejina, Alxa Youqi, Baiyanhot, Dengkou, Jailantai, Wuhai of Inner Mongolia, and Zhongwei, Qingtongxia, Huinong, Taole, Yinchuan in Ningxia Hui Autonomous Region. In total, 72 counties and cities in 4 provinces and autonomous regions were engulfed. About 1.1 million km² of land was directly affected which covers 11.5% of the total land territory of China and 12 million people were threatened.

The 5.5 sand-dust storm started at 20:00 hrs on May 3rd 1993 along with the southward cold air from Siberia. At 20:00 hrs on May 4th, strong winds of 20 m/s prevailed in the north of Xinjiang and a sand-dust storm was initiated at the periphery of the Gurban Tonggut Desert, in the northwest part of Urumqi. The weather charts of sky and ground at 08:00 hrs on May 5th indicated that the ground peak of the sand-dust storm moved eastward to Dunhuang, the western part of Jiuquan and, at the same time, just behind the storm peak, a 20-24 m/s wind weather appeared and developed in nearby Hami of eastern Xinjiang and along the Mazongshan Mountain of western Gansu, that moved southeastward. At 13:52 hrs on May 5th, strong winds had swept across Gaotai of western Gansu with a maximum velocity of 25 m/s and yellow winds prevailed and the sky became dark and visibility worsened. At 14:16 hrs on May 5th, the yellow storm had moved to Lingze and arrived in Zhangye at 14:19 and caused great damage in Minle at 14:25 where a serious sand-dust storm occurred.

At 15:42 hrs on May 5th, a strong sand-dust storm formed with maximum wind velocity of 34 m/s at force 12 (Beaufort scale). In a very short period of time, yellow sands blocked up the sky and the entire world was hazy. Heavy thunder exploded in air and dust cloud peaks rose to the atmosphere. Daylight was dim. Cloud colour varied from grey to red to black and visibility at ground level was near zero. The dust clouds moved quickly and overwhelmed everything in their path. By 16:40 hrs on May 5th, a strong sand-dust storm had reached Wuwei, Gulang by 17:00 hrs and swept across Jintai by 17:50 hrs. At 19:26 hrs, the storm landed in Zhongwei, in Ningxia and arrived in Taole (eastern Ningxia) at 20:02 hrs. Altogether, the strong storm travelled for 4 hours and 57 minutes from Gaotai in Western Gansu to Zhongwei in Ningxia. It finally died out in Taole and Huinong of Ningxia at 3:12 hrs and 9:37 hrs respectively on May 6th.

1.2. Characteristics of the form of the storm

Before the sand-dust storm passed through the territory, a grey-dark sand-dust wall appeared on the horizon; it came over quickly (*Photo 1*). On the flank side, it can be seen that the heavy and cold air inserted under the light and warm air in the shape of a wedge. The front peak of the cold air pillar with thick sand-dust near the ground surface was thin and the rear peak was deep and thick (*Figure 1a*). When it moved forward, due to the friction function of the ground surface, the front edge of the cold air wedge did not connect directly to the ground as false line AM' N' shows. Instead, it turns over to pull behind in a *"Nose"* BAMN form. It is called a cold air nose. The nose bottom (A) was at least 40 metres from the ground surface. It can be seen from the obverse side (*Figure 1b*) that the visible part that can be seen is the CD part of the cold air nose. It is just a small part of the forward-moving arc of cold air at the nose. From E and F points at the left and right sides, up to the G and H points, down to M and N points, a dense rim of sand-dust storm and its interior tumble becomes gradually unclear. For instance, the dark and light uneven layers of G and H above B can be identified, but the interior sand-dust tumbles (particularly point H) cannot be recognized. This unclear part is the part of the cold air nose that slopes backward in a far distance and corresponds respectively to points G and H in *map 1a*. Similarly, the alphabet letters in *map 1a* and *map 1b* correspond to each other.

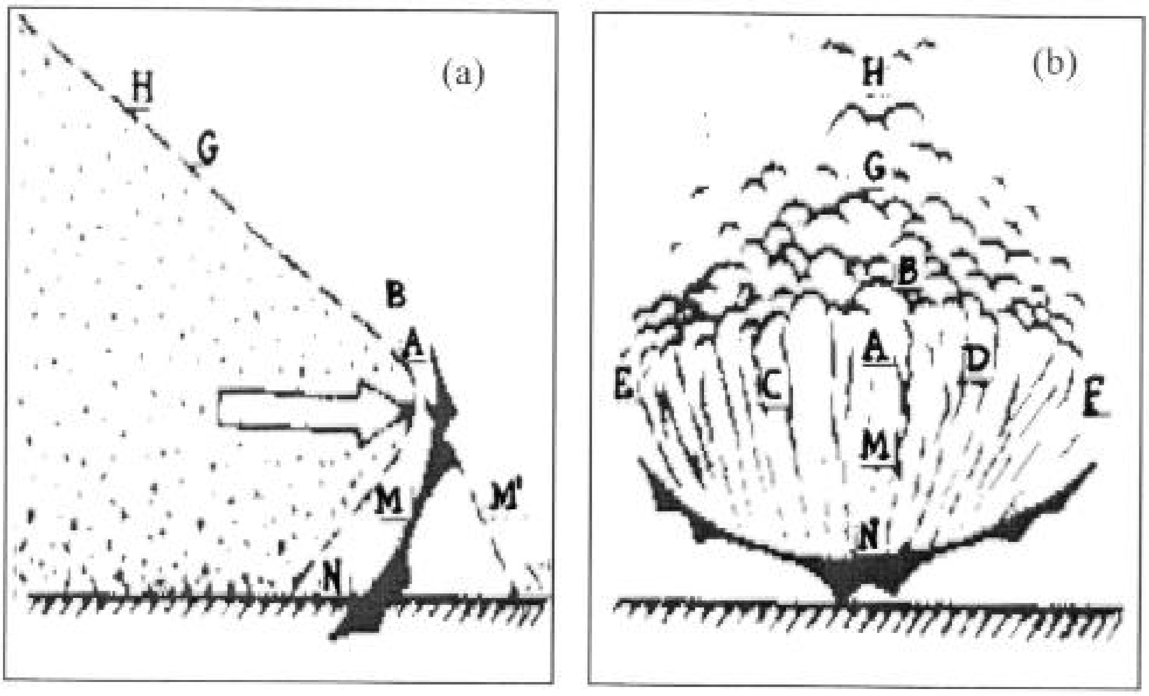

Figure 1: Sketch from a video capture of the side vision (a) and front-vision of sandstorm peak (b)

1.3. Characteristics of convection

The sand-dust wall was clearly 300 metres high and, in fact, the thick sand-dust peak was much higher. According to the analysis of dust accumulation on the long-standing snow on Wushaoling Mountain, it is estimated that the thick sand-dust peak was 700 metres. However, this sand-dust was already reduced when it crept to the Wushaoling Mountain. It was roughly estimated that the height of the peak in the serious section of Jinchang was more than 1,000 metres. In fact, it was calculated that, according to the brightness temperature of the thick peak on satellite images, the height was about 2,200 metres.

Before the arrival of the sand-dust storm, the near-ground air was unstable and sand-dust clouds inside the sand-dust wall rolled and turned over in waves. Along with the occurrence of this sand-dust storm, strong winds and thunder were observed in many regions and this indicates that, like hail and thunderstorms, the sand-dust storm belongs to convection weather.

1.4. Characteristics of optical phenomena

A sand-dust wall is composed of three strata. The upper stratum was yellowish and reddish, the bottom stratum was black in colour and the middle stratum was grey-black in colour. It was bright sometimes and dark at other times and metamorphosed in an unpredictable way. This is a normal optical phenomenon of sudden attenuation of sunshine as it cuts through uneven thick sand-dust walls (*see Chapter 2*).

When sun light goes straight through the atmospheric stratum, a series of changes of light reflection, absorption and scattering will occur as sunlight passes across cloud layers, and encounters suspended water drops and dust particles. As a consequence, disseminating direction of sunlight will be changed and sunlight intensity will be reduced. When the weather is clear without clouds, the sky is blue. When the weather is dusty, the sunlight will not only be significantly reduced because of absorption of dust particles and the colour of the sky becomes dark, but there is also more red and orange light. Light will be scattered as sunlight cuts through the thick dust peak and the colour of the sky becomes red. The time-space distribution of the thick dust peak is uneven and as a consequence, the thinness and thickness and density of the dust peak determine the distinct brightness and change of colour of the sky.

2. HAZARDS OF THE 5.5 SAND-DUST STORM

2.1. Forms of hazards

The 5.5 sand-dust storm was a highly destructive disaster. Everywhere it swept across, traffic lines and communication were blocked, water and electricity facilities were paralyzed, settlements and houses collapsed, grazing lands and farmlands were invaded with sand accumulation. It even led to death and loss of personnel. In addition, it resulted in atmospheric pollution and caused impacts to the ecological environment outside China's borders (including the Pacific Ocean near Hawaii).

2.1.1. Sand accumulation

Under the driving force of strong winds, sand particles under the lower stratum of the sand-dust peak roll forward. When the wind force became weaker or sand materials collided with an obstruction, a great amount of sand accumulated on the surface and buried farmland, attacked villages, mining sites, railways and highways, and water supplies. This form of disaster appeared especially at the periphery of oases and gobi[5] areas. It also happened in sandy desert or in the newly cultivated area at the desert periphery, or in the sand and gravel gobi area where human disturbance associated with resources development is frequent and severe.

2.1.2. Wind erosion: deflation and abrasion

Wind erosion does not only blow away fine clay minerals and organic matter in the soil, but also brings about sand accumulation on topsoil and on abandoned cropland and thus enlarges the area of desertification.

During the process of soil erosion, blown sands cut seedlings of cereal crops or may even destroy whole crops. This disaster mostly takes place in open fields with widely spaced tree networks and on farms without shelterbelts. Particularly, on newly cultivated farmland outside shelterbelts, sandy surface soil is more easily eroded under strong wind conditions.

2.2. Strong wind attack

When sand-dust storm enters into artificial oases, particularly the tree-networked area, sand-dust is manifested in the form of suspended dust because sand movement on the ground surface has been arrested. Under this circumstance, sand-dust storm is in fact caused by strong wind attacks. Strong wind pulls out trees with their root system, pushes down walls, ruins houses, turns over moving trains, breaks communication facilities and destroys agricultural installations.

2.2.1. Atmospheric pollution

The 5.5 sand-dust storm not only brought about harm to local people, but its dust particles also caused serious impacts to adjacent regions. The 5.5 sand-dust storm that prevailed in the Hexi Corridor brought suspension dust to Lanzhou (hundreds of kms further east) where atmospheric air quality was severely polluted and all factory workshops and office buildings had to turn on their lights during the day. Air inside rooms was full of mud smell and irritated the nose. Whitewash dusts floated everywhere. Respiratory diseases were spread. Particularly, the tailings dust exhausted from the metallurgy industry caused heavy metal pollution as these particles were entrained and tranported.

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[5] The term gobi refers to a stone-covered desert surface. The so-called Gobi desert in China is a vast expanse of such stoney desert but smaller areas of similar landform occur in scattered patches throughout NW China.

3. Economic loss

The 5.5 sand-dust storm caused serious economic loss that was as hazardous as a disaster caused by an earthquake. According to ground observation and investigation made by the expert group of the Ministry of Forestry, a total of 85 people died, 31 people were lost and 264 people were injured (most of these victims were children). Agriculture and animal husbandry were most severely hurt. In total 373,000 ha of crops were destroyed. 16,300 ha of fruit trees were damaged. Thousands of greenhouses and plastic mulching sheds were broken. 120,000 heads of animals were killed and lost. The fundamental agricultural installations and grassland service facilities were ruined. More than 1,000 km of irrigation channels was buried by sand accumulation. Many water resource back-up facilities, such as reserviors, dams, catchments, underground canals and flood control installations were filled up with sand silts. About 6,021 communication poles and electricity grids were pushed down and electricity distribution grids and communication services in some regions were stopped for several days. Some sections of railway and highway were interrupted due to deflation and sand accumulation.

The Lanzhou-Xinjiang Railway line was interrupted for 31 hours and the Wuhai-Jilantai Special Railway Line in Inner Mongolia was stopped for 4 days. About 37 freight trains were stopped or delayed. Approximately 28,000 tons of industry-use salt and nitre was blown away in Inner Mongolia, 4,412 houses were buried and numerous sheds and stalls for breeding animals collapsed. It is estimated that 560 million RMB Yuan (about USD $70 million) was lost. In addition, the sand-dust storm brought about a serious environmental crisis. In many regions, 10-30 cm of topsoil was deflated and soil fertility was reduced. At the desert periphery, sand dunes moved 1-8 metres forward and invaded into arable lands and grazing fields. The transport and movement of dust and sand during the storm increased the contents of dust in the air and polluted the atmosphere. For instance, in Jinchang in Gansu Province, the dust content in the air was as high as 1,016 mg/m^3, the dust content indoor was 86.7 mg/m^3, dust accumulation was 161-266 tons/ km^2 and these suspension dusts caused serious impacts to human health.

3.1. Calamity to traffic

The sand-dust storm brought about poor visibility and sand accumulation. It caused cessation of transport and even train derailments. For instance, the Lanzhou-Xinjiang Railway was interrupted for more than 30 hours. Similar disasters were caused to highways. Road bases were denuded and road surfaces were corroded and such damage weakened the performance of roads and the life of vehicles. The sand–dust storm produced severe threats to the aviation service, airports were closed and many air flights were delayed or cancelled due to its impact.

3.2. Disasters to agriculture and animal husbandry

In the areas adjacent to deserts, sandy land, gobi or in the oases[6] of deserts, because of the attack of the sand-dust storm, the land surface was violently destroyed. Near to the surface, strong wind erosion and sand movement occurred and crops were damaged and buried. Strong wind raised sand grains and dust particles, flower buds were blown off and melon and vegetable gardens were damaged. The 5.5 sand-dust storm, according to the statistics of Jinchang, Wuwei, Gulang, Jintai in Gansu provicne and Zhongwei in Ningxia Hui

[6] Oasis is a term used to describe irrigated agriculture on desert fringes. Sometimes these oases are an expanded version of a natural oasis but more commonly in China they were created in the last 50 years by diverting rivers and installing irrigation schemes.

Autonomous Region, destroyed 64,400 ha of farmland. The depth of erosion (soil loss) was about 10 cm and the maximum was 50 cm. The average loss of arable land due to wind erosion was 2,100 $metres^3$ per ha. Sand accumulation averaged 20 cm.

In the 5 counties mentioned above, about 750 power poles were pushed down and 22 km of electricity supply wires were cut, 89 sets of transformers and generators were damaged. Accumulated sands affected around 55 km of irrigation canals. About 20,000 ha of plastic mulching of cropping fields was blown away and 90,000 individual trees were pushed down during the 5.5 sand-dust storm.

3.3. Threats to industry production

The 5.5 sand-dust storm also damaged two electricity supply systems with a capacity of 35 kv and 6 kv of the Jinchuan Company of Jinchang. The main production assembly and some assisting networks were forced to stop production and the estimated direct economic loss was 83 million RMB Yuan (USD $10 million).

3.4. Loss of settlement

The 5.5 sand-dust storm flattened 4,412 houses and settlements in Jinchang, Wuwei, Gulang, Jintai in Gansu Province and Zhongwei in Ningxia Hui Autonomous Region.

3.5. Calamity to people's life and property

According to the statistics, 85 people were killed, 264 were injured and 31 lost during the 5.5 sand-dust storm. About 120,000 heads of animals died and were lost and 730,000 heads of animals were threatened by the sand-dust calamity.

4. PRESENT SITUATION IN THE AFFECTED REGIONS

After the 5.5 sand-dust storm, the Government of China attached great importance to the affected areas of the Hexi Corridor of Western Gansu and the sand-dust source area of Alxa of Western Inner Mongolia and a serious approach was adopted to reduce the severity of the calamity. Detailed efforts were made to study the mechanism of the formation of sand-dust storms and prediction and forecasting of such disasters (*see Part VI*). More attention was given to biological and engineering approaches. Policy and legal measures were adopted to control the expansion of land desertification. But because of the impact of La Nina events, strong cold flow and strong winds frequently occur in Northern China. Air temperature has obviously heightened, precipitation has declined, water resources became deficient and the ecology has further worsened. Since the late 1990s, the tendency of re-activation of sand-dust storm is increasing and particularly in 2000, the frequency of sand-dust storms has doubled up to the maximum record during the last five decades. From December 31st 2000 to January-April 2001, 9 sand-dust storms took place in the above mentioned regions. On 4 occasions there were threats to central northern China and the downstream regions of the Yangtze River. Sand-dust storms occur earlier in the spring and are more frequent than in any decade before and the whole nation now attaches great importance to the issue. The following are fundamental sources of sand-dust storms.

- **There are abundant sand-dust sources**. In Western Gansu and Western Inner Mongolia where sand-dust storms are frequent, there are more than 300,000 km^2 of sand deserts and gobi areas, more than 6,000 km^2 of dried up lacustrine basins, more than 500 km^2 of dried lakes and catchment, more than 1,000 km^2 of deflation, abrasion and denudation. All these landforms are the essential sources of sand-dust storms. In sand deserts, the silt content in sand material is generally 2-6% and the maximum is 10%. The silt content in gravel deserts or gobi desert is 16-35% and that in sandy loess is 20%. The dust-silt content in eroded land is as high as 80%. The silt content in dried up lacustrine sediments is more than 70% and fine particles in newly cultivated fields are more than 70%. Besides the natural landforms, artificial sediments, such as the tailing sands and dust coals are also a potential source of sand-dust storms.

- **Existing topography and landforms are conducive to sand-dust storms**. There are vast areas of gorges, inter-mountain corridors and plain landforms that are advantageous surface conditions to the sweep of strong cold air from the north.

- **Vegetative coverage is sparse and wind erosion is serious.** All the lakes in the mentioned regions are dried up, wetlands have declined and underground water tables have dropped. As a consequence, large areas of vegetation were degraded and/or withered and died and the land surface was exposed to serious deflation. The transitional zone at the desert periphery was interrupted and sand shifting and dune movement became active.

- **Water resources are mis-managed or irrationally used**. The deficiency of water reources downstream in inland rivers, the break of flow, the drying-up of lakes and the decline of underground water are the root causes of ecological deterioration.

Because of the above-mentioned causes, new sand-dust sources were enlarged in the affected regions and this is one of the reasons that frequency of sand-dust storms has increased. Since 1999, effective measures were adopted to slow down the frequency of sand-dust storms. For instance, a water-distributing plan of inland rivers was developed and water-saving techniques were extended to the upstream and middle reaches of inland rivers and a certain amount of inland-river water flow reached the downstream areas. But the water-use conflict downstream was only partially resolved. National and provincial nature preservations were established downstream to prevent the wetlands, lakes and desert plant communities along river course from degrading and withering. In some seriously degraded areas, ecological immigrants were appropriately moved out of the affected regions to allow revegetating the deteriorated lands. National projects to combat desertification and withdraw dryland farming for ecological restoration were financed and incorporated into the National Social and Economic Development Plan. Now the shed-feed breeding of livestock is actively encouraged to relieve pressure on the rangelands. It is planned that ecological deterioration will be controlled in near future.

5. ROOT CAUSES AND PROCESSES OF THE 5.5 SAND-DUST STORM

Sand-dust storms are a result of an interaction between the weather process and the land surface reactivation process. The weather processes include mainly the wind dynamic process and the thermal dynamic process. The surface reactivation and exposure process of sand material is composed climatically of drought and deficient rainfall and anthropologically of irrational activities, namely the mismanagement of water resources, over-cultivation, over-grazing and human-induced accumulation of wastes and tailings. The above-mentioned interactions caused the occurrence and development of the sand-dust storm.

5.1. Weather process

Wind and thermal dynamics are factors of the weather process favouring the formation of sand-dust storms. These two factors are the dynamic conditions to form sand-dust storms. Without these dynamic powers, sand-dust materials on land surfaces cannot be blown up into sky (entrained and transported, see Chapters 1 & 2).

5.2. Dynamic process of wind

Sand-dust cannot be blown up without wind: sand particles can move only under the condition of a certain wind force (*see Chapter 1*). When the wind reaches a threshold velocity, the sand-dust particles can break away and enter into movement. The threshold velocity is called sand-blowing wind. According to observations, when the wind velocity reaches 30 m/s, sand particles with a diameter of 0.5-1 mm can be blown up for several tens of cm high; sand particles of 0.125-0.25 mm can rise up to 20 cm high; fine sand dust of 0.05-0.005 mm can be blown up to 1.5 km; and very fine sand dust less than 0.005 mm can be lifted up to a height of 12 km.

The occurrence of sand-dust storms and serious wind denudation cause sand transport. Sand particles move in the form of creeping and saltation over a short distance. At the same time, fine dust materials can be lifted up into the atmosphere by vertical thermal convection and be transported for a long distance in a suspended form. Some samples of different locations have been tested in wind tunnels and sand-blowing rates under different wind velocities are listed in *Tables 1 – 3* below.

Table 1: Wind tunnel experiment of sand blowing rate on alluvial gobi desert in Jiuquan of Gansu Province

Wind velocity(m/s)	10	15	20	25	30.8
Sand blowing rate ($kg\cdot m^{-1}\cdot min^{-1}$)	0.0021	0.0388	0.0504	0.0866	0.1357

Table 2: Wind tunnel of sand blowing rate on alluvial-deluvial gobi in eastern Dunhuang of Gansu Province

Wind velocity (m/s)	7	15	20	25	32.15
Sand blowing rate ($kg\cdot m^{-1}\cdot min^{-1}$)	0.0020	0.0039	0.0113	0.0426	0.1124

Table 3: Wind tunnel experiment of blowing sand and suspension dust

Wind velocity (m/s)	7	15	20	25	32.15
Sand blowing rate ($kg\cdot m^{-1}\cdot min^{-1}$)	3,406.9740	13,534.8834	49,127.9070	112,558.1394	178,708.444
Sand blowing rate ($kg\cdot m^{-1}\cdot a^{-1}$)	88.6382	519.7386	2,976.7963	4,896.6110	6,235.7202

Gales or strong winds cause sand-dust storms: the formation of strong winds or gales needs proper atmospheric circulation conditions. Meteorological studies show that there are two major types of atmospheric circulation conditions.

5.2.1 Invasive strong cold air

The half a year of winter season is the most active season of cold air mass in the Northern Hemisphere (polar region) and cold air enters into China from different regions in the southern parts of Xinjiang almost every 5-7 days (see below). Northwest China is the gateway of cold air entering into China. The cold air in the Northern Hemisphere often land on Northwest China through different paths from Iceland and the New World islands of the Arctic Ocean. On the upper air weather chart, strong cold air moves southward at a height of 5,500 metres and cold low troughs with minimum air temperatures of 30-40^0 in the sky above Xinjiang are deepened. Behind the trough, a strong northern wind with a velocity of 30-40 m/s forces the air southward.

On the surface chart, a central air pressure with a strong high pressure of 1,050 hpa can be seen in Siberia, or Central Asia, and East Europe. In its front, a northeast-southwest oriented cold front enters into the northern part of Xinjiang from the north-northwest and crosses over the Tianshan Mts and sweeps across eastward into the western part of Inner Mongolia and the Hexi Corridor and is funneled straight to Ningxia and the north of Shaanxi. This cold front moves rapidly with a speed of 70-80 km per hour and sometimes even reaches 100 km per hour. When the cold air sweeps across all exposed surfaces sandy surface materials will be deflated and blown up forming sand-dust storm. Beside the southward movement of cold air from the north, another path of cold air comes from central Asia and crosses over the Pamir Plateau and enters southern Xinjiang. Under these circumstances sand-dust storm weather will be formed along Karshi, Hetian, Ruoqiang and the Hexi Corridor of Gansu.

Sand-dust weather with strong cold air does not always occur after the cold front; it sometimes occurs before the cold front. Meteorologists found, through analysis and studies of the 5.5 sand-dust storm in the Hexi Corridor, that the unstable warm air was lifted up and developed into a series of juxtaposed belt-shaped rainy-clouds, because of the fast advance of strong cold air. When it is powerfully developed, strong sinking air currents behind the belt-shaped rainy clouds will bring the cold air at high altitudes down to the land surface and form dense cold air mass with high pressure under the rainy clouds. It is meteorologically called thunderstorm high pressure. A squall line of medium scale weather system from several kilometres to 100-200 km at the horizon level can occur at the joining point of thunderstorms and front warm air. Where it passes over, wind direction will turn over suddenly, wind force will increase, air pressure will rapidly heighten, temperature will decrease and sand-dust storms will appear as a companion of the thunderstorm. For instance, when the squall line passed through Jinchang on the afternoon of May 5th 1993, air pressure was raised by 3.1 hpa in ten minutes, temperature dropped down for 6.6^0 in two minutes and wind velocity accelerated to 22.7 m/s. The sand-dust storm in Jinchang first occurred under the impact of a squall line before the strong cold front and second occurrence and enhancement took place after the disappearence of the cold front.

5.2.2. Thermal surface depression before the cold front

In spring and early summer, thermal processes in the Southern Xinjiang basin heat land surfaces before the cold front arrives. Warm air rises in cyclonic convergence inside the basin and forms a thermal depression. The rising convergence air current can stretch to the mesosphere at 3,000 metres. At high altitudes, the upper air is full of divergence air current. When the horizontal divergence air current of the upper air exceeds the horizontal convergence air current of lower air, compensation function of air current will be promoted and this promotes the continuous development of a thermal depression at the ground surface.

When the thermal depression is developed in the Tarim Basin, west-oriented strong wind weather, or east oriented strong wind first and then the west oriented strong wind later, will prevail in Hetian that is just behind the thermal depression and in south part of Bayan Gol, Mongolia Autonomous Prefecture of Xinjiang, that is just in front of the thermal depression. When the thermal depression moves eastward close to the western part of the Hexi Corridor of Gansu, sandstorms will possibly occur in Jiuquan Prefecture of Gansu. Wind strength of the thermal depression is determined by the intensity of pressure gradients between the Mongolian High Pressure and the Tarim Thermal Depression. Wind in the centre of thermal depressions is strongest. The duration of a sand-dust storm is determined by the duration of the thermal depression and the transporting speed.

5.3. Thermal dynamic process

5.3.1. Stability of air is the decisive element in the occurrence of sand-dust storm

If the air in the lower stratum is stable, drifting sand-dust cannot be entrained and blown up too high. If the air at the low stratum is unstable, drifting sand-dust will be entrained and blown up high in the air stratum. The thermal dynamic process of weather systems is the element causing instability in air and up-down vertical movement of air. It entrains and blows up sand-dust materials on land surfaces into high altitude forming sand-dust storm weather and fine dust transport in the atmosphere.

In arid zones in Northwest China, strong winds prevail almost every winter and spring seasons, but the occurrence of sand-dust storms does not develop along with each wind. Statistics show that strong wind weather is more frequent than sand-dust storm weather in some regions and sand-dust storm weather is more frequent than strong wind weather in other regions (*Table 4*). It is apparent that the frequency of strong wind weather and sand-dust storm weather is related to thermal conditions or surface soil composition, or to both of the two elements. It can be seen from *Table 4* that sand-dust storm weather in Hetian, Zhangye, Minqin, Yulin and Yan'an is more frequent than strong wind weather, which is related to the abundance of sand materials in the aforementioned regions. In Kuche, Jiuquan, Wuwei and Yanchi regions, the number of days with strong wind is equal to that of sand-dust storms and this is related to both the ground sand materials and thermal conditions. In the other regions, frequency of strong wind is higher than sand-dust storm weather and is related to sand materials in the regions.

Table 4: Mean days of wind and sandstorm in March-June over the years in the Northwest China

Location	March		April		May		June		Total in Mar-Jun	
	Wind	S-storm	Wind	S-storm	Wind	S-sanc	Wind	S-storm	Wind	S-storm
Kwlamiyi	4.4	0.1	8.4	0.1	11.5	0.2	12.1	0.1	36.4	1.4
Turpan	1.1	0.8	4.2	3.2	6.3	1.8	9.1	0.7	20.7	6.5
Kuche	0.6	1.1	3.4	3.6	3.3	2.7	4.0	3.0	11.3	10.4
Karshi	1.0	1.1	3.5	2.1	5.0	3.2	5.8	2.6	15.3	9.0
Hetian	0.8	4.4	1.5	6.1	1.8	6.9	2.1	3.2	6.2	23.6
Ruoqiang	3.6	3.3	6.2	3.4	7.2	3.4	5.7	1.9	22.7	12.0
An'xi	8.7	3.3	9.7	1.6	9.0	1.3	6.7	0.9	34.1	7.1
Dingxin	4.0	2.3	5.5	3.2	5.1	2.4	4.9	2.5	19.5	10.4
Jiuquan	2.3	3.0	4.1	3.7	2.5	1.9	2.4	1.4	11.3	10.0
Zhangye	1.6	3.1	2.8	3.8	2.5	2.7	1.9	2.1	8.8	11.7
Minqin	2.8	4.1	4.5	5.9	3.6	4.2	3.7	4.3	14.6	18.5
Wuwei	1.9	1.9	3.3	2.6	2.9	1.9	2.1	1.3	10.1	7.4
Lenghu	3.1	0.6	4.0	0.5	3.1	0.5	3.3	0.4	13.5	2.0
Xining	1.8	2.0	6.8	1.4	4.9	0.5	3.6	0.8	17.1	4.7
Maduo	9.6	1.6	6.7	1.3	5.1	1.2	1.6	0.1	23.0	4.2
Shizuishan	6.9	2.0	8.0	3.3	7.3	2.4	6.2	1.7	28.4	9.4
Yanchi	3.2	3.2	5.3	8.2	3.1	2.9	2.7	0.9	14.3	12.2
Yulin	0.9	2.6	2.1	3.3	1.7	2.0	1.8	1.8	6.5	9.7
Suide	8.6	1.3	10.8	1.9	10.8	1.9	10.2	1.1	12.4	6.2
Yan'an	0.2	0.7	0.2	1.1	0.2	0.3	0.3	0.2	0.9	2.3

5.3.2. Unstable air (high-pressure gradient force) is the thermal condition causing local sand-dust storms

The main origin of unstable energy during the 5.5 sand-dust storm weather process was the occurrence and development of low air depression (700 hpa) in the eastern Qinghai-Tibet Plateau that promoted the easterly air current in the eastern part and central part of the Hexi Corridor. At 08:00 hrs on May 5th, strong cold high pressure had entered into the northern part of Xinjiang and pressure difference between Urumqi and Yumen in Gansu Province was 21 hpa and the pressure gradient was 3-hpa/100 km. When the pressure gradient increased, the cold front moved forward with a speed of 50-60 km/h. At 14:00 hrs on that very day, the cold front moved into Jiuquan of Gansu and the difference value of the allobaric centre, in a duration of 3 hours before or after the cold front, was 9 hpa and the difference value of allobaric centre was 44 hpa in a duration of 24 hours before or after the cold front. At 17:00 hrs on that day, the temperature in Zhangye was 25^0 before the arrival of the cold front and the temperature in Dingxin (adjacent to Zhangye) was 7^0 after the cold front; the temperature gradient in this duration was 12^0/100 km. Such strong geostrophic deviating wind caused by pressure gradients played a decisive role to form the sand-dust storm. In addition, from 20:00 hrs on the 4th to 08:00 hrs on the 5th May, rapid currents of western wind at high altitudes accelerated and the dynamic subsidence brought about impoirtant impacts to the occurrence of sand-dust storm.

5.3.3. Rapid increase of air temperature and acceleration of cold-heat convection in regions where the sandstorm occurred

The 5.5 sand-dust storm: mean temperature, extreme average and extreme maximum temperature from January to May in 1993 in Jinchang of Gansu rapidly increased (*Table 5*). Similarly, in the sand-dust storm on December 31st 2000: mean temperature in December in 2000 in Minqin and other regions was 4^0 higher than mean temperature in the same period of time in history.

Table 5: Air temperature of Jinchang, Gansu from January to May

Air temperature (^{0} C)	Jan.	Feb.	March	April	May
Mean temperature	-8.6	-0.6	5.2	11.2	15.8
Extreme average	-1.7	6.1	11.6	17.8	22.2
Extreme maximum air temperature	7.8	15.9	18.5	28.1	29.6

5.4. Processes of reactivation and exposure of sandy topsoil

The process of reactivation and exposure of surface materials is a consequence of desertification and is one of the important processes contributing to sand-dust storms. Sand-dust storm frequency is an important criterion to assess the process, spread and reversal of desertification in the affected regions. Namely, the frequency and intensity of desertification in the affected region relates directly to the severity of desertification (*see Chapter 1*). On the contrary, the severity of desertification in the affected region reveals the intensity and frequency in the occurrence and development of sand-dust storms. The process of land desertification is closely related to factors of natural conditions and human initiatives.

5.4.1. Natural elements contributing to dust storms

Climatic regime, material sources, topographic conditions and underground water status are the main (closely correlated) factors of the natural environment and the formation of land desertification. Climatic factors include precipitation, precipitation variation, air temperature, wind regime, etc. A series of specific features, such as low biomass, sparse vegetative coverage and high intensity of exposed land in ecosystem characterize arid climatic environments. In such arid areas, frequent winds may cause soil erosion. For this reason, weather conditions, aridity and prevailing winds are the basic natural conditions that cause occurrence and development of land desertification. Material source is an environmental factor contributing to desertification, but human factors play an important part. In some regions where climate is not arid, but sand-dust sources are abundant, sand movement and sand-dust storms occur as well. In arid and semi-arid zones with similar climatic conditions, sand material sources are the most important impact factor.

The impacts of geomorphological conditions on the occurrence and development of land desertification are characterized by the following four aspects: a) the geomorphological position determines the distribution of land surface materials; b) the geomorphological condition affects the change of local wind force and contrast of erosive accumulation; c) the geomorphological position determines land-use patterns; d) and the geomorphological condition affects the distribution and storage of underground water. In the areas with abundant sand material, better underground water conditions is one of the effective elements that limits the occurrence and development of land desertification. Underground water regimes indicate water conditions in a region and water-holding capacities of soil. When the water-holding capacity of soil is 4% the sand-dust blowing up and sand transport will be negative.

Table 6: Composition of sand grains in sand desert in the Northwest China (%)

Desert	Items*	Very fine sand	Course sand	Medium Sand	Fine sand	Fine dust sand	Dust sand	No. of samples
Taklimakan	A.value	□	0.02	4.54	34.15	41.97	19.32	63
	M.value	□	0.40	43.1	77.9	67.70	49.10	
	Mi.value	□	□	□	4.9	5.9	3.3	
Gurban Tunggut	A.value	□	□	8.70	68.2	19.1	4.0	21
	Ma.value	□	□	50.8	92.3	58.9	12.9	
	Mi.value	□	□	0.1	27.8	7.0	0.4	
Baidan Jilin	A.value	□	3.40	23.4	61.4	9.82	1.98	17
	Ma.value	□	34.0	58.4	98.7	66.0	32.0	
	Mi.value	□	□	0.70	23.0	□	□	
Tengger	Me.value	0.01	1.60	6.61	86.88	4.90	□	33
	Ma.value	0.02	33.30	36.20	99.38	19.78	□	
	Mi.value	□	□	□	41.84	0.50	□	
Ulan Buh	Me.value	0.01	0.78	17.31	72.11	9.52	0.27	28
	Ma.value	0.02	7.00	58.7	97.50	42.9	5.59	
	Mi.value	□	□	□	32.10	0.40	□	
Kubqi	Me.value	□	1.10	1.90	85.3	11.70	□	11
	Ma.value	□	5.6	9.60	98.0	69.60	□	
	Mi.value	□	□	□	29.60	1.00	□	
Sandland east of the Y.River, Ningxia	Me.value	□	0.13	17.99	75.05	60.16	0.67	44
	Ma.value	□	3.00	69.99	93.00	37.48	6.00	
	Mi.value	□	□	0.5	30.00	0.10	□	
Mu Us Sandy Land	Me.value	□	3.2	41.20	47.3	8.3	□	15
	Ma.value	□	17.00	67.10	89.85	36.56	□	
	Mi.value	□	□	0.60	21.98	3.02	□	

*Average value, Maximum value and Minimum value (10 point)

5.4.2. Climatic factors

5.4.2.1. Drought, sparse rainfall and unstable precipitation

Northwest China is located inland of the Eurasian continent far from oceans and blocked by high mountain ranges and plateaus. In particular the up-lift area of the Qinghai-Tibet Plateau is the barricade of the summer monsoon. The warm moist vapour cannot reach Northwest China and, as a consequence, the region is dry. Precipitation decreases progressively from east to west. In the eastern part of the Helan Mountain, annual precipitation varies from 200-400 mm and that in the west of the Helan Mountain is less than 200 mm.

Precipitation in the central and eastern parts of the Taklimakan Desert, eastern Xinjiang, the western Qaidan Basin and the Baidan Jilin Desert, annual rainfall is less than 50 mm and even below 25 mm.

Precipitation is sparse and unevenly distributed. The annual variation of rainfall is 30-40% in the eastern regions and more than 40% or even as high as 50% in the western regions. The rainy season is also uneven and is mostly concentrated in the period of June-August. Most rainfall is concentrated in several days and this makes for prolonged drought periods (210-300 days). Spring drought is especially serious. The evaporation is severe and varies generally from 2,000-3,000 mm and even as high as 4,000 mm in some regions. In consideration of aridity, it is 2.5-4.0 in the eastern region and exceeds 4.0 in the western region. Among them, aridity in the eastern Xinjiang and Taklimakan Desert is as high as 16 or even reaches 60.

5.4.2.2. Strong wind force and prevailing frequency

Northwest China is under the influence of northwest and southeast winds and follows the seasons. In winter, impacted by Mongolian High pressure, NNE-SSW oriented divergence air currents are formed near the 96°E longititude and cause the formation of NNE wind regimes in the eastern part of the Tarim Basin in Xinjiang and in the western part of the Hexi Corridor, Gansu. The eastern divergence air current passes over the Ningxia Plain and the Ordos Plateau in northwest wind along the north edge of the Alxa Plateau. In summer, secondary torrid air is moved northward and the westerly wind is blocked by the Pamir Plateau and turned over. One air current crosses over the Pamir Plateau Outlet and enters into the western part of the Tarim Basin, and another air current enters into the North of Xinjiang through the western inlet of the Jungger Basin. Therefore, NW wind is the prevailing wind in the north of Xinjiang, the Hexi Corridor, and the Ningxia Plain. Impacted by the southeast monsoon, SE wind is the prevailing wind in the eastern part of the Helan Mts.

Mean annual wind velocity is 3.3-3.5 m/s and mean wind velocity in spring seasson is 4.0-6.0 m/s. There are approximately 200-300 days where the wind exceeds the threshold wind velocity. There are 20-80 days when the wind force is at or above 8 on the Beaufort scale. Strong wind appears along the China-Russia and China-Mongolia border. Particularly in the gorges, valleys and outlets of mountains, like the Alashankou Gorge, Dabanchen and Qijiaojin, wind force is normally at force 12. The seasonal change of wind velocity is significant and almost all wind at force 8 is concentrated in the spring season, accounting for 40-70% of the total frequency of wind.

5.4.2.3. Reduction of water resources

Because of global warming, prolonged drought on a large scale is causing severe impacts to various water resources (glaciers, lakes and runoff).

Glaciers retreat: In Northwest China, water resources originate from high mountain glaciers. Because of global warming and drought, the glaciers retreat. For instance, the Altay Mts., the Tianshan Mts., the Pamir, and Qilian Mts. and 73% of the 227 registered glaciers are under retreat. According to ground measurements, the glacier areas of the Urumqi River of the Tianshan Mts. and the Shuiying River of the Qilian Mts. have retreated for 43% and 46% respectively since the Small Glacial epoch. The average retreat speed of glaciers in Northwest China is 10-20 metres per year.

Drying up of lakes: There are many inland lakes without outlets in Northwest China that are impacted seriously by climate variations and human activities. Lakes on the plain are mainly affected by human activities. For instance, the Lop Nor was a well-known inland lake and it covered an area of 3,000-km² one century ago because of the discharge of the Tarim River. Because of artificial embankments and reservoir catchments, the water flowing into the lake became less and less and the size of the lake contracted 2006 km² in total in the 1950s. It was completely dried up in 1972. Sogo Nor in western Inner Mongolia was named a natural oasis in history and it is dried up nowadays. The Qinghai Lake is an upland lake and water discharge of the lake is decreasing because of the arid climate and the development of 55,000 ha of irrigated agriculture near the lake. From 1956-86, the water level had declined to 3.35 metres. In recent years, because of water consumption exceeding supply, average perennial water deficiency is 456 million m^3/a, lake water level declines at an average rate of 10.57 m^3/a and water surface contracts at an average area of 9.43 km^2/a thus forming an exposed shore around the lake. In recent decades, the average annual decline rate is 13 cm. At the same time, due to the deterioration of the ecological environment, the land desertification process is accelerating and sand content in streams linking the lake is increasing. It is estimated that the total annual sand transport is 607,500 tons.

Change of runoff: The shrinking of lakes indicates the decrease of runoff. With regard to average runoff of rivers on Xinjiang's mountains in the past three decades, river flow comes from rainfall in Northern Xinjiang and is seriously being decreased and the proportion of river flow that comes from melting water of glaciers in southern Xinjiang is being increased. Along with the retreat of glaciers on a large scale, the rate and total runoff of melting water of glaciers in river flow are being decreased.

5.4.2.4. Abundant sand materials

Northwest China is an important source of inland sand-dust storms in Asia: the type of sand-dust is diversified and the area threatened is vast. It contains not only sand-dust storms caused by natural factors, but also the ones caused by human factors. Along with changes in natural conditions and human interruption factors, the system of sand-dust sources is unstable and is a major supplier of material for sand-dust storms. Desert, gobi, desertified land and loess supply sufficient sources of sand-dust materials for storm events. The area of desert in Northwest China is 503,000 km² and Gobi covers an area of 381,500 km². Desertified lands are approximately 184,400 km² and loess plateaus cover an area of 225,200 km². In total, the four types of affected lands occupy 1,2941 million km² of the land representing 42.52% of the total land territory of Northwest China. Sand and dust materials from the above-mentioned lands have all made a certain contribution to the occurrence and development of sand-dust storms.

Table 7: Microelements in aeolian sands in Hexi, Gansu (mg/kg)

Elemen	Ba	Mn	P	Sr	Zr	Cr	Rb	V	Zn	Ni	Cu	Y	Pb	Co	N	As
Conten	637 3	436.	318. 8	218.2	141.8	63.5	66.3	58.5	34.1	20.9	13.8	14.8	11.9	9.5	8.	6.2

Table 8: Composition of sand grains on gobi desert

Type of Gobi	Sampling site	Depth (cm)	Grain size (mm) and composition (%)							
			Grave l	Very coarse sand	Coarse sand	Medium Sand	Fine sand	Very fine sand	Dust sand	Clay particles
			72.0	2-1.0	1-0.5	0.5-0.25	0.25-0.125	0.125-0.063	0.063-0.002	<0.002
Alluvial gobi	40 km east Dunhuang	0-3	28.3	5.77	6.37	7.64	7.2	12.84	31.93	
		Less 3	23.2	7.07	8.5	9.64	11.84	19.57	20.18	
	Yumen Pass	0-2	18.04	2.34	4.41	8.46	13.4	28.8	24.56	
		Less 2	15.87	2.43	4.33	12.30	17.73	27.56	19.78	
Deluvial gobi	50 km east An'xi	0-2	28.21	2.96	5.26	9.76	10.26	19.53	24.02	
		Less 2	12.33	8.47	9.12	15.31	12.61	13.63	28.53	
	Yumen Town	0-5	43.07	3.76	3.39	6.53	7.93	18.46	16.86	
		Less 5	31.5	5.0	4.87	9.7	12.33	19.10	17.50	

Table 9: Composition of Loess particles

Soil	Sampling site	Depth (cm)	Grain size (mm) and Composition (%)				
			mid size sand	Fine sand	Very fine sand	Dust sand	Clay
			0.5-0.25	0.25-0.125	0.125-0.063	0.063-0.002	<0.002
Loess	Shenmu County, Shaanxi			0.27	51.03	47.83	0.96
Sandy loess	Chuanbei, Yulin				78.48	20.32	1.20

5.4.2.5. Advantageous geomorphologic conditions causing sand-dust storms

Landform and geomorphological features play significant roles in the distribution of sand-dust sources for sand-dust storms, running paths, blocking air currents, friction, diffusion, narrow-pipe (funneling) effects and local thermal functions. It is clear that landform and geomorphological features have a positive influence on the occurrence, development, acceleration and destructive force of sand-dust storms. It can be summarized in the following manifestations.

A. Geomorphological structure and sand-dust materials

The large geomorphological skeleton in Northwest China is inter-mountain basin or inter-distribution of upland plain and lowland. In Xinjiang, the Jungger Basin is located amongst the Altay Mts. and Tianshan Mts. the Tarim Basin is situated between the Tianshan Mts. and Kunlun Mts. In Gansu, the Qilian Mts. in the south and the Longshou Mts. in the north bound the Hexi Corridor. The Dahuang Mts. and Yumu Mts. divide the Hexi Corridor Basin into three small basins: namely the Wuwei Basin, Zhangye Basin and Jiuquan Basin. In Inner

Mongolia, broken basins and mountains surround the Ordos Plateau. The Yellow River plain is located in the north and the Ushen Lowland is situated in the south of the Ordos Plateau. In Qinghai, the Qaidan Basin is seated amongst the Altay Mts. and Kunlun Mts.

Figure 2: Travelling paths of sandstorm in Northern China

In the above mentioned basins and plains, huge accumulations of loose sediments are deposited in deserts, sandy lands, gobi, loess, dried-up river beds, denuded hills, alluvial-deluvial plains and lacustrine plains. These geomorphological types are typical of the Quaternary sediments.

B. Geomorphological structure and sweeping path of strong sand-dust storms

The spacial distribution of geomorphological features plays an obvious limiting function of the running path of strong sand-dust storms. First, the influence of topography cannot be ignored as to its influence on the entry of cold air. Outlets of high mountains, gorges or plain terrains serve the entry of strong cold air. The running paths of strong sand-dust storms in China are divided into three directions, namely the western path, northwest path and north path.

The running path of strong sand-dust storms is restricted either by upper-level air pressure fields, or the geomorphological structure. It can be seen from *Figure 2* that the eastward movements of strong sand-dust storms from the western and the northwestern path are mainly influenced by the latitudinal oriented mountain systems of the Qingling Mts. and Yingshan Mts. The underlying surface along the path of sandstroms is mainly gobi and sandy desert. Because of the increase of turbulence thermal exchange volumes, strong thermal convection was brought about, movement energy of sand-dust storm was heightened and intensity of sand-dust storm was intensified. However, due to the block barricades of the Qingling Mts. and Da Xinganling-Taihang Mountain systems, strong sand-dust storms do not cross over these two topographic limits. Along the northern path, strong sand-dust storms can move explosively southward because of the smooth terrains of Inner Mongolia Upland that helps the cold air from Lake Baikal drive straight downward and form strong sand-dust storms on the Inner Mongolia Upland and Ordos Plateau.

Sand-dust storms from the northern path normally cause a few calamities in the eastern parts of the Da Xinganling Mts. and Taihang Mts.

C. Geomorphological structure composition and its impacts on wind force

Air currents enter mountain valleys from open piedmont hills and air density at the inlet of the valleys is increased, wind velocity is strengthened and wind force is accelerated under the function of revolving flow of the two-side hills. It is estimated that wind velocity will be increased 17% inside the valley than that in the open piedmont. When the air current enters into the valley, due to the influence of two-side slopes, the friction will be increased and wind speed will be gradually decreased. In comparison with the wind velocity in open piedmonts, wind velocity will be decreased 35% at the outlet of valleys. The air current will be diffused when it moves out of the valley and the narrow-pipe function of the valley will disappear, and flow speed will be slow under the influence of the barricade function of a mountain. At a reasonable distance from the outlets of valleys, due to weakness of the barricade function of mountains at two sides of the valley, flow speed will once again be gradually increased and wind velocity will be restored to the same as that in the open piedmont (*Table 10, Figure 3*).

Table 10: Wind velocity observation in gullies of 2 metres deep

Sites	Distance to gully (m)	Wind velocity (m/s)	Wind velocity rate in comparison with velocity outside gully	Rate of increase and decrease (%)	Remark
1	0	10.8	100	0	Length of gully is 1,143 metres; Width of gully is 30 metres.
2	113	12.6	117	+17	
3	773	11.1	103	+3	
4	998	9.2	85	-15	
5	1068	8.7	81	-19	
6	1143	7.1	66	-34	
7	1248	6.1	57	-43	
8	1298	6.6	61	-39	
9	1398	6.7	62	-38	

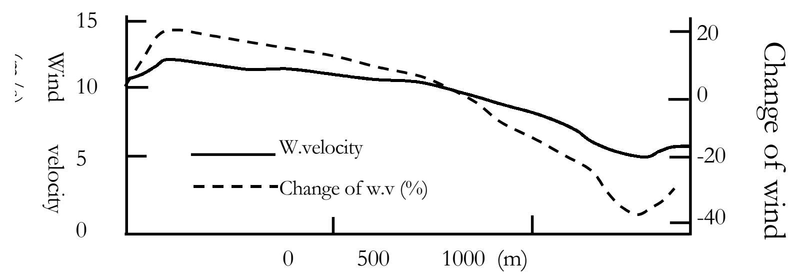

Figure 3: Wind velocity at horizontal level under narrow gully function

On the windward slopes (natural slope exceeds 70 degrees) of steep mountains and hills, because of the block and hinderance of the mountain barricade, some of the air current is lifted up and the speed of the air current close to the ground is obviously reduced in a certain scope. The intensity of air current reduction fields is related to the height of mountains and hills. When the mountain is higher, the scope of air current reduction fields is wide (it is normally four times the height of mountains.) The closer to foothills, the higher the intensity of wind speed reduction. Wind velocity in front of foothills, in comparison with wind velocity in remote plain terrains, is decreased by 67.4% (*Table 11, Figure 4*).

Table 11: Change of horizontal wind velocity at height of 2 metres on the windward slope

Sites	Distance to foothill (m)	Wind velocity (m/s)	% of site 8th	% decline in wind velocity	Times of distance to Mt.	Remark
1	Hillside 0	6.55	32.6	67.4	0	Relative height of Mt. is 75 metres
2	34	10.45	52.1	47.9	0.45	
3	64	13.82	69.0	31.0	0.85	
4	94	15.07	75.2	24.8	1.25	
5	124	17.33	64.4	13.6	1.65	
6	179	18.02	90.0	10.0	2.49	
7	282	19.02	95.2	4.8	3.76	
8	382	20.06	100.0	0	5.09	

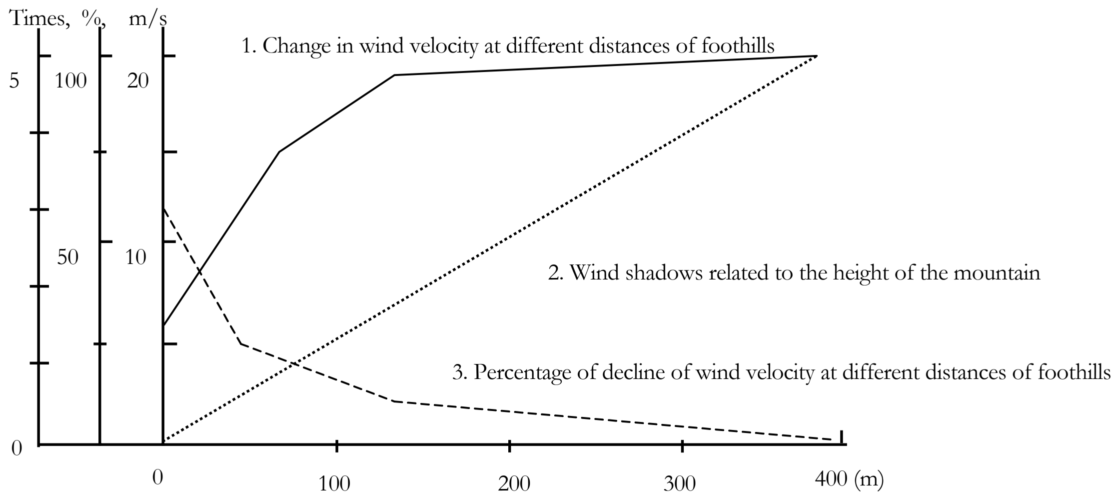

Figure 4: Wind velocity change on windward side of steep slope

On the leeward slope of steep mountains, because of the barricade function of mountains and the revolving flows on the top of mountains and on two sides, strong eddy currents are formed behind the mountain. There is a wind shadow that occurs on the leeward slope and its size is related to the height of the mountain. The higher the mountain is, the bigger the wind shadow is (it is normally twelve times as big as the mountain body.) Wind velocity at the foot of hill or mountain is low. In comparison with wind velocity at the piedmont terrain, wind velocity at foothills is lowered 61.4% (*Table 12, Figure 5*).

On gentle hills and mountains (natural slope degree is 7-5°). Air current at windward slopes is impacted by hills. The reductive scope of wind speed is related to the height and slope of hills. The higher and more gentler the hill and slope is, the bigger the impact scope, but the smaller the reduction of wind velocity. The lower the hill and the steeper the slope, the smaller the impact scope is and the higher reduction of wind velocity. Reduction rate of wind velocity at foothills is maximum and can be 22.6% (*Table 13, Figure 6*).

Under the barricade function of mountains, the air current on the leeward slope of gentle mountains varies at great rates. According to observation, the impact scope is fourteen times the height of the mountain. The reduction of wind velocity at a distance of two times the height of a mountain is maximum and can be 40% (*Table 14, Figure 7*).

Table 12: Wind velocity on leeward side at a height of 2 metres under barricades

Sites	Distance to hillside (m)	Wind velocity (m/s)	% of wind velocity of sites and base point	% decline wind velocity	% of distance to hill height	Remark
Base point	No mt. Impact	17.8	100	0		Relative height of hill 165 metres
1	0	6.7	38.6	61.4	0	
2	150	11.2	63.0	37.0	0.91	
3	300	14.1	79.2	22.8	1.82	
4	400	15.2	85.4	14.6	2.41	
5	700	15.6	87.6	12.4	4.24	
6	1,400	16.1	90.5	9.5	8.49	
7	1,700	17.2	96.0	3.4	10.39	

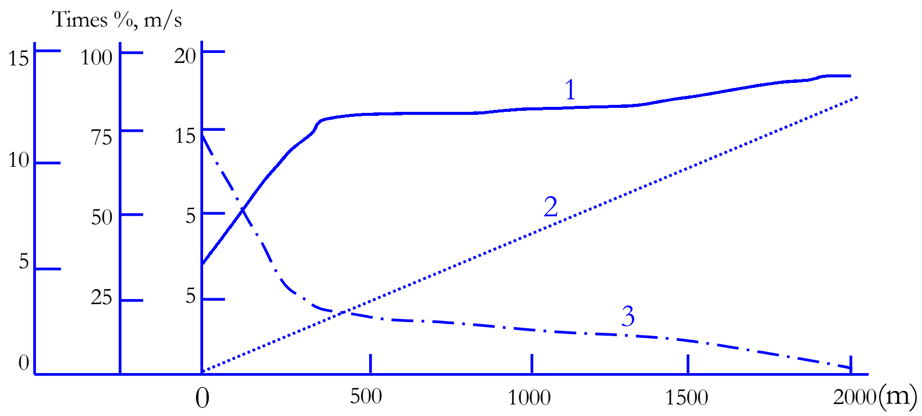

Figure 5: Wind velocity change at leeward-side of steep slope

Table 13: Wind velocity at horizontal height of 2 metres on gentle slope

Site	Distance to hillside (m)	Wind velocity (m/s)	Rate of wind velocity of sites in comparison of site 6 (%)	% decline wind velocity (%)	Times of distance to hill	Remark
1	0	12.7	77.4	22.6	0	Relative height of hill is 81 metres
2	51	13.2	80.5	19.5	0.63	
3	105	14.6	89.1	10.9	1.24	
4	178	15.4	94.9	5.1	2.14	
5	378	15.8	96.2	3.8	4.67	
6	578	16.4	100	0	7.14	

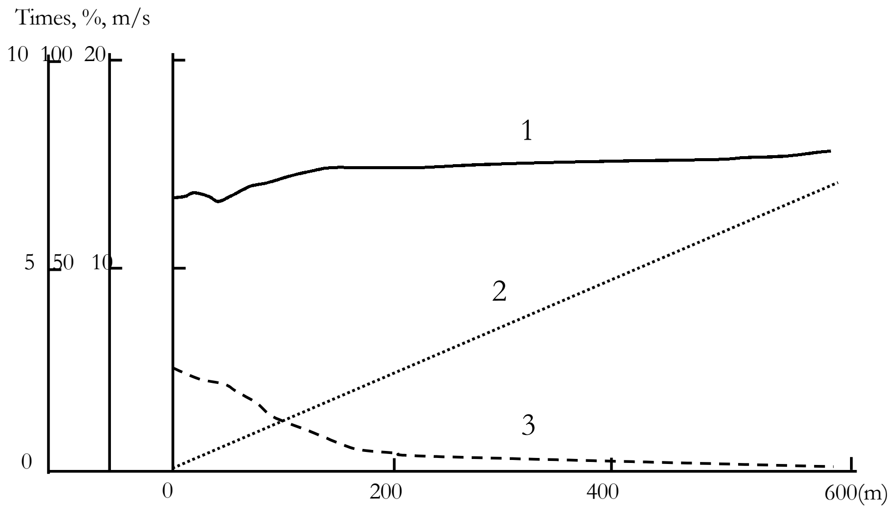

Figure 6: Wind velocity change on gentle windward slope

Table 14: Wind velocity under barricades on leeward slope

Sites	Distance (m)	Wind velocity* (m/s)	% of site to base	% Decline of w.v. on base point	Ratio of distance to hill height	Remark
Base Point		20.1	100			Relative height of hill is 73 metres
1	60	12.7	62.9	37.1	0.82	
2	113	12.1	60.3	39.7	1.55	
3	168	11.9	59.2	40.8	2.30	
4	258	13.9	69.2	30.8	3.54	
5	433	14.2	70.7	29.3	5.94	
6	643	15.8	78.7	21.3	8.81	
7	875	17.9	89.1	10.9	11.99	
8	1031	18.7	92.1	6.9	14.0	

* Wind velocity = w.v.

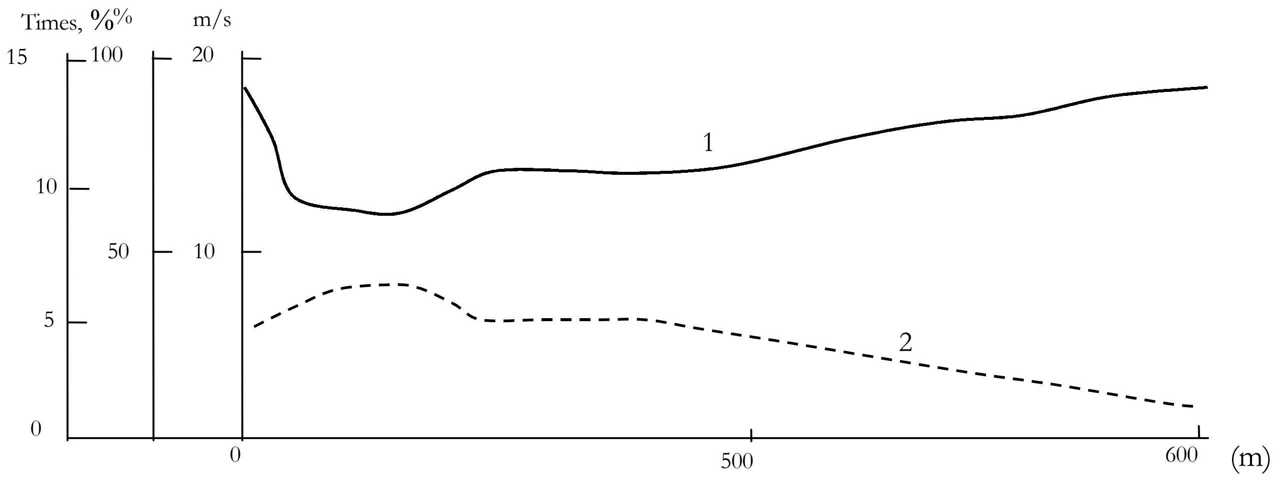

Figure 7: Wind velocity on gentle leeward slope

Because of the differences in geomorphological structure in southern and northern Xinjiang, dynamic wind conditions of sand-dust storms are different. The Southern Xinjiang basin is located at the western and southwest parts of Mongolian High Pressure zones; cold air in the winter season flows backward to the eastern open gorge of the basin and then eastern wind and northeastern wind are formed in the eastern part of the basin. The western part of the basin, under the impact of invasion of western cold air, western wind and northwestern wind prevails. Xinjiang is located on the northern side of thermal low pressure; climate in the summer season is under the influence of local topographic circulation, where eastern wind prevails in eastern Xinjiang and western wind is the dominant wind in western Xinjiang. In the Tarim Basin, there are two perennial wind systems namely, the western wind that prevails in the vast area of the western region of the Niya River and the eastern wind that prevails in the vast area of the eastern region of the Niya River. The Niya River and its adjacent area is a convergence zone of the eastern wind system. Furthermore, in northern Xinjiang, there are approximately 5 sand-dust storm days and in southern Xinjiang, average annual frequency of sand-dust storms is 20-30 days.

The Hexi Corridor, a long and narrow belt lined by Qilian Mts. in the south and Longshou Mts. in the north, Gansu Province is characterized by its narrow-pipe function. The Hexi Corridor is divided into two parts: east corridor and west corridor centred from the boundary line of Jinta-Jiuquan. The western corridor covers a wide *"narrow-pipe"* amongst the Qilian Mts, Mazong Mts. and Ser Ula Mts. The eastern corridor covers a tight *"narrow pipe"* amongst the Qilian Mts., Longshou Mts., and Heli Mts. When air currents flow over these two narrow pipes respectively, wind velocity will be heightened and wind force will be strengthened. Wind regimes of Dunhuang, Anxi and Yumen in the two narrow pipes is cited in *Table 15*.

It can be seen from *Table 15* that the western corridor can heighten mean annual wind velocity by 91% and wind velocity in sand-dust storm seasons in spring by 74%. Wind regimes of several counties in the central part of the narrow pipe are cited in *Table 16*. It clear from *Table 16* that, from the western entrance to the eastern outlet of the Hexi Corridor, mean annual wind velocity is increased by 40% and up to 60% in spring season. The maximum wind velocity of the 5.5 sand-dust storm in various counties along the Hexi Corridor proved the above conclusion. Record of maximum wind velocity from the western to the eastern corridor was: Gaotai 21 m/s; Lingze 21 m/s; Minle 23 m/s; Yongchang 28 m/s; and Gulang 25 m/s. The regular gradual increase of wind velocity in the Hexi Corridor is the manifestation of the narrow-pipe function of the corridor.

Table 15: Wind velocity in different seasons in Hexi Corridor, Gansu province

Site	Met. Station	Average wind velocity (m/s)					>force 8 wind (days)
		Annnual mean	Winter	Spring	Summer	Autumn	
West Hexi County	Dunhuang	2.2	2.1	2.7	2.2	1.8	15.4
	An'xi	3.7	3.4	4.4	3.5	3.3	68.5
	Yumen	4.2	4.7	4.7	3.6	3.9	42.0

Source: Soil and Water Resources in Hexi of Gansu and Their Rational Development and Utilization, 1980.

Table 16: Wind velocity in east Hexi Corridor, Gansu

Site	Met Station	Average wind velocity (m/s)					>force 8 wind (days)
		Annual mean	Winter	Spring	Summer	Autumn	
East Hexi County	Gaotai	2.5	2.2	3.1	2.6	2.1	9.1
	Lingze	2.5	2.8	3.4	3.2	2.5	21.7
	Minle	3.4	3.4	3.7	3.4	3.1	11.2
	Yongchang	3.2	3.0	3.7	3.0	3.0	18.3
	Gulang	3.5	3.7	3.3	3.7	3.5	4.5

6. CONCLUSIONS

Sand-dust storms are both a symptom and a consequence of desertification. They are an environmental disaster in China. Regrettably, the frequency and severity is increasing.

There are five principal ingredients to such wind-related calamities. There must be:

1. A source of material, such as fine sediments that can be entrained and transported.
2. Wind power at a velocity and in a direction that will raise and carry the sediments.
3. Weather conditions that favour the developmnent of convection cells that can generate enough energy.
4. Landforms and geomorphological features that favour wind funneling.
5. Soil surfaces that are susceptible to erosion by wind – usually devoid of vegetation or other protection.

Northwest China has all five prerequisites. The situation has gotten worse because the situations described in points 1 & 5 above have increased as a result of poor land management over the past decades. This has been brought about by faulty policies and by uninformed human actions.

Since the early 1990s the government at all levels is paying close attention to the problem and measures to mitigate the effects of sand-dust storms are being put in place.

An analysis of the root causes shows the vital role that environmental management plays and the significance of involving the local land users in the control of desertification and sand-dust storms.

7. FURTHER READING

Chen Longheng, 1993, *Damage of Strong Sandstorm in Ningxia and Alxa of Inner Mongolia and Control Strategy*, Journal of Desert Research, (3), 9.

Chen Mingjian, 1993, *Study and Discussion on Black Windstorm, Gansu Meteorology*, 11 (3).

Cheng Daoyuan, 1994, *Atmospheric Dust Source and Duststorm*, World Desert Research, (1) 5.

Dept. of Geosciences, Chinese Academy of Sciences, 2000, Root Causes of Sand-Dust Weather in Northern China and Controlling Strategy, Impact of Science on Society, 4.

Fu Youzhi, et al, 1993, *Root Causes and Prediction of Black Windstorm in Hexi of Gansu*, Gansu Meteorology, 11 (3).

Jiang Fengqi, et al, 1993, *Investigation Report of Strong Sandstorm in Ningxia*, Applied Ecology, 4 (4).

Qian Zheng'an, 1993, *Investigation Report on 5.5 Strong Sand-Dust Storm in Gansu and Ningxia*, Atmospheric Information, (4) 3.

Su Yucheng, 1993, *Analysis of Sandstorm on May 5th 1993 in Hexi Corridor*, Gansu Meteorology, 11 (3).

Wang Jiaying, 1963, *China Geological History*, Science Press, p. 110.

Wang Jixi, 1993, *Analysis on Causes of Black Windstorm on May 5th 1993 in Gansu*, Gansu Meteorology, 11 (3).

Yang Gengsheng, 1996, *Black Windstorm in Northwest China and Calamity Reduction Approaches*, Journal of Desert Research, 16 (2).

Yang Gengsheng, 1993, *Developmental Process of 5.5 Black Windstorm and Controlling Strategy*, Journal of Desert Research, 13 (3).

Yang Gengsheng, 1993, *Disasterous Status and Strategy against Black Windstorm on May 5th 1993 in Northwest China*, Gansu Meteorology, 11 (3).

Zhao Xingliang, 1993, *Damage of Strong Sand-Dust Storm in Gansu and Countermeasures*, Journal of Desert Research, 13 (3).

Zhu Zhengwen, 199, 3*Report on Black Windstorm on May 5th 1993 in Gansu*, Gansu Meteorology, 11 (3).

PART II

THE GREAT NORTH AMERICAN DUST BOWL: A CAUTIONARY TALE

Possibly one of the best known and best documented ecological disasters in the early part of the 20th century, the Great North American Dust Bowl has lessons for present day governments grappling with the problems of accelerated desertification, increasing frequency and severity of dust storms and the economic and human impacts.

By a combination of prompt government action, widespread cooperation from the people at the grass root level, the development of appropriate and competent technical support services and the timely investment by the government, the calamitous situation was reversed.

The potential for a repeat occurrence, albeit on a smaller scale, still exists and the implementation of a proper monitoring system and eternal vigilance should ensure that the situation stays under control.

The two analyses of the dust bowl in this Part provide useful summaries of what happened and more importantly, what was done to remedy the situation.

Chapter Four

FIGHTING DUST STORMS: THE CASE OF CANADA'S PRAIRIE REGION

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Key words: Canada, prairie, sand dunes, drought, soil erosion, land degradation, climate change

SYNOPSIS

Although Canada has only 26,000 km^2 of sand dunes, which represent less than 0.3% of the national land surface, the country is plagued by localized dust storms and drought, especially in the Prairie Provinces of Manitoba, Saskatchewan and Alberta. A host of factors such as topography, climate, vegetation cover and soil types generate the ideal conditions for dust storms to occur, on average, up to five times per year. The occurrence of dust storms tends to peak in April, with a secondary peak in August. Since the Prairie region began to be opened up for settlement and agricultural production in the late 19th century, poor farming practices aggravated soil degradation. In consequence, dust storms and drought events have had significant impacts on the economy of the Prairie region, the wellbeing of the local residents and the integrity of the ecosystems. At least 161 million tonnes of soil is lost each year because of wind erosion, and the annual on-farm costs of wind erosion in the Prairie Provinces are about USD $249 million.

In response to the Dust Bowl of the 1930s, the Federal Government created the Prairie Farm Rehabilitation Administration to implement programmes and initiatives aimed at soil conservation. The severe drought of the 1980s resulted in an intensification of Government programmes to facilitate soil erosion control. This chapter has three objectives. First, a description is provided about the overall situation regarding dust storms in Canada's Prairie Provinces, with a synthesis of the consequences of dust storms. Second, the programmes and initiatives taken by the Government over the past decades are reviewed, highlighting their effectiveness in reducing the impacts of dust storms and controlling wind erosion of soils. Third, several emerging issues concerning dust storms and drought are discussed in the context of climate change, pointing out the direction for future research in the area.

KEY POINTS

1. *A host of factors such as topography, climate, vegetation cover and soil types generate the ideal conditions for dust storms to occur but anthropogenic factors are critical.*

2. *Dust storms and drought events have had significant impacts on the economy of the Prairie region, the well being of the local residents and the integrity of the ecosystems.*
3. *During the "Dust Bowl" days of the 1930s, some areas were known to have been stripped entirely of topsoil – a loss of about 2,000 t/ha, and almost 20% of the improved farmland of the Prairie Provinces were eroded by wind during that period.*
4. *The decade of severe dust storms and drought in the 1930s forced a major rethinking of agricultural practices in Western Canadian. To tackle the grave ecological problems, a series of measures were taken in a massive campaign to save the Prairie region from turning into a wind-blown wasteland of sand dunes. The 1930s' Dust Bowl prompted the conscious adoption of new thinking on drought adjustments and stimulated the creation of governmental agencies to promote soil conservation*
5. *One of the biggest challenges is to address the issue of climate change. It has been recognized that climate is the greatest single factor affecting agricultural productivity in Canada. Most climate change scenarios show an increase in temperature and reductions in soil moisture.*

1. INTRODUCTION

Covering a total area of almost 10 million km^2, Canada is the world's second largest country, surpassed only by the Russian Federation. Canada has 10 provinces which, according to climatic conditions and soil types, fall into four major regions: Atlantic (Newfoundland, Prince Edward Island, Nova Scotia and New Brunswick), Central (Quebec and Ontario), Prairie (Manitoba, Saskatchewan and Alberta), and Pacific (British Columbia). Besides, there are three territories in the north: Nunavut, Northwest Territories and Yukon.

Figure 1: Map of Canada

Canada is a spectacular land of contrasts in geography, climate and soils. The country's landscape is enormously diversified, because it encompasses Arctic tundra, vast mountain ranges and forests, extensive plains and prairies, oceanic systems and inland waters and other ecosystems. Canada's climate is as varied as its landscape. The usual air flow from west to east is disrupted in winter when cold, dry air moves down from the Arctic and in summer when warm, tropical air moves up from the southeast. Added to these factors are the effect of mountain ranges, plains and large bodies of water. In consequence, while temperature and precipitation differ from one region to another, natural hazards in the form of dust storms and drought occur frequently, especially in the Prairie region. Due to the harsh northern climate, only 12% of Canada's land is suitable for agriculture and, therefore, most of the 30 million Canadians live within 300 km of the country's southern border with the United States, in a long and thin band stretching between the Atlantic and the Pacific Oceans (*see Canada Information Office 2000*).

Table 2: Basic facts about Canada

Province / Territory	***Land (km^2)***	Freshwater (km^2)	Total area (km^2)	Population (10^3)
Newfoundland	***373,872***	***31,340***	***405,212***	538.8
Prince Edward Island	5,660	-	5,660	138.9
Nova Scotia	53,338	1,946	55,284	941.0
New Brunswick	71,450	1,458	72,908	756.6
Quebec	1,365,128	176,928	1,542,056	7,372.4
Ontario	917,741	158,654	1,076,395	11,669.3
Manitoba	553,556	94,241	647,797	1,147.9
Saskatchewan	591,670	59,366	651,036	1,023.6
Alberta	642,317	19,531	661,848	2,997.2
British Columbia	925,186	19,549	944,735	4,063.8
Yukon	474,391	8,052	482,443	30.7
Northwest Territories	1,183,085	163,021	1,346,106	42.1
Nunavut	1,936,113	157,077	2,093,190	27.7
Canada	9,093,507	891,163	9,984,670	30,750.1

Source: Statistics Canada (2000). Population refers to that of 2000.

Strictly speaking, Canada has no true deserts, although sand dunes cover 26,000 km^2, which is just under 0.3% of the country's total land surface (David 1979). Canada is a country that suffers from a variety of natural hazards and, among them, dusty wind and drought have plagued the Prairie region since it was opened up for agricultural development in the latter half of the 19th century. This chapter describes the Canadian experience in dealing with the problem of dust storms and drought, with a focus on the Prairie Provinces. In the next section, an overview of the occurrence of dust storms is provided, followed by a depiction of the causes and consequences. In section 3, the major initiatives and programmes that have been launched by the Canadian Government over the past decades are reviewed. The final section is devoted to a brief discussion of the challenges facing the Canadians in the 21st century.

2. DUST STORMS IN CANADA'S PRAIRIE REGION

Alberta, Saskatchewan and Manitoba are referred to as Canada's Prairie Provinces. They cover a total area of some 196 million ha, or 19.6% of the country's territory. Land elevations are the highest in southwest Alberta (exceeding 1,500 m) and decrease to sea level along the Manitoba coastline of Hudson Bay.

Situated along the northern limit of the North American Great Plains, Canada's Prairie region is located within a large semi-circle extending from the Rocky Mountains to the Red River Valley. Encompassing the southern portions of the three Prairie Provinces, the region contains a diversity of ecosystems and landscapes. Climate, topography, vegetation, and soil capability are highly varied throughout the region. Characteristic landforms include large expanses of flat to gently undulating plains, rolling foothills, coulees, active sand dunes, large irrigation reservoirs, lush wetlands, dense river valley forests, exposed bedrock and sandstone.

The Prairie region is underlain by Pleistocene sedimentary rock, and the present landscape was formed after the last glacial period ended 12,000 years ago. After the retreat of the glaciers, increasing periods of drought slowly starved the post-glacial forests. A flora of deep-rooted grasses and other drought-resistant vegetation emerged and formed the dominant vegetation of the Prairies. In addition to grasses, there are varieties of shrubs. Taller shrubs and trees are found in areas where there is sufficient moisture. At the prairie fringe, grasslands intermingle with aspen (*Populus tremuloides*) woodlands. The soils of the Prairie region are primarily of glacial moraine and lacustrine origin (Herrington et al. 1997).

Distance from the sea, reinforced by the Rocky Mountain barrier on the west, makes the Prairie region an extensive area of continental climate. Hot summers and cold winters are the norm, with temperature extremes ranging from 40^0 C to -40^0 C. Low precipitation is a defining characteristic of the region. With an annual average of 250-750 mm of rain and snow, the region is considered an arid to semi-arid environment. The moisture-rich Red River Valley of Manitoba receives about 500 mm rainfall each year. High wind is also an important component of prairie weather. It evaporates moisture from soil and plants, especially in the southern parts. Because there are no major bodies of water lying near enough upwind relative to the prevailing wind direction, drought is frequent and dust storms often occur in dry seasons (Allen 1973; LaDochy and Annett 1982).

2.1. The Prairie Region – Canada's Bread Basket: settlement and opening-up

Containing some 37.7 million hectares of developed agricultural land, the Prairie Provinces represent more than 80% of Canada's agricultural land base. Agriculture is the backbone of the Prairie region, which is well known for being the prominent wheat growing area in the country. In fact, the plains of Alberta, Saskatchewan and Manitoba are among the richest grain-producing regions in the world, hence, having earned the title *"the bread basket of the world"* (Murray 1980, p.4).

In 1690, Henry Kelsey of the Hudson's Bay Company became the first European to explore the Canadian Prairies. He described the area as *"barren ground"* and this impression had much influence on the general image of the region as *"a western wasteland"* (Allen 1973, p.18).

Just under five decades after the establishment in 1818 of the 49^{th} parallel of latitude as the borderline between Canada and the United States, the Dominion of Canada came into being in 1867 under the terms of the *British*

North America Act. Soon after Confederation, Canada found itself in a vigorous westward expansion. Thousands of square miles of territory, which formerly had been considered of little value, began to be opened up for settlement. However, the western Canadian plains were nearly uninhabited until 1880-81 (Murray 1980).

The westward expansion was enabled by the arrival of waves of immigrants from Europe. Nevertheless, many new settlers were unimpressed with the wild and bleak landscape. To most of these European immigrants, the unfamiliar prairies provided a stark contrast to the seemingly more hospitable environment of their homeland. Spread of farming into the region was impeded by the early description of the area as the *"Great American Desert."* After settlement started to build up in the second half of the 19th century, the droughts of 1860-62, 1870-73, 1886-89 and 1893-95, along with severe frost damage to crops, resulted in emigration from the prairies. It was during this period that some farmers adopted methods of dry farming and that earlier maturing varieties of wheat were being developed. The methods of dryland farming became much improved toward the end of the 19th century, resulting in a new wave of immigrants who came to settle and develop the area (Swainson 1970).

Two important factors provided strong impetus to the settlement and opening up of the Prairie region. The first one was the adoption in 1872 of the Dominion Lands Act by the Parliament, because the Act fostered homesteading. In order to encourage settlement, the Dominion Government ordered extensive land surveys in 1871. Specifically, the size of a township was declared to be a square of 36 sections of 640 acres each, which were again sub-divided into quarter sections of 160 acres. Even-numbered sections of land were available for homesteads, whereas the Government reserved odd-numbered sections. Any settler at the age of 18 and above was eligible for requesting a homestead by paying a USD $10 registration fee, and the settler obtained ownership of the land after living on it six months every year for three years if a house and barn had been built and 40 acres broken (Murray 1980).

The second factor was the construction of the Canadian Pacific Railway (CPR). After the completion in 1885 of the CPR that connected Montreal and Vancouver, the Dominion Government conducted a vigorous advertising campaign for settlement and special low shipping rates were announced for settlers (Murray 1980). This lent a spirit of adventure as well as a promise of prosperity for the new settlers. With the help of the railway, thousands of settlers from eastern Canada and from countries, all over the world made the Prairie region their home.

Historians view the period from the 1860s to the 1930s as the era of large-scale agricultural settlement in Canada (MacEwan 1952; Friesen 1984; Thompson 1998). Initially, the Prairie region was part of the Canadian North-West Territories. Manitoba became a province in 1870, but Alberta and Saskatchewan did not establish their provincial status until 1905.

Since the 1880s, the biggest change to the Canadian Prairies has been the shift from native grasslands to cultivated crops. Large areas of native vegetation were removed, and the previously rich topsoil was broken in order to support crops grown for human and livestock food. In spite of the fact that by the beginning of the 20th century the settlers began to learn to conserve the natural environment, the Prairies have continued to experience changes. Actually, throughout the past 12 decades, the rate of change to the Prairie region has been rapidly accelerating, largely due to human activities. Many people have questioned the wisdom of opening the southern grasslands to farming, because the early homesteaders did not realize that they contributed to opening the prairie soil to wind and water erosion (Waiser 1996). Nevertheless, Gray (1996) argues that, as a nation, Canada could not have existed without the settling and farming of the Prairies.

2.2. Sand Dunes, the Palliser Triangle and regional climate

In spite of the fact that no true deserts exist in Canada, a significant portion of the country lies within the world's arid to semi-arid zones (Thomas 1997). Due to a lack of vegetation and being exposed to strong winds, parts of the Canadian Arctic exhibit a desert-like appearance. Sandy soils in Prince Edward Island, coupled with constant wind, make this area at highest risk from wind erosion in Atlantic Canada. There is some potential for wind erosion in southern Ontario, especially on sandy soils (Bird and Rapport 1986). The Osoyoos arid biotic region in southern British Columbia (BC) is often regarded as Canada's mini-desert where the country's only "Desert Centre" is open to the public for education and research purposes.
Covering 26,000 km^2, sand dunes are widely dispersed from coast to coast and may be found in every province and territory. According to David (1979), nearly half of Canada's dune area is concentrated in Alberta where the Richardson River Sand Hills is believed to be Canada's largest single dune occurrence. Saskatchewan and Manitoba account for 36% and 10% of the country's dune area respectively.

Sand dunes result from the interaction of sand and climatic factors such as wind and water (Raup and Argus 1982). Canadian dunes are mostly classified as "wet sand dunes" (David 1977, 1979, 1981), with moisture contents of 4-8% (Lemmen et al. 1998). Contiguous dune occurrences range in size from several dozens of square kilometers to over 1,200 km^2. The Athabasca region, which is situated in northwestern Saskatchewan and the neighboring portion of Alberta, witnesses the occurrence of large sand dunes. Two of Canada's largest active dunes are located along the south shore of Lake Athabasca. They cover some 385 km^2 in area and measure 30 m in height. Nowhere else in the world are dunes found this far north (Canada Information Office 2000). Sandstone from which the dune sand and gravel have been derived (Raup and Argus 1982) underlies most of this region. However, these dunes have largely been neglected because of the relatively low population density in the area. In the early 1980s, a major study regarding the area was completed thanks to Federal-Provincial collaboration (see Mackenzie River Basin 1981). However, that study failed to look into the interactions between the physical and biological components of the ecosystems of the region.

Another region where clusters of sand dunes are found is the southern Saskatchewan, southeastern Alberta and southwestern Manitoba. The region is also known as the Palliser Triangle, named after John Palliser (1807-1887) who was leader of a British expedition in the 19th century. Palliser explored the region in 1857 to ascertain its potential for agricultural settlement (Lemmen et al. 1998; Rees 1988; Allen 1973). Without any hesitation, Palliser declared this region uninhabitable and unsuitable for agricultural development for the simple reason that it was too dry (Gray 1996; Momatiuk and Eastcott 1991). Palliser's report laid the basic conceptual framework for subsequent interpretation of the physical geography of the Canadian Prairies. As a matter of fact, the region was so dry that the corner joining southwestern Saskatchewan and southeastern Alberta has earned the name *"an empire of dust"* (Jones 1987).

Table 3: Seasonal rainfall and snowfall at selected locations in the Prairie Region

Season	Weather parameter	Lethbridge	Saskatoon	Winnipeg
Winter	Rain (mm)	1.2	1.5	2.3
	Snow (cm)	69.4	53.8	59.8
Spring	Rain (mm)	63.5	54.1	90.1
	Snow (cm)	49.4	27.5	30.6
Summer	Rain (mm)	148.9	158.2	231.1
	Snow (cm)	0.2	0.0	0.0
Fall	Rain (mm)	46.9	39.9	80.8
	Snow (cm)	31.1	24.2	24.3
Annual	Rain (mm)	260.5	253.7	404.3
	Snow (cm)	150.1	105.5	114.7

Source: Adapted from Herrington et al. (1997), Table 8 on p.15 (1961-1991 data).

Extending along the Canada-US border, the Palliser Triangle covers more than 200,000 km^2. Lemmen et al. (1998) have found that sand dunes cover more than 3,400 km^2 in the region and most of them are stable at present, containing only a few active dunes (<0.5% by area). Excessive eolian activity and low precipitation, with annual precipitation as low as 250-300 mm characterize this southerly portion of the Prairie region. Therefore, lands that are stripped of protective vegetation become exposed to wind.

Aerial photographs indicate that although eolian activity declined from the 1940s to the 1980s, when relatively humid climatic conditions prevailed, active sand surfaces markedly expanded in some areas in rapid response to the drought years of the 1980s (Lemmen et al. 1998). Snowfall generates about 80% of prairie stream runoff and is often the only major runoff source for small streams. The strong moisture deficit that characterizes the regional climate produces little additional runoff except when sporadic, high-intensity rainstorms occur in areas where topography and geology inhibit infiltration. For more theoretical treatment of topics such as dusty wind, sand dunes and sedimentary processes, see Kostaschuk (2000), Beierle and Smith (1998), Villard and Kostaschuk (1998), Vance (1997), Hogg (1994, 1997), Gill (1996), Ruz and Allard (1995).

2.3. Dust storms – severe natural hazards

Dry land is usually dominated by eolian activity, in which wind is the major agent of erosion (Thomas 1997). Wind erosion has been a continuous problem in Western Canada since cultivation began (PFRA Shelterbelt Centre 2000). In the southernmost parts of the Prairies, the prevailing winds come from the west, including the southwest and northwest.

As the prevailing winds carry, warm, moist pacific air east across the mountains, the air cools and moisture falls as rain or snow. More moisture falls in the form of snow as the air moves farther east. Because the mountains in the region lie north-south, there is no barrier to cold arctic air sweeping down from the north to fill the entire Prairies with cold winter. Equally, there is no obstacle to warm and dry masses of air that pushes north from the American southwest. Therefore, there is turbulence, cloud, wind and precipitation (Elias 1999). While strong winds are common in spring, severe storms tend to occur in summer, sometimes accompanied by tornado force winds. Fields that have a dry, loose soil surface and little vegetation are most susceptible to wind erosion. Dust storms often occur quite suddenly and waves of dusts sent by gusting wind can be seen miles away (Tinker and Itani 1999). With moving dust walls that roll and roll and blanket everything, dust storms are locally *called "a blackout"* (Momatiuk and Eastcott 1991, p.115).

Severe dust storms are sometimes called sandstorms or "dust devils" because they sound more picturesque. However, there is considerable difference between the two. Dust from earth or soil tends to rise to great heights, but sand does not (Brown 1963). A *"dust devil"* is a small atmospheric vortex, which is made visible by rotating clouds of dust or debris. In terms of long-term frequencies, the number of days when strictly-defined dust storms occur may be around five per year in some parts of Saskatchewan, but strong dusty winds affect a much wider area (Wheaton and Chakravarti 1990).

Desert-like conditions are observed in many areas of the Prairie region. For instance, in the Red Deer River Valley, Alberta, excessive forces of water and wind erosion have created strange shapes in the sandstone called *"hoodoos,"* and soil erosion has, in turn, created shifting sand dunes. The land most susceptible to wind erosion is southeastern Alberta and southwestern Saskatchewan. Although specific data is not available, during the *"Dust Bowl"* days of the 1930s, some areas were known to have been stripped entirely of topsoil – a loss of about 2,000 t/ha, and almost 20% of the improved farmland of the Prairie Provinces were eroded by wind during that period (Bird and Rapport 1986).

Historians have recorded many accounts of local residents enduring suffocating dust storms (for instance, see Jones 1986, 1987). Farmers found their eyes full of dirt and they had to feel their way home from field. Momatiuk and Eastcott (1991) describe people pulling their shirts over heads or lying down and putting their noses into garments to try to filter out some of the dust. Senior residents on the Prairies still remembered the *"Dirty 1930s"* when local residents faced horrendous conditions. Every conceivable calamity occurred, from sandstorms to unrelenting drought to scorching temperature. Worse still, people had to set their cups and plates upside down on the table to keep the dust out till mealtime.

Perhaps, the most vivid depiction of the dust-blowing on the Canadian Prairies in the 1930s is supplied by Gray (1996, p.11) as follows:

> "Blowing topsoil drifted like snow across the railway tracks in Alberta. It blew from the poor land onto the good land in Saskatchewan and kept Regina, Moose Jaw and Swift Current coated with dust inside and out. It bathed Winnipeg in a perpetual yellow overcast. Roads made impassable by snowdrifts in the winter were drifted into impassability again with blowing topsoil in the summer. The drifts built up till they covered the fences, choked out the shelterbelts and gardens, reached the roofs of the chicken houses, blew in through the cracks around farmhouse windows and under farmhouse doors to drive the inhabitants out of their houses and out of the country."

However, prior to the late 1980s, virtually no scientific analysis of dust storms in the Canadian Prairie region existed. Sparrow (1984) argued that nearly 58% of the total annual soil loss due to wind and water may be ascribed to wind erosion which would account for a conservative estimate of 161 million t. Wheaton and Chakravarti (1987) made a pioneering contribution with their study of the temporal, spatial and climatological aspects of dust storms in Saskatchewan. In that study, after providing a brief review of the dust storm literature, they proposed a definition that *"...a dust storm is an atmospheric disturbance with moderate to strong winds, blowing soil particles, and visibility reduced to 1 km or less at eye level"* (p.8). Moderate-to-strong winds are understood to attain speeds of 20-49 km per hour at 10 m above the ground. Wheaton and Chakravarti (1990) extended the scope of their previous analysis to the entire Prairie region, with an examination of the temporal, spatial and some climatological characteristics of dust storms and the associated risk of soil erosion. Their research findings are of great importance because the results contribute, in a significant way, to the understanding of the dust storm problem in Canada and the impacts on soil conditions. It appears that, at present, their work still represents the most comprehensive analysis of the dust storms in the Canadian Prairie region. Hence, it serves as the basis for much of the description below.

According to Wheaton and Chakravarti (1990), the southern parts of the Prairie Provinces, i.e., the Palliser Triangle, are frequently attacked by blowing wind and dust storms due to a combination of factors including topography, climate, natural vegetation and soil conditions. Specifically, the yearly average of mean daily wind speed is 10-35 km/h. The annual precipitation is between 250 mm and 450 mm, about two-thirds of which tend to occur during the summer (May-August) period. These physical factors in conjunction with the unique local land-use patterns create an ideal setting for the occurrence of dust storms.

In Canada, weather stations do not report dust storms directly. However, Environment Canada does require the observance and subsequent reporting of blowing dust or sand along with the status of visibility. Hence, Wheaton and Chakravarti (1987, 1990) use their definition and derive the frequency of dust storms by examining weather reports concerning the events of blowing dust and reduced visibility of 1 km or less. *Figure 2* depicts the annual frequency of dust storms in the Prairie Provinces for the period 1977-1985. It is important to note that the number of days is the annual mean on an areal basis. In other words, the mean was calculated by summing up the annual total number of days when occurrence of dust storms was recorded for all weather stations and dividing the sum by the number of stations. This approach would ensure that the total number of dust storms in the area was spatially averaged to avoid the double counting problem, because two or more stations may have reported the same dust storm.

At least two features are obvious from *Figure 2*. First, during the period under examination, a primary peak occurred in 1981 in terms of the frequency of the mean annual areal number of days with dust storms, with two secondary peaks in 1977 and 1984, respectively. The diagram clearly exhibits a year to year variation in the frequency. However, this variation must be interpreted with caution and needs to be validated with more data. Based on analysis of dust storms that have occurred elsewhere, Goudie and Middleton (1992) have found that a cyclical pattern is rather common with dust storms and the frequency of dust events is often dictated by natural processes, such as precipitation totals, snow cover, wind strength and so forth.

Second, from a spatial perspective, dust storms occurred more frequently in Saskatchewan and Manitoba than in Alberta. Specifically, the weather station at Regina in central Saskatchewan recorded 19 days with dust storms in 1981, which were the greatest annual total number of days for the entire Prairie region throughout the period. The second highest number of days with dust storms was 14, again in 1981, which was recorded at Moose Jaw in southern Saskatchewan. Evidently, the central part of Saskatchewan around the Regina, Moose Jaw and Saskatoon areas has the greatest mean annual number of dust storms in Canada, with an average of more than 5 dust storms being recorded annually. The frequency of dust storm occurrences comes down to 2-4 dust storm days per year in southern Alberta and 4-5 dust storms in southern Manitoba.

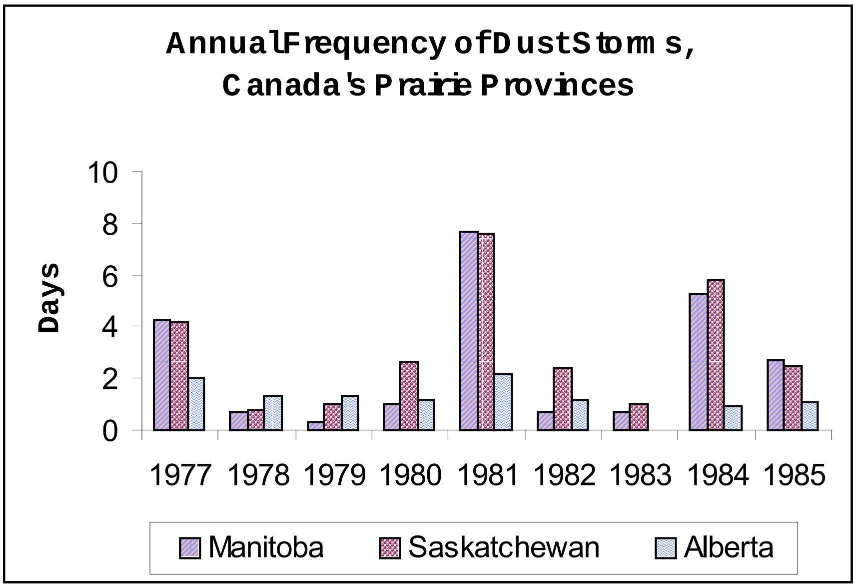

Figure 2: Annual frequency of dust storms in the Prairie Provinces, 1977-85

Wheaton and Chakravarti (1990) analyzed in detail the temporal dimension of the dust storm problem. For instance, a close examination of the monthly frequency of dust storms reveals an evident seasonal pattern. It appears that the occurrence of dust storms tends to concentrate in two periods in a year, with a major peak in April and a minor peak in August. Focusing on Saskatchewan, Wheaton and Chakravarti (1990) suggest the following principal reasons for spring being the primary peak time of dust storms: (i) wind speed is higher for most Prairie locations in springtime; (ii) spring is also the time when vegetative cover tends to be sparse; and (iii) soils are usually quite dry at this time as precipitation often occurs in June. Nevertheless, when compared with Saskatchewan and Manitoba, the spring peak is much less pronounced in Alberta.

It is well known that there tends to be more dust in the air during periods of drought or prolonged dry spells than during periods of normal precipitation. Empirical evidence confirms that dust levels are indeed positively correlated with the severity of drought and length of dry periods (Lemmen et al. 1998; LaDorchy and Annett 1982). Drought leads to poor crop growth, lower yield and reduction in vegetation cover, and causes depletion of soil moisture, making the soil susceptible to wind erosion. In the Prairie Provinces, erosion can take place year-round, often during extreme weather events, such as high winds, and particularly during years of consecutive droughts. The drought of 1988 was considered the most severe in recent decades. As a result, the number of dust storms equaled or exceeded previous record maximums for two stations in each of the Prairie Provinces and was above average at a number of other locations (Wheaton et al. 1992). Clearly, there is an urgent need to carry out further research to investigate the linkages of climatic factors with dust storms, as well as their relationships with other environmental aspects, such as vegetative cover, land use patterns, crop residue parameters and so forth (Wheaton et al. 1992; Wheaton and Chakravarti 1990).

For the sake of completeness, a chronology of the main dust storm occurrences is compiled in *Appendix I.* As drought is the most significant climatic characteristic of the Prairie region, drought events are also included in the appendix. It is worthwhile noting that although observations began to be made in selected meteorological sites as early as the 1870s and the 1880s (e.g., 1872 for Winnipeg and 1883 for Regina), nationwide climatological records of a systematic nature did not come into being until 1948 (Environment Canada 2000a, *"Climate Trends and Variations Bulletin for Canada;"* Herrington et al. 1997). Therefore, information about events in the late 19th century and early 20th century may be based on anecdotal accounts from various sources and should be interpreted with caution.

2.4. Consequences of Dust Storms

Soil erosion causes redistribution of soil in the landscape due to the actions of wind, water and tillage (Lemmen et al. 1998). All three agents of erosion affect much of the Canadian Prairie region. In fact, wind erosion was identified as a menace to farming activities in Manitoba as early as the 1880s (Jones 1987). Similar recognition was obtained in Saskatchewan in the 1890s (MacEwan 1952) and in Alberta in the 1910s (Gray 1996). By far the most disastrous dust storms and droughts occurred in the *"Dirty Thirties,"* which affected all three Prairie Provinces. Between 1933 and 1937, precipitation decreased by almost half in the region. As a result, wheat and corn production declined 32% and 50%, respectively; 200,000 farms went bankrupt, 300,000 people migrated from the Prairie region, and 50,000 farmers had to live on government relief (Herrington et al. 1997). In the Palliser Triangle alone, 10,000 families were forced to abandon their farms, and many men simply jumped a freight train, their belongings on their backs, and left the Prairies (Gray 1996). On August 1, 1931, the severity of dust storms and drought aroused national concern because the Canadian Red Cross launched an appeal for food and clothing for 125,000 destitute farm families who had suffered three consecutive crop failures (Gray 1996).

Throughout the 1930s, wind erosion and drought intensified. At a certain point in time, drought events embraced 250 municipalities and well over 7 million ha of the Prairie region. No accurate account was ever made of the actual acreage ruined by wind erosion. The phrase, *"blowing out of control,"* was frequently used to refer to land being denuded of the topsoil. Gray (1996) described fence building as an approach to catch the weeds, which would, in turn, catch and hold the soil. This was seen as absolutely necessary because, in a single year there would be enough soil blown along a barbed wire fence to have it completely buried. Severe droughts over the 1930s brought the plague of grasshoppers. In the first year of the outbreak in Alberta, the infestation involved approximately 4,100 km^2. By 1939, the infested area exceeded 155,000 km^2. In Saskatchewan the area grew from a mildly infested 4,000 km^2 in 1931 to some 260,000 km^2, or more than 40% of the provincial land base (Gray 1996).

It was truly a struggle to wrest a living from the Prairie soil. Numerous accounts have been recorded of farmers losing the fruits of their labors with little left (Murray 1980). Dust storms and drought strike townships as well as farm fields and do considerable damage to property and crops. Taking the dust storms and drought of 1988 for example, the direct production loss is estimated to have reached USD $1.8 billion (Wheaton et al. 1992). The calamities cost the Canada Government USD $1.4 billion in insurance and subsidies (Etkin 1997). Provinces also incur costs due to crop damage from natural hazards such as dust storms and drought. On average, Saskatchewan incurs the greatest costs, over USD $130 million per year (measured in 1995 constant dollars), and crop losses for Manitoba run around USD $30 million per year. It is estimated that the annual on-farm costs of wind erosion in the Prairie Provinces are about USD $249 million (Wheaton and Chakravarti 1990). *Table 3* highlights the most expensive dust storm/drought-related disasters in Canada.

Table 4: Most expensive dust storm/drought-related disasters in Canada

Date	Disaster	Region	Economic Impact (1989 constant dollars)
1936	Dust storms, drought and heat wave	All provinces	USD $514 million of wheat losses
1961	Dust storms and drought	*Prairie Provinces*	***USD $668 million of wheat losses***
Summer 1979-80	Dust storms and drought	Prairie Provinces	USD $2.5 billion
1984	Dust storms, drought and heat wave	Western provinces	USD $1 billion
Summer 1988	Dust storms, drought and heat wave	Prairie Provinces + Ontario	USD $1.8 billion of output losses; USD $4 billion of export losses

Source: Compiled from Etkin (1997), *Table 2.2b*.

Dust storms and drought lead to depletion of the soil's capacity to grow crops, increases in variability in soil and crop yield and reduction in water and air quality. Soil erosion also results in loss of organic matter because erosion removes the soil fractions that contribute to nutrient availability and help maintain a good physical environment for plant growth. Severe loss of soil reduces the rooting volume available to plants, further depleting nutrient and water availability.

According to Bird and Rapport (1986), the annual rate at which soil forms in Canada is estimated to range between 0.25-1.0 t/ha; in contrast, annual erosion rates of 20-25 t/ha are quite common. Sparrow (1984) made a conservative estimate that Canada's annual soil loss due to wind and water erosion would reach 277 million tonnes, nearly 58% being caused by wind erosion. The effects of dusty wind on crop yields and soil productivity are substantial. It has been determined that more than 50% of annually cropped fields are exposed to erosion each year in the Prairie region (PFRA 2000a). In recognition of the severe problems associated with wind erosion, the Canadian Government has acted. The major programmes and initiatives are described in the ensuing section.

3. FIGHTING DUST STORMS: PROGRAMMES AND INITIATIVES

Institutionally, Canada's battle against dust storms and drought began with the establishment of the Dominion Experimental Farms system on June 2, 1886. This system did considerable foundation work and paved the way for more ambitious framework in later years (Gray 1996). The decade of severe dust storms and drought in the 1930s forced a major rethinking of agricultural practices in Western Canadian. To tackle the grave ecological problems, a series of measures were taken in a massive campaign to save the Prairie region from turning into a wind-blown wasteland of sand dunes. The most famous example was the establishment of the Prairie Farm Rehabilitation Administration (PFRA) as a new institutional framework.

3.1. Institutional framework

If the 1930s' Dust Bowl prompted the conscious adoption of new thinking on drought adjustments and stimulated the creation of governmental agencies to promote soil conservation, the PFRA is clearly the most remarkable Canadian achievement. The Prairie Farm Rehabilitation Administration was established by an Act of Parliament in 1935 in response to frequent dust storms, widespread drought and farm abandonment of the 1930s. Initially, the objective was to control soil drifting, but the mandate was quickly expanded to a wider scope to: *"…secure the rehabilitation of the drought and soil drifting areas in the Provinces of Manitoba, Saskatchewan and Alberta, and to develop and promote within those areas, systems of farm practice, tree culture, water supply, land utilization and land settlement that will afford greater economic security…"* (Vaisey et al. 1996). The PFRA provided not only the leadership but the muscle and equipment required mounting the campaign against the pernicious dust storms (Gray 1996; Wettlaufer and Brand 1992). For a history of the PFRA and its accomplishments see *Figure 3*.

Other institutional arrangements have also played important roles and a case in point is the Manitoba Crop Diversification Centre (MCDC). The MCDC is a three-way partnership between an industry consortium, MHPEC (the Manitoba Horticulture Productivity Enhancement Centre Inc.) and the governments of Canada and Manitoba. The primary goal of the MCDC is the investigation and demonstration of economically and environmentally sustainable crop production. This includes crop diversification and intensive agricultural technology practices and facilitating development of value-added processing of Manitoba grown crops. This is accomplished by bringing together partnerships with the appropriate expertise and the provision of suitable land and facilities. Activities at the MCDC sites include testing and demonstration of current irrigation technologies, field testing of crop performance under irrigated and dryland conditions. The MCDC also carries out the evaluation and demonstration of specialty and niche crops that offer higher value diversification opportunities, good market potential and value-adding possibilities. Programme delivery mechanisms consist of field demonstrations, publication of fact sheets and bulletins, and presentation of seminars and courses for producer training in partnership with provincial, federal and industry initiatives. Much of MCDC's work is conducted in cooperation with outside agencies, groups and individuals. The Centre provides a variety of assistance for research and demonstration activities, including technical support and use of its facilities and land.

PFRA HIGHLIGHTS

1935	Passing of PFRA Act on April 17. Mandate is limited to 5 years. Activities to control soil drifting are funded. Agricultural Improvement Associations are organized to demonstrate new farming practices
1936	Reservoirs and irrigation works are built or repaired in southwest Saskatchewan. Farmers are resettled on or near the projects
1937	The Act is amended to add land utilization and land settlement. PFRA Advisory Committee gets down to business in Regina on May 6, 1937, and the Community Pasture Program begins in the same year. Sixteen community pastures are fenced and seeded by December and opened for grazing in 1938
1938-39	Heavy spring runoff damages some newly constructed earth dams. Other dams are sandbagged for protection
1939	PFRA's mandate is extended by removing original 5 year limit
1941	First Pasture Managers' conference is held, with 43 pastures operating and another 11 under development
1946	Money for soil drifting control is removed from PFRA's budget. Emphasis is placed on "structural" projects in water and pasture development
1948	PFRA is granted special funds for construction of irrigation and drainage works in BC, with most work done in the interior of BC
1961	Agricultural Rehabilitation and Development Act (ARDA) is passed. PFRA helps administer and provides technical support for the Act in Western Canada.
1964	Community pastures are built on Indian reserves for the first time. Grazing revenues are shared with the native bands
1965	Hydrology staff write the first computer programs used by PFRA and run them on leased computers in Regina
1968	PFRA is transferred from Dept. of Agriculture to Forestry and Rural Dept.
1969	PFRA becomes part of the newly created Dept. of Regional Economic Expansion
1975	40th Anniversary. By April, PFRA has helped with 95,999 dugouts, 10,516 wells, 11,260 stockwatering dams, and 6,037 irrigation projects
1983	PFRA is transferred back to Agriculture Canada
1984	PFRA co-administers the federal-provincial Prairie Livestock Drought Assistance Program
1985	PFRA administers the federal Crop Drought Assistance Program
1988	PFRA delivers government emergency drought programs for livestock, greenfeed, and water supplies
1989	National Soil Conservation Program accords are signed by federal and provincial governments. Permanent Cover Programs are announced for the Prairie region, paying farmers to seed forage on annually cropped marginal lands
1997	National Soil and Water Conservation Program begins
1998	PFRA launches Prairie Agricultural Landscapes project, studying prairie land resources and their ability to support agricultural production and processing

Source: Adapted from *PFRA: A Brief History*. Agriculture and Agri-Food Canada web site: .ca/pfra/pfhiste.htm.

Figure 3: Accomplishments of the Prairie Farm Rehabilitation Administration

3.2. Programmes and Initiatives

In spite of the negative effects of dust storms and drought on farming and rural life in the Canadian Prairie region, the natural hazards have had positive effects as well. For instance, the Dust Bowl of the 1930s resulted in the Canadian Parliament's approval of huge funding allocation to finance a variety of programmes in controlling the blowing wind. For instance, in 1937, the expenditure of USD $10 million at an annual level and an overall cost of USD $500 million was approved (Gray 1996).

Since the 1930s, a large number of initiatives have been launched at both the federal and provincial levels, and programmes have been implemented mainly through the PFRA. In 1983, the PFRA published a report titled *"Land Degradation and Soil Conservation Issues on the Canadian Prairies."* The report concluded that the biggest threats facing agriculture in the Prairie region were wind erosion, water erosion, salinity and organic matter decline. This assessment formed the cornerstone of a great deal of subsequent soil conservation programming in the region. Non-governmental organizations (NGOs) and other groups have also made significant contributions. In the mid-1980s, a *"Wild West Programme"* was initiated by the World Wildlife Fund Canada in response to the issue of wildlife habitat loss (Dyson 1996). Since then, a new agricultural production system has evolved, with the philosophy of sustainable agro-ecosystems taking roots in the mainstream thinking. The new approach provides a conceptual framework to integrate the environmental, economic, and social impacts of farming activities.

Recently, Canada has announced its successful implementation of the National Soil and Water Conservation Programme (NSWCP). The NSWCP was a two-year federal programme, which ended March 31, 2000. It has a strong emphasis on water-related environmental issues, in addition to the more traditional focus on soil. Funding approvals are guided by four strategic directions, namely, (1) stewardship, (2) technology (research and development), (3) marketing, and (4) increasing awareness. NSWCP delivery emphasized developing the tools and information needed, working in partnership teams and building capacity at the community level to address site specific issues. Across Canada, USD $10 million was allocated to address the impact of agricultural land use on water quality and advance environmental sustainability initiatives. Funding for the NSWCP came from the USD $60-million-a-year Canadian Adaptation and Rural Development fund announced in the 1995 Federal Budget. The programme was put in place to support Canada's sustainable agricultural development. On the Prairies, USD $3 million was delivered through the PFRA to eligible organizations for soil and water conservation projects with a focus on water quality. In Alberta, USD $1.2 million was targeted to address the primary issues of manure management and riparian area management.

3.3. Approaches and practices

Agricultural practices vary widely across Canada. It may be argued that it is precisely dust storms and drought that taught Canadian farmers in the Prairie region new farming methods and techniques. This section describes several important approaches and practices that have been adopted in the Canadian Prairie region.

3.3.1. Better Management Practices

The potential for environmental problems due to agricultural activities is well documented. There are practical ways to ensure that risks to the environment are minimized without sacrificing economic productivity. These pollution-preventing farming methods are known as Better Management Practices (BMPs). According to Hilliard and Reedyk (2000), there are three general types of BMPs. The first category emphasizes reduction in the use of inputs in the interests of pollution prevention. The less a potentially harmful substance is used in agriculture, the less likely it is to affect other parts of the environment. This applies most directly to fertilizers, manure and pesticides. Nutrient management is the practice of applying fertilizers and manure only in the amounts that can be taken up by a crop. Applications in excess of the actual needs have the potential to enter surface and ground water. The use of herbicides and insecticides can be minimized through *"Integrated Pest Management."* This refers to a management strategy that includes an understanding of the target pest and use of a combination of physical, chemical, biological and cultural controls.

The second type of BMP is directly concerned with erosion and runoff control. Practices such as strip-cropping, shelterbelts and use of cover crops prevent erosion and reduce the movement of nutrients and pesticides from agricultural land. Residue management through conservation tillage and continuous cropping has proved effective at controlling erosion, but the approach is likely to require higher inputs of fertilizer and herbicides.

The third type involves the planting of barriers and buffers to intercept and contain contaminants that are being carried from agricultural lands. In most cases, these are strips of vegetation that slow the velocity of runoff water enough for sediment to settle out, water to infiltrate into the ground and nutrients to be taken up by plants. Grassed waterways, vegetative strips and field borders are examples of buffers that can be used in annually cropped fields. Where buffer zones surround a stream or lake, they are usually referred to as *riparian buffers*. The vegetation helps capture sediment and nutrients from water and stabilize the banks and shores from erosion.

Sound management practices are powerful tools in protecting soil and water. In the Prairie Provinces, farmers have used windmills to raise domestic water from underground aquifers or to collect surface runoff in excavated tanks (Heathcote 1983). However, they cannot be expected to solve all water quality problems. Many of the factors that reduce water quality on the Prairies occur naturally. BMPs are the first step in the process of soil conservation and water quality enhancement. Many of the potential negative impacts of farming can be greatly reduced by use of BMPs. In some cases, adopting BMPs is simply a matter of common sense and carries little or no extra cost, such as proper disposal of hazardous materials. In other instances, significant costs may be incurred. For example, planting of buffers to protect water quality may be costly. Several practices are presented in more detail below.

Agriculture-related environmental changes vary with cropping practices. According to Bird and Rapport (1986), wide-row crops (which include corn, soybeans, sunflowers, dry field peas, field beans, potatoes and vegetables), are generally associated with high rates of use of fertilizers and pesticides, and with increased risks of soil erosion. Close-row crops (which include wheat, oats, barley, mixed grain, flaxseed, canola, mustard seed and rye) are frequently associated with decreased soil organic matter and nutrient content and (especially when irrigated) with the spread of salinization. Forage crops (which include hay, alfalfa and other fodder crops) tend to retain the natural characteristics of the land, although they are sometimes associated with intensive livestock operations where runoff may pollute local water bodies.

3.3.2. Summerfallow and its decline

One unique farming practice in the Prairie region is called *"summerfallow."* Under this practice, some fields are not cropped for the spring-to-fall growing season in order to conserve soil moisture and regenerate nutrient supplies (Vaiser et al. 1996). Traditionally, many Canadian farmers considered summerfallow to be a necessary practice for dryland crop production. However, research results have shown that summerfallow, which usually involves mechanical cultivation of the soil to control weeds, has not been very kind to the land (PFRA 1999a). In fact, the practice has been identified as a major contributing factor for increased soil erosion, decline in organic matter and higher risk of salinity. Bird and Rapport (1986) reported that, in the Prairie Provinces, erosion per ha from summerfallow averaged more than twice that from wheat in a wheat-fallow system and 40 times more than wheat in a 5-year rotation with oats, barley and hay. Therefore, as shown in *Table 4*, summerfallow has declined steadily since the 1980s. In recent years, some new techniques that are collectively known as "conservation fallow" appear to gain popularity. One such technique is known as *"Chemical Fallow,"* which involves the spraying of herbicides to reduce tillage and retain surface residues to help trap snow and reduce evaporation losses.

Other solutions include *"Zero Tillage."* Also known as *"Minimum Tillage,"* zero tillage is an operation that places seed and fertilizer into a seedbed with minimum soil disturbance, packs the furrow and retains adequate surface residues to prevent soil erosion. Zero tillage seeding provides considerable benefits by slowing organic matter depletion and allowing for runoff reduction and better water infiltration. A scheme known *as "Crop Residue Management"* has substantially reduced the risk of erosion because it decreases the period during which soils are exposed to erosion by wind or water. Canadian farmers on the Prairies have been convinced that this type of direct seeding protects young seedlings from heat and wind stress during early growth stages (PFRA 1999c). Preliminary studies indicate favorable economic returns for this type of conservation fallow approach. For instance, the approach results in fewer tractor hours, hence, saving farming costs (PFRA 1999a, 1999c).

Table 5: Change in farmland uses in Canada's Prairie Provinces

Region	Total area of farms (km^2)	Land in crops (km^2)	Tame or seeded pasture (km^2)	Summerfallow (km^2)
Manitoba				
1981	76,159.3	44,203.7	3,525.1	5,983.4
1986	77,402.3	45,193.4	2,749.4	5,092.1
1991	77,249.9	47,610.5	3,412.9	2,970.0
1996	77,321.4	46,991.5	3,562.4	3,236.5
Saskatchewan				
1981	259,470.9	117,408.6	9,753.6	67,044.6
1986	265,993.6	133,258.1	8,787.3	56,582.5
1991	268,654.9	134,589.2	10,756.6	57,128.3
1996	265,690.6	143,986.5	12,333.1	44,314.5
Alberta				
1981	191,085.1	84,412.4	15,814.4	22,054.7
1986	206,553.4	91,625.2	13,768.1	21,270.1
1991	208,110.0	92,920.4	17,424.8	17,714.0
1996	210,292.3	95,465.5	19,146.0	14,367.4
Canada				
1981	658,889.2	309,658.1	44,047.3	97,019.1
1986	678,257.6	331,812.4	35,592.2	84,990.2
1991	677,537.0	335,077.8	41,412.2	79,209.5
1996	680,549.6	349,187.3	43,491.4	62,607.3

Source: Statistics Canada (2000).

It is estimated that more than 60% of the farms in the Prairie region are now using some form of conservation tillage practices and this figure will likely increase as more farmers learn about these practices. Among the various specific conservation tillage approaches, strip farming has been identified as one of the most effective.

3.3.3. Strip farming for wind erosion control

Also called *"Strip Cropping"* or *"Contour Cropping,"* Strip Farming is the practice of growing crops between alternate strips of summerfallow (Bircham and Bruneau 1985). The idea is to reduce wind erosion by reducing wind speed on the surface of the soil and the distance the wind travels across exposed summerfallow. Another benefit is the increased soil moisture from snow catch. Over the past decade, PFRA (1999d) has played a large role in popularizing the methods of arranging fields into strips. The most commonly used method is to determine the rotation and divide fields into strips of desired width. In a typical two-year, fallow-grain rotation, seeding takes place in every other strip and the alternate strips are summerfallowed. Farmers as well as researchers have recognized that strip widths are dependent on soil type, wider for loams and narrower for clay and sandy soils, to effectively control soil drifting. Furthermore, it is important to arrange strips north and south for maximum erosion prevention because the prevailing winds on the Prairies are northwest or west in direction. Research findings have shown that strip farming may be supplemented with field shelterbelts (Indian Head Agricultural Research Foundation 2000).

The 1980s witnessed not only a new cycle of drought in the Prairie region but also a new wave of global environmental movement. In response to these challenges, initiatives were launched thanks to increasing Federal-Provincial cooperation. Good examples include the signing of Economic and Regional Development Agreements in the mid-1980s and the initiation of the National Soil Conservation Programme in 1989 (Vaisey et al. 1996). These new programmes brought about changes in, among other things, farming practices. The Permanent Cover Programme (PCP) is an example of a special programme implemented primarily for reducing soil degradation on marginal lands that had high erosion risk under annual cultivation.

3.3.4. The Permanent Cover Programme

The PCP was first announced in 1989 as a 3-year programme for the Prairie Provinces. According to Vaiser et al. (1996), marginal lands in Classes 4, 5 and 6 under the Canada Land Inventory were targeted for conversion to alternative uses. What is unique about the PCP is the incentive structure and payment schemes that have been built into the programme design. Specifically, any Prairie farmers were eligible for financial assistance if they chose to sign long-term contracts on conversion of lands from annual crops to perennial forage or forest cover. Initial payments of USD $50 or USD $125 per ha for seeding were made depending on whether the contract was for 10 or 21 years. After the establishment of forage or tree covers, a one-time payment was made, using a bid price based on the market value of similar land. Farmers were allowed to continue to use the land, primarily for cattle grazing or forage production. The PCP proved to be so popular among farmers that the programme was extended in time and expanded in area to include parts of BC. In total, the PCP succeeded in attracting 15,000 contracts (of which 64% under long-term contracts for 21 years) that involved 521,998 ha of marginal lands being converted from annual crops to forage or other uses (see *Table 5*).

Table 6: Canada's Permanent Cover Programme: Contracts and Area

Contract type	Seeding only (ha)	10-year contracts (ha)	21-year contracts (ha)	Total (ha)
British Columbia	0	1,265	3,567	4,832
Alberta	54,039	65,962	100,704	220,705
Saskatchewan	0	58,374	150,701	209,075
Manitoba	20,877	22,519	43,990	87,386
Total	74,916	148,120	298,962	521,998

Source: Compiled from Vaiser et al. (1996), *Table 2*.

Although the PCP cost the Canadian Government USD $74 million in payments, the benefits are considered to have outweighed the costs. Some of the benefits accrued to the government while others went to society at large. Vaiser et al. (1996) estimated that the programme resulted in USD $11.8 million as savings for 1993 alone in terms of government crop insurance, farmers' stabilization funds and so on. Other benefits included reduction in soil degradation, water quality improvement, wildlife habitat enhancement and savings by local governments for removing wind and water borne sediments from road ditches and drains. There is no question that ultimately the local farmers benefited the most from implementing the programme. Having recognized that farmers' participation in this kind of scheme hinges on the availability of adequate incentives, all contracts contained a so-called *"escape clause"* to permit withdrawals by those who saw the need to terminate contracts in accordance with established liquidation provisions. Policy makers were fully aware of the need to monitor programme implementation to ensure that farmers maintain their lands under forage and forest cover.

During the past century or so, Canadian farmers in the Prairie region have adapted to climate change by irrigating their crops. While this has been an effective adaptation strategy in the past, the approach is now less and less attractive because of growing uncertainty in water supplies. Also, converting to more drought-tolerant crops has proved to be a successful strategy. For instance, some farmers have begun to diversify into specialty crops such as mustard seed, dry peas and lentils (Herrington et al. 1997).

3.3.5. Shelterbelt planting

Along with forage cover, forests are recognized as the best line of defense against drifting soils. Growing shelterbelts has long been considered an effective practice to reduce soil erosion (PFRA 1999b). In Canada's Prairie Provinces, tremendous efforts have been made in building field shelterbelts, farmstead shelterbelts and forest belts.

3.3.6. Field shelterbelts

Field shelterbelts consist of rows of trees planted on agricultural land to protect crops and soil, to catch and distribute snow, and to improve the microclimate for crops. On the Canadian Prairies reduction of soil erosion by wind is the major reason for planting shelterbelts. Trees and shrubs have been planted where soil is easily blown or where little vegetative cover remains. Recent research shows that field shelterbelts reduce wind speeds for a distance of 20 to 30 times their own height and increase crop yields considerably (Indian Head Agricultural Research Foundation 2000). Other benefits include enhanced wildlife habitat and improved scenic landscapes (PFRA 1999b). Studies from Saskatchewan, Manitoba and parts of the United States have shown an average yield increase of 3.5% for wheat from fields sheltered by mature shelterbelts (PFRA Shelterbelt Centre 2000).

It is believed that ideal field shelterbelts for Canada's Prairie region would consist of tall, long-lived trees that are not competitive with nearby crops and do not occupy too much land (PFRA Shelterbelt Centre 2000). However, it has been recognized that excessive distance between trees can greatly reduce shelterbelt effectiveness. The trees should be drought hardy, winter hardy, disease, and insect herbicide tolerant and have a porosity of 30-50% during the erosion period of the year, that is, spring and fall. Green ash (*Fraxinus pennsylvanica*) and caragana (*Caragana arborescens*) are highly recommended for field shelterbelt use because these species have many desired characteristics. Specifically, green ash is tall, long-lived and hardy. It is also relatively non-competitive and compact in form. The principal drawback to this species is that it sheds out leaves late in the spring when the most severe wind erosion occurs. Likewise, caragana is long-lived and non-competitive. While caragana is very hardy and pest resistant its major drawbacks are its low height (maximum less than 6 m), which reduces the overall protection it can give and its low porosity. Alternative trees being evaluated by the PFRA Shelterbelt Centre staff includes Siberian larch (*Larix sibirica*), Scots pine (*Pinus sylvestris*), Ussurian pear (*Pyrus ussuriensis*) and Bur oak (*Quercus macrocarpa*). Besides, Villosa lilac (*Syringa villosa*) and chokecherry (*Prunus virginiana* var. *Melanocarpa*) are also being used as shrubs either by themselves or in combination with green ash.

In addition to their role in reducing soil erosion, protecting farmyard from year-round winds and providing habitat for wildlife, trees and shrubs can also provide valuable products such as fuelwood, lumber, pulp and fruit. Fruit production and processing represent potential business opportunities for many Prairie farmers and, with proper management, high quality fruit crops can be grown. An important factor for success is the use of tree and shrub species, which are adapted to the local climate. Buffalo berry (*Shepherdia argentea*), sea-buckthorn (*Hippophae rhamnoides*) and chokecherry are commonly used in farmyard and field shelterbelts and wildlife plantings. The Mongolian cherries (*Prunus fruticosa*), Nanking cherries (*Prunus tomentosa*) and highbush cranberries (*Viburnum trilobum*) are less competitive and require more weed control and protection to ensure a fruit crop. The main limitations to fruit production on the Prairies are the short frost-free period, extreme temperatures, low rainfall and strong winds. However, the Prairie climate offers the advantages of abundant sunshine for fruit ripening and low humidity reducing the incidence of disease. A list of species used in shelterbelt planting in the Canadian Prairie region is provided in *Appendix 2*.

In shelterbelts, fruit-bearing shrubs are planted at a 1-m spacing within the row. If more than one row of shrubs is planted, usually 5-6 m space is left between rows. Chokecherry has been found to be more suited to the exposed conditions on the outside edges of the orchard, where they will provide additional shelter to the less hardy fruit-bearing species in the centre of the orchard. Actually, shelterbelts around an orchard are essential for growing bush fruits on the Prairies. The PFRA researchers have found that this approach helps reduce desiccation by hot, drying winds in summer and cold, dry winds in winter (Indian Head Agricultural Research Foundation 2000). Further, shelterbelts prevent wind damage to shrubs, loss of fruit at harvest, reduce evaporation and trap snow for moisture. For the best shelter, it is necessary to plant an outside row of deciduous trees/shrubs and an inside row of spruce (*Picea spp*.) or pine around the orchard. The deciduous trees provide shelter within 5 years. The conifers are slower growing but provide protection in all seasons. Preferably, the conifers may be spaced 3.5 m apart within the row to allow 6 m between the conifers and other tree rows. The best deciduous shrubs for shelter are caragana and lilac. It is useful to bear in mind that 15 m should be left between the orchard trees and the shelterbelts to avoid branch-breakage from large snowdrifts on the lee of the shelterbelts.

3.3.7. Farm Shelterbelts

Without doubt, properly planned shelterbelts provide many benefits to farm families. They reduce wind, control blowing snow and protect livestock, buildings and gardens. Up to five rows of trees are recommended on the north and west sides to provide protection from prevailing winds. Two or three rows are usually adequate on the east and south side for effective shelter. As a rule of thumb, farmstead shelterbelts need to be tall, fast growing, long-lived and dense in both summer and winter. Since the outside row usually acts as a snow trap, dense shrub species such as caragana, villosa lilac, or chokecherry are used. The second row tends to be a fast-growing species such as willow (*Salix spp*.) or Manitoba maple (*Acea negundo*). Long-lived species like green ash are planted in the third row. The fourth and fifth rows, which are closest to the yard, are tall, dense and long-lived. Conifers such as white spruce (*Picea glauca*) and Scots pine are suitable species because they benefit from the early protection provided by the outer rows (PFRA Shelterbelt Centre 2000). In addition, poplars (*Populus spp*.) are also commonly used species (Murray 1980). Interestingly, in order to benefit wildlife, farmers are advised in recent years to include in the outer row fruit-bearing shrubs, such as chokecherry, buffaloberry and sea-buckthorn.

3.3.8. Forest Belts

By definition, a forest belt is a field shelterbelt consisting of at least 3 rows of trees or shrubs. Forest belts serve the same purpose as field shelterbelts, but are expected to create a forest environment between rows when the tree canopy closes. A typical forest belt is designed in such a way that taller species are in the middle and shorter species are on the outside. The benefits fall into the following five categories. (1) Forest belts reduce soil erosion, trap snow, and increase crop yields more efficiently than regular shelterbelts, because they are denser and are less likely to have gaps in them. (2) Increase biodiversity. Forest belts harbor insects, birds, wild flowers, mammals and mushrooms, and provide habitat for wildlife. (3) Reduce global warming. Forest belts are more effective than regular shelterbelts in serving as a carbon sink. (4) Provide direct income. Forest belts give the farmer opportunity to harvest fruit products, pulp, lumber, maple syrup and so on. (5) Beautify landscape by providing long-term shelter, because forest belts are comprised of many species with varied life spans.

3.3.9. Riparian Enhancement and Range Improvement

As mentioned earlier, one of the main funding and delivery programmes in the Canadian Prairies for the period from 1998-2000 was the National Soil and Water Conservation Programme. Under this joint Federal-Provincial programme, riparian enhancement and range improvement were two primary objectives. Fostering sound soil conservation and riparian management practices is essential in protecting water supply for livestock, wildlife, human use and irrigation. For these purposes, a series of activities have been undertaken in support of appropriate livestock and cropping management practices that maintain or improve water quality within riparian areas (PFRA 2000b).

Specifically, the PFRA is responsible for providing technical information and support for projects related to riparian management and water quality protection, as well as financial assistance for municipalities and local NGOs. Many of these projects are partnerships with producers, land users and communities. These partnerships have been encouraged to identify priorities for future soil and water conservation initiatives and undertake stream bank enhancement activities.

In the Prairie region, sound range management is understood to include adjusting numbers of animals to compensate for periods of drought, using planned grazing systems with pasture rest periods, better fencing and watering systems to protect riparian areas, and permanent cover for all pasture lands. The Community Pasture Programme (CPP) is by far the largest, and also the longest running, contribution that the PFRA has made to soil conservation in the Prairie Provinces. Overall, the rate of cultivation of native prairie land has slowed steadily over the last few decades and considerable marginal lands have been returned to permanent cover. The general principle is that lands that are not suitable for cultivation are used as rangeland for cattle production. It has been found that diverse plant communities are more resistant to, and recover more fully from, major drought.

Since the CPP started in 1937 for the primary purpose of reclaiming badly eroded areas, the programme has returned more than 145,000 ha of poor quality cultivated lands to grass cover and it currently encompasses in excess of 900,000 ha of rangeland (PFRA 2000a). It has been recognized that fostering sound soil conservation and riparian management practices on the Prairies is essential to protecting water supply for livestock, wildlife, human use and irrigation. Many farmers and small communities are increasingly recognizing the need for good environmental stewardship. Various programmes exist which encourage rural landowners to maintain or create habitat for wildlife. Maintaining good water quality in a watershed often requires controlling runoff and livestock access to riparian areas and reducing the amount of time livestock spend in riparian areas. Because each watershed has its unique challenges, the PFRA staff have worked very hard to help land users and communities identify suitable practices.

The list of success stories associated with the PFRA is fairly long, including: (i) improving runoff management, (ii) cleaning drainage schemes, (iii) sealing abandoned wells, (iv) agroforestry, which is sometimes dubbed as an effort to develop two industries for the price of one, and (v) using the Geographic Information System (GIS) for better land use planning. Because PFRA programmes have played a prominent role in healing *"the wounds of the Palliser Triangle"* and restoring its productivity (Waiser 1996), Gray (1996) proposes that the victory in limiting the impacts of dust storms and soil erosion in the Palliser Triangle of the Prairie region is recognized as Canada's greatest accomplishment since the completion of the Canadian Pacific Railway.

4. DISCUSSION AND CONCLUSION

Agriculture is a vital force in the Canadian economy. It is estimated that the agricultural sector currently provides some 437,000 jobs, which represent about 1.5% of the country's total population and 3% of its workforce. Another 1.5 million, or 10% of the total labor force, are employed in food and beverage processing, food retail, food services, and related industries in the agri-food system. All in all, the agri-food sector generates about 8% of Canada's gross domestic product (Canada Information Office 2000). However, due to climatic factors and soil conditions, only 7-8% of Canada's land-base, or approximately 68 million ha, can be used for crop production (Environment Canada 2000b). Therefore, it is all the more important to ensure sustainable agriculture in Canada's Prairie region.

While the landscape of the Prairie region is influenced by a variety of natural processes such as wind, drought, flood, fire and so on, agriculture is critically dependent on soil and water that are directly affected by climate. According to Wheaton et al. (1992), the Prairie farms are, perhaps, the most climatically sensitive in Canada. For instance, during the drought of 1988, when mean annual temperature was 2-4^{0}C above the 30-year mean and precipitation was roughly half the 1950-1980 average, a 29% decline in wheat production contributed to a USD $1.5 billion drop in farm receipts in Saskatchewan alone (Lemmen et al. 1997).

The recognition of the adverse effects of dust storms have aroused growing concern about the implications of high-yield agricultural production, particularly when coupled with such soil-degrading factors as wind and water erosion, organic matter loss, salinization, acidification, contamination, compaction and disturbance of agricultural soils. These concerns are linked to technological and market influences that have resulted in changes in cropping practices, conversion of prime agricultural lands to other uses, and economic pressures that encourage farmers to seek short-term solutions (Bird and Rapport 1986).

In order to achieve sustainable development in the agriculture sector, one of the biggest challenges is to address the issue of climate change. It has been recognized that climate is the single greatest factor affecting agricultural productivity in Canada. Most climate change scenarios show an increase in temperature and reductions in soil moisture, with potential disruptions to agriculture, forests, energy, water and wildlife throughout the Prairie Provinces (Herrington et al. 1997). Lemmen et al. (1997) present a scenario projecting that the water table will likely fall by 4 m below its present level and wind erosion will become worse. In meeting the challenges of global climate change, the future of Canada's farming will clearly depend on its ability to maintain the natural resources, such as soil, water and air. Factors that serve as indicators of changing soil quality and agriculture sustainability include organic-matter loss, nutrient content, acidification, salinization, erosion and compaction. In the final analysis, maintenance of soil quality determines whether agricultural production can be sustained over time. Sustainable agriculture requires that soil, water and air quality be maintained. Prairie soils now face a number of serious threats. Salinity, erosion, organic-matter loss and other problems are affecting millions of hectares, although improvements in agricultural technology have masked many of their effects. The farmlands of Western Canada are both precious and fragile.

Canada is serious about addressing climate change and other environmental concerns. In August 1995, a National Environmental Strategy for Agriculture and Agri-Food was developed to set the tone for future environmental stewardship in the country. In February 2000, the *Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project* was released by the Government of Canada. This 6-year collaborative study involving various levels of government, the agri-food sector and educational and research institutions, has helped enhance the sector's understanding of how to sustain Canada's natural resources. While reviewing the significant progress that has been achieved, the document reaffirms the Canadian Government's commitment to reducing soil erosion and improving air quality.

Canada's agriculture is vital to the country's social, cultural and economic future. Improved farming practice as well as modern technology has rehabilitated the southern portion of the Prairie Provinces into productive dryland. Only 60 years ago, high winds combined with desert-like summer heat and little rain raised dust storms that each year stripped the prairie land of its thin, fertile topsoil. By developing a totally new farming system and technology, Canadians have converted such areas into some of the richest grain fields in the world. This chapter has described Canada's experience in fighting against dust storms and drought. Great achievements have been made by generations of Canadians in minimizing the effects of soil erosion and impacts of dusty wind. The sentiment of the Canadians on the Prairies may be summarized as *"Dust but never Despair"* (using the words of John W. Fisher in his CBC radio broadcast of March 1944, quoted by Rees 1988, p. 134.). In fact, Canada takes great pride in the contribution that it has made to world agriculture. The measures that Canadians have taken against dust storms and drought, the discoveries that they have made and the methods that they have devised will pay dividends in increased food production in the semi-arid areas of the world for generations to come (Gray 1996). Canadians are reminded, from time to time, of the challenge of fighting incessant dust storms.

Appendix 1: Dust storms and drought-related events in Canada

1886-89	Severe drought conditions in the Prairie region
1893-95	Severe drought events in large area of the Prairies
1912-13	Severe drought conditions in the Palliser Triangle
1917-20	Occurrence of major wind erosion in the Prairie region, with severe black blizzards in Alberta
1930s	The 1930s are known as the *"Dust Bowl Era."* Between 1933 and 1937, the Prairie region experienced only 60% of its normal rainfall. Thousands of livestock were lost to starvation and suffocation, crops withered and a quarter of a million people across the region abandoned their land to seek better lives elsewhere
May 12, 1934	Black blizzard carrying tons of dusts blowing across Western Canada from the Rocky Mountains to the Great Lakes and the Prairie region facing the greatest grasshopper invasion in history
July 5-17, 1936	The deadliest heat wave in history. Temperatures exceeding 44^0C in Manitoba and Ontario claimed 1,180 Canadians (mostly the elderly and infants) during the longest, deadliest heat wave on record. Four hundred of these deaths were caused by people who drowned seeking refuge from the heat. The heat was so intense that steel rail lines and bridge girders twisted, sidewalks buckled, crops wilted and fruit baked on trees
July 5, 1937	Hottest day on record. The highest temperature ever recorded in Canada was recorded at Midale and Yellowgrass, Saskatchewan when the mercury soared to 45^0C
1957-62	Unusually dry period across the Prairie region, dramatically increasing demands for water development projects
1961	One of the driest years on record across most of the Prairie Provinces. Many areas in the drought-stricken Prairie region received only 45% of normal precipitation. In Regina, every month but May was drier than normal, and for the 12-month crop year the precipitation total was the lowest ever. The duration, severity and size of the area effectively made this drought the worst on record. Losses in wheat production alone were USD $668 million, 30% more than in the previous worst year, 1936
1976	Severe dusty wind during spring
1977	Start of a widespread dry period that will last for more than a decade
1980	Severely dry year. Emergency programmes are introduced, including the Herd Maintenance Assistance Programme under PRFA
1981	Severe dust storms during spring
1984	Severe dust storms and drought conditions in summer
1985	Severe drought conditions in summer
Sep. 1987- Aug. 1988	*"USD $4 Billion Drought."* Across the southern Prairies, the hottest summer on record, combined with half the normal growing season rainfall and a virtually snow-free previous winter, produced a drought that rivaled the 1930s in terms of intensity and duration of the dry spell. About 10% of farmers and farm workers left agriculture in 1988. Effects of the drought were felt across the country as lower agricultural yield led to higher food and beverage prices for consumers
June 15, 1995	Powerful winds exceeding 100 km/hour swept across Fillmore, Saskatchewan. It blew the roof off a grain elevator, broke a radio tower, toppled a chimney on a church, and damaged dozens of buildings
1998	Another dry year, with a yearlong heat wave, comparable to the droughts of 1936-37, 1961 and 1984-85. Canada experienced its second warmest winter and warmest spring, summer and fall on record. Temperatures in 1998 were an average of 2.4 degrees warmer than normal and it was the

warmest year of the 20th century. Crops and pastures were affected, and people were forced to haul water

Source: Adapted from Environment Canada (2000a); PFRA Shelterbelt Centre (2000); Gray (1996); Bird and Rapport (1986), and Murray (1980). Heat wave is defined as a period with more than three consecutive days of maximum temperature at or above 32^0 C.

Appendix 2: Tree species used in shelterbelt planting in the Prairie Region

Common name	Scientific name
Balsam fir	*Abies balsamea*
Amur maple, Ginnala maple	*Acer ginnala*
Manitoba maple, Boxelder	*Acer negundo*
Speckled alder	*Alnus incana*
White birch	*Betula pendula*
Caragana, Siberian peashrub	*Caragana arborescens*
Hackberry	*Celtis Occidentalis*
Red-osier dogwood	*Cornus Stolonifer*
Beabed hazelnut	*Corylus cornuta*
European cotoneaster	*Cotoneaster integerrimus*
Arnold hawthorn	*Crataegus arnoldiana*
Round-leaved hawthorn	*Crataegus rotundifolia*
Russian olive	*Elaeagnus angustifolia*
Wolf-willow, silverberry	*Elaeagnus commutata*
Winterberry	*Euonymus bungeanus*
Green ash	*Fraxinus pennsylvanica*
Siberian salt tree	*Halimodendron halodendron*
Sea-buckthorn	*Hippophae rhamnoides*
European larch	*Larix decidua*
Dahurian larch	*Larix gmelinii*
Siberian larch	*Larix sibirica*
Amur honeysuckle	*Lonicera maackii*
Tatarian honeysuckle	*Lonicera tatarica*
Siberian crabapple	*Malus baccata*
Manchurian crabapple	*Malus baccata var. Mandshurica*
Niedzwetzkyana crabapple	*Malus pumila var. Niedzwetzkyana*
Ponderosa pine	*Pinus ponderosa*
Siberian pine	*Pinus sibirica*
Red pine	*Pinus resinosa*
Scots pine	*Pinus sylvestris*
Mongolian pine	*Pinus sylvestris var. Mongolica*
Assiniboine poplar	*Populus x deltoides "Assiniboine"*
Manitou poplar	*Populus x deltoides "Manitou"*
Walker poplar	*Populus x deltoides "Walker"*
Prinsepian cherry	*Prinsepia sinensis*
American plum	*Prunus americana*
Western sand cherry	*Prunus besseyi*
Mongolian cherry	*Prunus fruticosa*
Amur cherry	*Prunus maackii*
Canada plum	*Prunus nigra*
Mayday	*Prunus padus var. Commutata*
Pincherry	*Prunus pensylvanica*
Nanking cherry	*Prunus tomentosa*
Black-fruited choke cherry	*Prunus virginiana var. Melanocarpa*
Ussurian pear	*Pyrus ussuriensis*
Bur oak	*Quercus macrocarpa*
Mongolian oak	

Golden currant	*Quercus mongolica*
Hedge rose	*Ribes aureum*
Prickly rose	*Rosa spp.*
Wood's rose	*Rosa acicularis*
Red elder, elderberry	*Rosa woodsii*
Silver buffaloberry	*Sambucus racemosa*
Showy mountain ash	*Shepherdia argentea*
Western snowberry, buckbrush	*Soibus decora*
Villosa lilac, late lilac	*Symphoricarpus occidentalis*
Japanese elm	*Syringa villosa*
Siberian elm	*Ulmus davidiana var. Japonica*
Highbrush cranberry	*Ulmus pumila*
	Viburnum trilobum

Source: PFRA Shelterbelt Centre (1989, 2000).

Appendix 3: Acronyms and abbreviations

ARDA	Agricultural Rehabilitation and Development Act
BC	British Columbia
BMP	Better Management Practices
CBC	Canadian Broadcast Corporation
CPP	Community Pasture Programme
CPR	Canadian Pacific Railway
GIS	Geographic Information System
MCBC	Manitoba Crop Diversification Centre
MHPEC	Manitoba Horticulture Productivity Enhancement Centre
NGOs	Non-Governmental Organizations
NSWCP	National Soil and Water Conservation Programme
PCP	Permanent Cover Programme
PFRA	Prairie Farm Rehabilitation Administration

5. References

Agriculture and Agri-Food Canada. 1995. *National Environment Strategy for Agriculture and Agri-Food*. Document prepared for the Federal and Provincial Ministers of Agriculture. Ottawa.

Allen, R. (ed.). 1973. *A Region of the Mind – Interpreting the Western Canadian Plains*. Regina, Saskatchewan: Canadian Plains Studies Centre, University of Saskatchewan.

Anderson, J. 1984. Dust storm! *Chinook* 6(3): 71-73.

Bauer, D.J. (ed.). 1988. *Proceedings of the Prairie Drought Workshop*. Saskatoon, October 11-13, 1988. Ottawa: Environment Canada.

Beierle, B., and D.G. Smith. 1998. Severe drought in the early Holocene (10,000-6800 BP) interpreted from lake sediment cores, southwestern Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 140(1-4): 75-83.

Bircham, P.D., and H.C. Bruneau. 1985. *Degradation of Canada's Prairie Agricultural Lands: A Guide to the Literature and Annotated Bibliography*. A report of the Land-Use Policy and Research Branch. Working Paper No. 37. Ottawa: Environment Canada.

Bird, P.M., and D.J. Rapport. 1986. *State of the Environment Report for Canada*. Environment Canada, Ottawa.

Brown, S. 1963. World of the Desert. The Bobbs-Merrill Company, Inc., New York.

Canada Department of Agriculture. 1980. *Drought Situation in Western Canada*: Discussion Paper. Ottawa.

Canada Information Office. 2000. *Facts on Canada – Geography*. Ottawa.

Canadian International Development Agency. 1997. *Meeting the Challenge – Canada's Commitment to the United Nations Convention to Combat Desertification*. Ottawa.

Chakravarti, A.K. 1972. The June-July precipitation pattern in the Prairie Provinces of Canada. *The Journal of Geography* 71: 155-160.

Chakravarti, A.K. 1976. Precipitation deficiency patterns in the Canadian Prairies, 1921 to 1970. *Prairie Forum* 1(1): 95-110. Regina: The Canadian Plains Research Centre.

David, P.P. 1977. Sand Dune Occurrences of Canada: A Theme and Resource Inventory Study of Eolian Landforms of Canada. Contract No. 74-230. Ottawa: Department of Indian and Northern Affairs, National Parks Branch.

David, P.P. 1979. Sand dunes in Canada. *Geos* (Spring Issue): 12-14. Department of Energy, Mines and Resources of Canada.

David, P.P. 1981. Stabilized dune ridges in northern Saskatchewan. *Canadian Journal of Earth Sciences* 18: 286-310.

Dormaar, J.F., and R.L. Barsh. 2000. *The Prairie Landscape: Perceptions of Reality*. Mimeo. September.

Dyson, I.W. 1996. Canada's Prairie Conservation Action Plan. In: Fred B. Samson and Fritz L. Knopf (eds.) *Prairie Conservation – Preserving North America's Most Endangered Ecosystem*, pp.175-186.

Elias, P.D. 1999. *From Grassland to Rockland – An Explorer's Guide to the Ecosystems of Southernmost Alberta*. Calgary, Alberta: Rocky Mountain Books.

Environment Canada. 1997. *The Canada Country Study: Climate Impacts and Adaptation: The Canadian Prairies Summary*. Ottawa.

Environment Canada. 2000a. *Top Weather Events of the 20th Century*. Environment Canada: The Green Lane – Fact Sheet.

Environment Canada. 2000b. *Cultivating A Secure Future: Rural Development and Sustainable Agriculture in Canada* – A Canadian contribution to the land use dialogue at the 8th Session of the United Nations Commission on Sustainable Development, April 24 – May 5, 2000. Ottawa: Environment Canada.

Etkin, D., M.T. Vázquez, and I. Kelman. 1998. *Natural Disasters and Human Activity – A Contribution to the North American Commission on Environmental Cooperation State of the Environment Report*. Environment Canada: The Green Lane.

Etkin, D. 1997. Climate change and extreme events: Canada. Chapter Two in: Volume VIII *National Cross-Cutting Issues, Canada Country Study: Climate Impacts and Adaptation*. Ottawa: Environment Canada.

Friesen, G. 1984. *The Canadian Prairies – A History*. Toronto: University of Toronto Press.

Fryer, H. 1977. *Alberta – The Pioneer Years*. Langley, B.C.: Stagecoach Publishing Co. Ltd.

Gill, T.E. 1996. Eolian sediments generated by anthropogenic disturbance of playas: human impacts on the geomorphic system and geomorphic impacts on the human system. *Geomorphology* 17(1-3): 207-228.

Goudie, A.S., and N.J. Middleton. 1992. The changing frequency of dust storms through time. Climatic Change 20(3): 197-225.

Gray, J.H. 1996. *Men Against the Desert*. Second Edition. Saskatoon & Calgary: Fifth House Publishers.

Heathcote, R.L. 1983. *The Arid Lands: Their Use and Abuse*. London: Longman.

Herrington, R., B.N. Johnson, and F. Hunter. 1997. *Responding to Global Climate Change in the Prairies*, Volume III of *Canada Country Study: Climate Impacts and Adaptation*. Ottawa: Environment Canada.

Hilliard, C., and S. Reedyk. 2000. Agricultural Best Management Practices. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

Hogg, E.H. 1994. Climate and the southern limit of the western Canadian boreal forest. *Canadian Journal of Forest Research* 24(9): 1835-45.

Hogg, E.H. 1997. Temporal scaling of moisture and the forest-grassland boundary in western Canada. Agricultural and Forest Meteorology 84: 115-122.

Hope, E.C. 1938. Weather and crop history in Western Canada. *Canadian Society of Technical Agriculture Review* 16: 347-358.

Indian Head Agricultural Research Foundation. 2000. *The Effects of Shelterbelts on Cropping and Tillage Practices*. Indian Head, Saskatchewan.

Jones, D.C. 1986. *"We'll All Be Buried Down Here": The Prairie Dryland Disaster 1917-26*. Calgary: Alberta Records Publication Board, Historical Society of Alberta.

Jones, D.C. 1987. *Empire of Dust – Settling and Abandoning the Prairie Dry Belt*. Edmonton: The University of Alberta Press.

Kendrew, W.G., and B.W. Currie. 1955. *The Climate of Central Canada: Manitoba, Saskatchewan, Alberta, and the Districts of Mackenzie and Keewatin*. Ottawa: E. Cloutier, Queen's Printer.

Kostaschuk, R. 2000. A field study of turbulence and sediment dynamics over subaqueous dunes with flow separation. *Sedimentology* 47(3): 519-531.

LaDochy, S., and C.H. Annett. 1982. Drought and dust: a study in Canada's Prairie Provinces. *Atmospheric Environment* 16(6): 1535-41.

Larney, F.J., M.S. Bullock, S.M. McGinn, and D.W. Fryrear. 1995. Quantifying wind erosion on summer fallow in southern Alberta. *Journal of Soil and Water Conservation* 50(1): 91-95.

Lemmen, D.S., and R.E. Vance (eds.). 1999. *Holocene Climate and Environmental Change in the Palliser Triangle: A Geoscientific Context for Evaluating the Impacts of Climate Change on the Southern Canadian Prairies*. Geological Survey of Canada Bulletin 534. Ottawa: Natural Resources Canada.

Lemmen, D.S., R.E. Vance, I.A. Campbell, P.P. David, D.J. Pennock, D.J. Sauchyn, and S.A. Wolfe. 1998. *Geomorphic Systems of the Palliser Triangle, Southern Canadian Prairies: Description and Response to Changing Climate*. Geological Survey of Canada Bulletin 521. Ottawa: Natural Resources Canada.

Lemmen, D.S., R.E. Vance, S.A. Wolfe, and W.M. Last. 1997. Impacts of future climate change on the southern Canadian Prairies: A paleoenvironmental Perspective. *Geoscience Canada* 24(3): 121-133.

MacEwan, G. 1952. *Between the Red and the Rockies*. Toronto: University of Toronto Press.

Mackenzie River Basin Committee. 1981. *Athabasca Sand Dunes in Saskatchewan*. Mackenzie River Basin Study Report Supplement 7. Canada – Alberta – British Columbia – Saskatchewan – Northwest Territories – Yukon Territory.

Magill, B.L., and F.Geddes. 1988. *The Impact of Climate Variability and Change on the Canadian Prairies*. Proceedings of the Symposium, Edmonton, September 9-11, 1987. Edmonton: Alberta Environment.

Melton, F.A. 1940. A tentative classification of sand dunes: Its application to dune history in the southern high plains. *Journal of Geology* 48: 113-174.

Momatiuk, Y., and J. Eastcott. 1991. *In a Sea of Wind: Images of the Prairies*. Camden House, Ontario.

Murray, O. (ed.). 1980. *Yesterday's Prairie Wind* – A History of Gainsborough, Ash Grove, Cayuga, Clairemont, Fern, Newlyn, Winlaw and Winmore. Compiled and published by the Gainsborough and District Historical Society. Gainsborough, Saskatchewan, Canada.

Odynsky, W.M. 1958. U-shaped dunes and effective wind directions in Alberta. *Canadian Journal of Soil Science* 38: 56-62.

Péwé, T.L. (ed.). 1981. *Desert Dust: Origin, Characteristics, and Effect on Man*. Special Paper 186. Boulder, Colorado: The Geological Society of America.

PFRA Shelterbelt Centre. 1989. *Shelterbelt Species*. Indian Head, Saskatchewan: Prairie Farm Rehabilitation Administration Shelterbelt Centre, Agriculture Canada.

PFRA Shelterbelt Centre. 1992. *Fruit-bearing Shrubs for Multi-Use Shelterbelts and Orchards*. Indian Head, Saskatchewan: Prairie Farm Rehabilitation Administration Shelterbelt Centre, Agriculture Canada.

PFRA Shelterbelt Centre. 2000. *Design Shelterbelts to Prevent Wind Erosion*. Indian Head, Saskatchewan: Prairie Farm Rehabilitation Administration Shelterbelt Centre, Agriculture and Agri-Food Canada. Web site: http://www.agr.ca/pfra/shbpub/shbpub12.htm.

PFRA. 1987. *Conservation Reserve for Marginal Land Conversion*. Regina: Prairie Farm Rehabilitation Administration, Agriculture Canada.

PFRA. 1999a. *Economics of Conservation Fallow*. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

PFRA. 1999b. *Economics of Shelterbelts*. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

PFRA. 1999c. *Economics of Zero Tillage*. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

PFRA. 1999d. *Strip Farming for Wind Erosion Control*. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

PFRA. 2000a. *Prairie Agricultural Landscapes: A Land Resource Review*. Regina: Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

PFRA. 2000b. Riparian Enhancement Projects. Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada.

Raup, H.M., and G.W. Argus. 1982. *The Lake Athabasca Sand Dunes of Northern Saskatchewan and Alberta, Canada*. Publications in Botany, No. 12. Ottawa: National Museums of Canada, National Museum of Natural Science.

Rees, R. 1988. *New and Naked Land – Making the Prairies Home*. Saskatoon: Western Producer Prairie Books.

Ruz, M.-H., and M. Allard. 1995. Sedimentary structures of cold-climate coastal dunes, eastern Hudson Bay, Canada. *Sedimentology* 42(5): 725-734.

Samson, F.B., and F.L. Knopf (eds.). 1996. *Prairie Conservation – Preserving North America's Most Endangered Ecosystem*. Washington, D.C.: Island Press.

Sanderson, M. 1948. Drought in the Canadian Northwest. *Geographical Review* 38: 289-299.

Sparrow, H.O. 1984. *Soil at Risk, Canada's Eroding Future*, A Report on Soil Conservation by the Standing Committee on Agriculture, Fisheries and Forestry to the Senate of Canada. Ottawa: Senate of Canada.

Statistics Canada. 2000. *Use of Farmland, Canada and Provinces*. Ottawa.

Swainson, D. 1970. *Historical Essays on the Prairie Provinces*. Toronto: McClelland and Stewart Limited.

Thomas, D.S.G. (ed.). 1997. *Arid Zone Geomorphology – Process, Form and Change in Drylands*. Second Edition. Chichester: John Wiley & Sons.

Thompson, J.H. 1998. *Forging the Prairie West – The Illustrated History of Canada*. Oxford: Oxford University Press.

Tinker, R., and F. Itani. 1999. Prairie wind. *Canadian Geographic*, Special Issue Annual, p.67.

Tremblay, L.P. 1961. Wind striations in northern Alberta and Saskatchewan, Canada. *Geological Society of America Bulletin* 72: 1561-64.

Vaisey, J.S., T.W. Weins, and R.J. Wettlaufer. 1996. *The Permanent Cover Programme – Is Twice Enough? Soil and Water Conservation Policies: Successes and Failures*. Paper presented at a conference held in Prague, Czech Republic, September 17-20, 1996.

Vance, R.E. 1997. The geological survey of Canada's Palliser Triangle Global Change Project: a multidisciplinary geolimnological approach to predicting potential global change impacts on the Northern Great Plains. *Journal of Paleolimnology* 17: 3-8.

Villard, P., and R. Kostaschuk. 1998. The relation between shear velocity and suspended sediment concentration over dunes: Fraser Estuary, Canada. *Marine Geology* 148(1-2): 71-81.

Waiser, B. 1996. Foreword. In: James H. Gray *Men Against the Desert*. Second Edition. Saskatoon & Calgary: Fifth House Publishers.

Wettlaufer, R.J., and P.B. Brand. 1992. *Adoption of Soil Conservation Practices on the Canadian Prairies*. Paper presented at the International Symposium on Adopting Conservation on the Farm held in Honolulu, Hawaii, October 1992.

Wheaton, E.E. 1984. *Climatic Change Impacts on Wind Erosion in Saskatchewan, Canada*. SRC Technical Report No. 153. Saskatchewan Research Council, Saskatoon.

Wheaton, E.E., and A.K. Chakravarti. 1987. Some temporal, spatial and climatological aspects of dust storms in Saskatchewan. *Climatological Bulletin* 21(2): 5-16.

Wheaton, E.E., and A.K. Chakravarti. 1990. Dust storms in the Canadian Prairies. *International Journal of Climatology* 10: 829-837.

Wheaton, E.E., L.M. Arthur, B. Chorney, S. Shewchuk, J. Thorpe, J. Whiting, and V. Wittrock. 1992. The Prairie drought of 1988. *Climatological Bulletin* 26(3): 188-205.

Wilhite, D.A. 1993. *Drought Assessment, Management and Planning: Theory and Case Studies*. Boston: Kluwer Academic Publishers.

Wilhite, D.A., W.E. Easterling, and D.A. Wood (eds.). 1987. Planning for Drought: Toward a Reduction of Societal Vulnerability. Boulder, Colorado: Westview Press.

Wolfe, S.A., D.R. Muhs, P.P. David, and J.P. McGeehin. 2000. Chronology and geochemistry of late Holocene eolian deposits in the Brandon Sand Hills, Manitoba, Canada. *Quaternary International* 67(1): 61-74.

World Wildlife Fund Canada. 1988. *Prairie Conservation Action Plan, 1989-94*.

Chapter Five

DUST BOWL IN THE 1930S AND SANDSTORMS IN 1999 IN THE USA

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Key words: Climate change, desertification, Dust Bowl, sandstorms, USA, El Nino, soil conservation, climate change, aerosols

SYNOPSIS

This chapter provides some detailed descriptions and analyses of major sand and dust storms occurring in the US during the 1930s and more recently in 1999. The Southern High Plain region is one of the dustiest areas in the United States. Although the most famous dust storms occurred during the 1930s, several notable outbreaks of sand and dust storms took place in western Texas and southeastern New Mexico in 1999. These storms, associated with cyclones crossing the region, have caused dust falls in regions hundreds to thousands of kilometers downwind, resulting in serious economic and ecological damages. Extreme drought and misuse of lands were the major causes of the Dust Bowl, and dust aerosols in the Southern High Plains were produced almost exclusively by direct wind erosion of unvegetated or disturbed soils. A series of remedies, such as the so-called "New Deal Remedies" initiated by the US government in the 1930s, were very effective to slow the occurrence of dust and sandstorms. Recently, strong El Nino events improved land management practices and soil conservation programmes apparently combined to keep the overall prevalence of dust storms in the Great Plains well below the extent of those in the earlier dusty decades.

KEY POINTS

1. *A dozen massive dust storms scoured northern China in the spring of 2000 as unusually strong winds swept through vast, arid northern deserts and sparse grasslands that stretch from Mongolia and northwestern Xinjiang right to Beijing's backyard. Much of the sand dumped on Beijing area came from even worse-affected areas further north in Inner Mongolia, where burgeoning livestock herds have grazed once plentiful grasslands bare (Science and Technology Daily, May 15, 2000). These storms caused so much damage that Chinese Premier Zhu Rongji described the sandstorms as "an alarm for the entire nation" in a rare television address after these sandstorms occurred, and called for effective remediation and prevention of these harmful disasters (see Chapters 3, 10, 11, 12).*

2. *What caused these sandstorms? It is generally believed that prolonged drought, excessive grazing and timber cutting, and the cultivation of grasslands, riverbanks and mountains with corn and other grains*

have made northern China a dust bowl (see Part V). Population growth and industrial development drain reservoirs and underground water tables faster than they can be replenished, leaving city residents and farmers alike without enough water to drink or irrigate crops. The scarcity threatens China's ability to feed itself and is a severe handicap for growing industries. More than one-quarter of China is desert. Nearly 2,500 km^2 is lost to sand each year, mainly in impoverished areas where local inhabitants traditionally raise corn, horses and goats and thus depend on the land to survive (Zhu and Chen 1994; Wang 1996; Ci, 1997).

3. *However, sandstorms are not limited to developing countries such as China. In the United States, sand and dust storms happened not only in the 1930s when serious drought and land misuse resulted in a "Dust Bowl" over large areas in the Great Plains (Hurt 1981; Howarth 1984; Lee et al. 1999), but also in recent years (Gill et al. 2000). Although the total number of days in which blowing sand and dust was reported or forecast were much fewer in 1999 (~ 40) than in the previous few years (~ 60) in this region, several notable outbreaks of dust storms took place in western Texas and southeastern New Mexico in the spring of 1999. Sand and dust storms also occurred in January and September of 1999 elsewhere. All these storms caused serious personal and property damages (Gill et al. 2000).*

4. *This chapter provides some detailed descriptions and analyses of several major sand and dust storms that occurred in the US during the 1930s and recently in 1999. It is the hope that such information will provide useful insights into what is happening in northern China and how we can find effective mitigation approaches for these ecological and economic disasters.*

1. DESCRIPTION OF THE DUST BOWL IN THE US DURING THE 1930S

The Dust Bowl was an ecological and human disaster that took place in the southwestern Great Plains region of the United States in the 1930s (Bonnefied 1979; Hurt 1981; Howarth 1984; Lee et al. 1999). The Dust Bowl got its name on April 15, 1935, the day after Black Sunday (*see below*), and lasted about a decade. Its primary area of impact was the southern Plains, while the northern Plains were not so badly affected (*Figure 1*). In fact, the agricultural devastation lengthened the Depression, whose effects were felt worldwide.

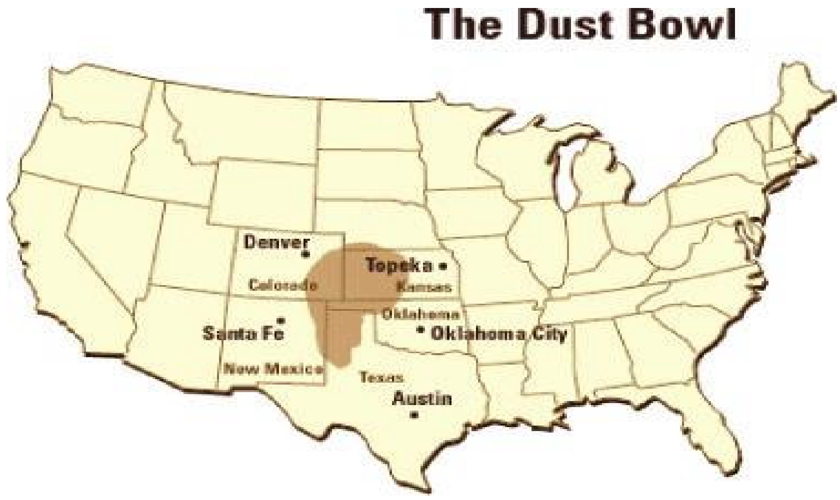

Figure 1: Map of the USA, showing the location of the Dust Bowl (shaded area)

As John Steinbeck wrote in his 1939 novel, The Grapes of Wrath: *"And then the dispossessed were drawn west- from Kansas, Oklahoma, Texas, New Mexico; from Nevada and Arkansas, families, tribes, dusted out, tractored out. Carloads, caravans, homeless and hungry; twenty thousand and fifty thousand and a hundred thousand and two hundred thousand. They streamed over the mountains, hungry and restless - restless as ants, scurrying to find work to do - to lift, to push, to pull, to pick, to cut - anything, any burden to bear, for food. The kids are hungry. We got no place to live. Like ants scurrying for work, for food, and most of all for land."*

On April 14, 1935 (Black Sunday), *"after weeks of dust storms, one near the end of March destroying five million acres of wheat, people grateful to see the sun went outside to do chores, go to church, or to picnic and sun themselves under the blue skies. In mid-afternoon, the temperature dropped and birds began chattering nervously. Suddenly a huge black cloud appeared on the horizon, approaching fast. Those on the road had to try to beat the storm home. Some had to stop on their way to seek shelter in an abandoned adobe hut, sitting for four hours in the dark, fearing that they would be smothered and forth along the road…"*

The storm on Black Sunday was one of the most serious sandstorms of the 1930s, and the damage it caused could not be calculated for years (*Figure 2*). Coming on the heels of a stormy season, the April 14 storm hit as many others had, only harder. *"The impact is like a shovel full of fine sand flung against the face,"* Avis D. Carlson wrote in a New Republic article. *"People caught in their own yards grope for the doorstep. Cars come to a standstill, for no light in the world can penetrate that swirling murk… The nightmare is deepest during the storms. However, on the occasional bright day and the usual gray day we cannot shake from it. We live with the dust, eat it, sleep with it, watch it strip us of possessions and the hope of possessions. It is becoming real. The poetic uplift of spring fades into a phantom of the storied past. The nightmare is becoming life."*

Figure 2: Illustration of Dust Bowl days in the USA in the 1930s. Counter-clockwise from left-top: a dust storm approaching a highway; a village swallowed by the dust storms; a house hit by a dust storm; a car stopped by the dust; a family suffers from the dust storms; a street during a dust storm; a farm threatened by a dust storm (photo credit: US National Archives)

Because of the Dust Bowl, millions of hectares of farmland became useless, and hundreds of thousands of people were forced to leave their homes (Hurt 1984; Lee et al. 1999). When the drought and dust storms showed no signs of letting up, many people abandoned their lands. Others would have stayed but were forced out when they lost their lands in bank foreclosures. In all, one-quarter of the population left, packing everything they owned into their cars and trucks, and headed west toward California. Although overall three out of four farmers stayed on their land, the mass exodus depleted the population drastically in certain areas (Worster 1979; Svobida 1986).

The Dust Bowl exodus was the largest migration in American history (Bonnefield 1979). By 1940, 2.5 million people had moved out of the Plains states. Of those, 200,000 moved to California. When they reached the border, these *"ecological immigrants"* did not receive a warm welcome, as described in this 1935 excerpt from Collier's magazine: *"Very erect and primly severe, [a man] addressed the slumped driver of a rolling wreck that screamed from every hinge, bearing and coupling. 'California's relief rolls are overcrowded now. No use to come farther,' he cried. The half-collapsed driver ignored him – merely turned his head to be sure his numerous family was still with him. They were so tightly wedged in, that escape was impossible. In fact, the Los Angeles police chief then went so far as to send 125 policemen to act as bouncers at the state border, turning away "undesirables."*

2. DESCRIPTION OF RECENT SERIOUS SAND AND DUST STORMS IN THE US

In recent years, dust and sandstorms still occur (although less frequently) in the US. For example, the first half of April 1999 was a time of significant blowing dust events in the south central United States. On April 9, 1999, an intense dust storm was observed over Colorado and Kansas. The following week, on April 14, 1999, another intense dust storm took place in western Texas and southeast New Mexico (Gill et al. 2000). Here are described and analyzed several dust and sandstorms occurring in the year 1999, according to Gill et al. (2000).

<u>*January 21, 1999*</u>

Large plumes of blowing dust and sand were seen over parts of northern Mexico, southern Arizona/New Mexico, and southwest Texas on 21 January 1999. Several dry lakebeds exist over that semi-arid desert region, which are often the source of sand and dust particulate in high wind events such as this. High Wind Warnings and Blowing Dust Advisories were issued for parts of southwest Texas, where winds were 65-80 km/hr (with gusts of 110-130 km/hr in some mountain passes). Automated surface reports did record reductions in surface visibility, often less than 1.6 km (*Figure 3*). A strong jet streak was rounding the base of a broad trough over the southern Rocky Mountains on this day. NOAA wind profiler data from White Sands, New Mexico showed the strong core of winds (> 50 m/s) between 8-10 km above the surface, and the gradual downward mixing of higher wind speeds during the day.

Figure 3: Comparison of visibility in a city of West Texas before and during a sandstorm on January 21, 1999 (photo credit: T.E. Gill)

<u>*April 8, 1999*</u>

On the late afternoon of April 8, 1999, an intense dust storm was observed over Colorado and Kansas (*Figure 4*). Scientists at NOAA (National Oceanic and Atmospheric Administration) described the storm as follows:

"A powerful storm centered over eastern Nebraska on the evening of April 8 was producing severe thunderstorms in Iowa and Missouri. The storm continued to the east overnight spawning tornadoes in the state of Illinois and Ohio. Notice the light brown area then curves from western Colorado, over Kansas and into the storm's circulation. This is airborne dust that has been carried off the High Plains by strong winds flowing into the storm center. Winds flow counterclockwise and around the low-pressure system and spiral toward the center. Evidently, on the afternoon of April 8, 1999, there was a

sudden burst of high surface velocity in Colorado and Kansas. At the peak where the dust is observed, the friction velocity exceeded 50 m/s."

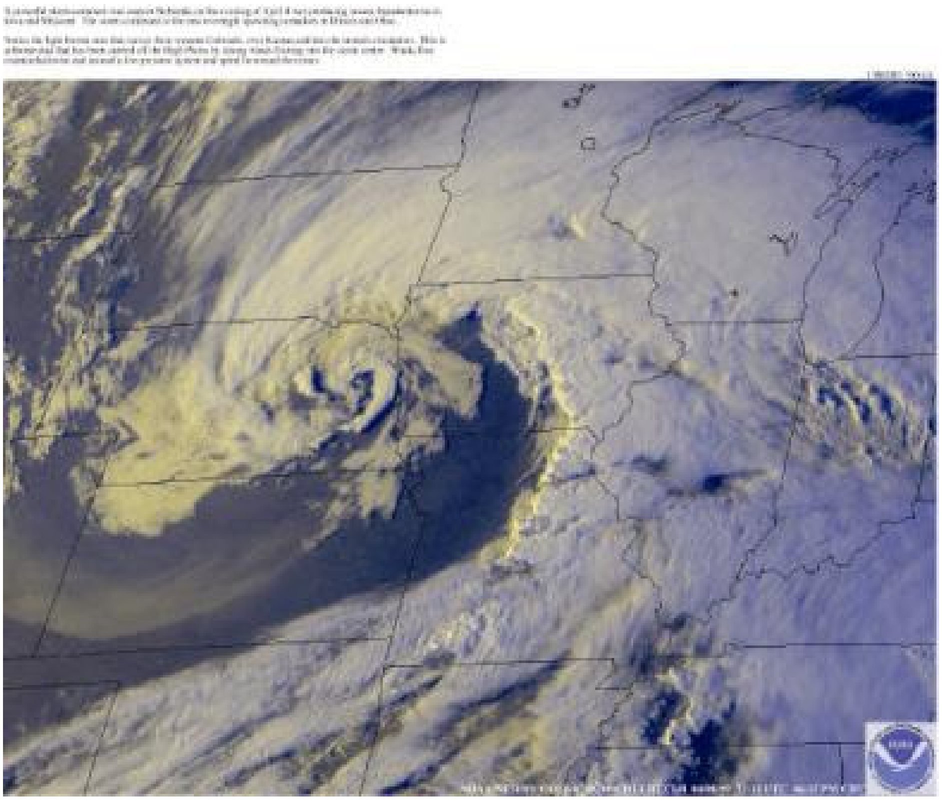

Figure 4: AVHRR satellite image of the brown dust cloud over Colorado and Kansas on April 18, 1999 (photo credit: NOAA)

<u>*April 14, 1999*</u>

On April 14, 1999, another intense dust storm took place in western Texas and southeast New Mexico (*Figure 5*). First the start of a dust storm was observed over the White Sands to the west, but dust plumes were building to the west, partially obscuring the view of the San Andres Range across the basin. During the day of April 14, 1999, a very strong low-pressure system crossed the base of the Texas Panhandle into Oklahoma. High winds blowing counterclockwise around the back side of this cyclone began in the late morning and were sustained at high velocities throughout the day, due to the extremely strong pressure gradient. Lubbock, a northwestern city of Texas, had sustained wind velocities of approximately 60 km/hr for over 6 hours, with gusts as high as 100 km/hr. A 105-km/hr gust was recorded at 4:57 PM at the Texas Tech University weather station. Widespread but relatively minor wind damage occurred in the city of Lubbock and in several other cities of west Texas.

Many sites in west and central Texas and extreme southeast New Mexico reported blowing dust on the evening of April 14^{th}. *"Dust"* or *"Haze"* was reported by weather stations within an area bounded roughly by Hobbs, NM: Junction, TX: Killeen, TX: Abilene, TX: Childress, TX: Lubbock, TX. Sites north and west of this polygon generally experienced some precipitation, which may have inhibited significant dust entrainment. The source area of this dust was probably closest to Lubbock. As the clouds cleared, dust became visible on satellite imagery.

<u>*May 4-5, 1999*</u>

The dust storms of 4-5 May 1999 comprised the largest dust outbreak from western Texas in perhaps a decade or more. Dust was produced from western Texas and New Mexico and deposited at least as far away as Iowa and Illinois (*Figure 6*). On the afternoon of May 4 1999, a very large strong low-pressure system was slowly moving NE out of Oklahoma, where the day before it was responsible for one of North America's most devastating tornado outbreaks. High winds blowing counterclockwise around the back side of this cyclone began in western Texas and eastern New Mexico during the late morning and were sustained at high velocities throughout the day, due to the extremely strong pressure gradient. Winds were sustained at approximately 64 km/hr or more, gusting to over 80.5 km/hr through the afternoon into early evening over a large area of west Texas and southern and eastern New Mexico.

Figure 5: Wind and dust storm in West Texas and Southeast New Mexico on April 14, 1999 (photo credit: T.E. Gill)

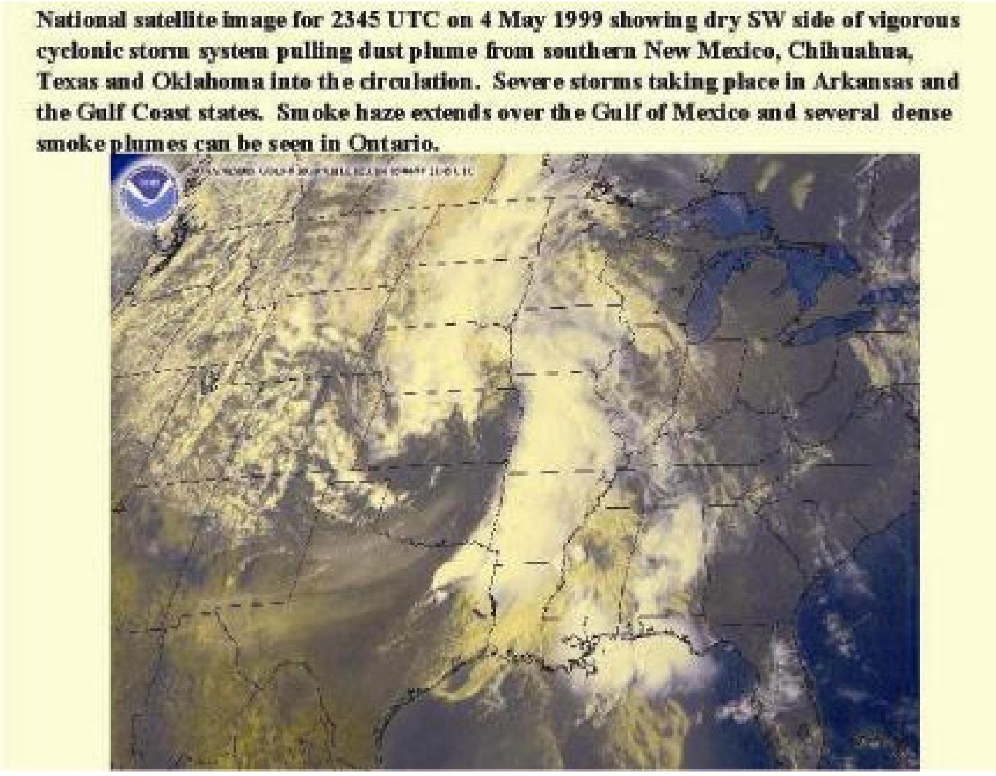

Figure 6: Satellite image of a sandstorm over southern New Mexico, Chihuahua, Texas and Oklahoma on May 4, 1999 (photo credit: NOAA)

Soil particles were lofted into the unstable atmosphere over a large area, which led to a dusty haze reducing visibility over much of Texas and Oklahoma. By late afternoon, visibility in downtown Lubbock, Texas was near zero in blowing dust. Dust was reported in surface weather observations as far east as Fort Sill, Oklahoma. Two discrete bands of mineral dust could be observed on satellite imagery (both visible and infrared). One extended across northern Chihuahua, Mexico and southern New Mexico south and east of Deming, across El Paso and the Permian Basin of Texas as far east as the eastern edge of the Edwards Plateau. The other source area was over the Southern High Plains from approximately Hobbs and Clovis, New Mexico towards Lubbock and Childress, Texas, arcing northeast into Oklahoma.

Dust was transported long distances in significant quantities from this event. The Dallas-Fort Worth area was put under an air quality alert due in part to particulate matter from the Southern High Plains, which coated vehicles in the Dallas area overnight from the 4th to the 5th of May. There were wire-service reports of reddish-brown dust covering automobiles in southeastern Iowa on the 6th of May, and anecdotal reports of dustfalls as far northeast as Michigan. Additional erosion and re-suspension of previously deposited dust took place on the afternoon of May 6, when winds gusted to 20 m/s at Lubbock International Airport and 27 m/s at Texas Tech University, Lubbock.

Sept. 25, 1999

On September 25, 1999, dust storms that brewed up at 10:20 am from the winds of an approaching cold front caused several chain reaction wrecks on highways in Oregon that killed 6 and sent dozens to the hospital. A blinding dust storm (*Figure 7*) triggered one of Oregon's deadliest strings of highway pileups in recent history. At least three accidents involving 50 vehicles killed six people and injured 23 others along a four-mile stretch of Interstate 84 between Hermiston and Pendleton, Oregon. More multiple-vehicle pileups on three highways in Eastern Oregon and Washington sent scores of others to hospitals as wind gusts of up to 136 km/hr blew all day across dry, tilled wheat fields and sagebrush desert. Another apparent chain reaction involving 5 trucks and 11 other vehicles happened in I-84's eastbound lane near mile-marker 198, taking four lives and resulting in injuries to many others.

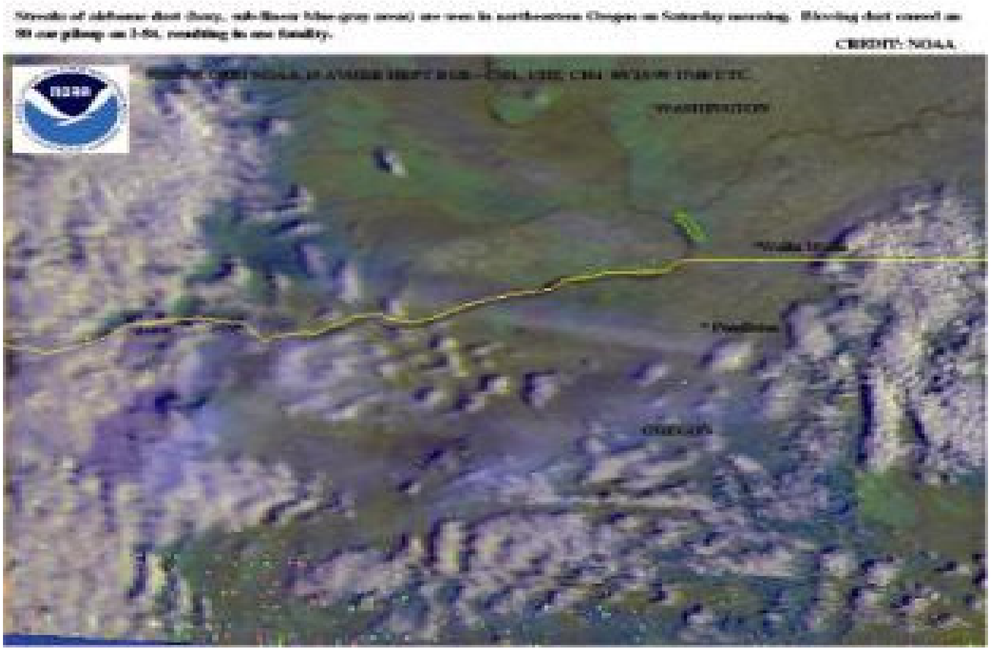

Figure 7: Streaks of airborne dust (hazy, sub-linear blue gray areas) were seen in northeastern Oregon on September 25, 1999 (photo credit: NOAA)

3. CAUSES OF DUST AND SANDSTORMS IN THE US

Many factors cause dust and sandstorms. In the US, the most important causes of dust and sandstorms include the misuse of land, prolonged drought and special soil properties in the Great Plains.

3.1. Misuse of land

Poor agricultural practices and years of sustained drought caused the Dust Bowl. Although dry spells are unavoidable in the Great Plains of the US, occurring roughly every 25 years (Warrick et al. 1975; Warrick 1980), it was the combination of drought and the misuse of land that led to the incredible devastation of the Dust Bowl years. Originally covered with grasses that held the fine soil in place, the land of the southern plains was plowed by settlers who brought their farming techniques with them when they homesteaded the area (Hurt 1981; Svolida 1986). Wheat crops, in high demand during World War I, exhausted the topsoil. Overgrazing by cattle and sheep herds stripped the western plains of their cover. When the drought hit, the land just blew away in the wind.

The Plains grasslands had been deeply plowed and planted to wheat. During the years when there was adequate rainfall, the land produced bountiful crops. However, as the droughts of the early 1930s deepened, the farmers kept plowing and planting and nothing would grow. The ground cover that held the soil in place was gone. The Plains winds whipped across the fields raising billowing clouds of dust to the sky. The sky could darken for days, and even the most well-sealed homes could have a thick layer of dust on furniture. In some places the dust would drift like snow, covering farmsteads.

3.2. Prolonged drought

Drought is another factor responsible for the Dust Bowl during the 1930s (*Figure 8*). The drought hit first in the eastern part of the country in 1930. In 1931, it moved toward the west. By 1934 it had turned the Great Plains into a desert. *"If you would like to have your heart broken, just come out here,"* wrote Ernie Pyle, a reporter in Kansas, just north of the Oklahoma border, in June of 1936. *"This is the dust-storm country. It is the saddest land I have ever seen."*

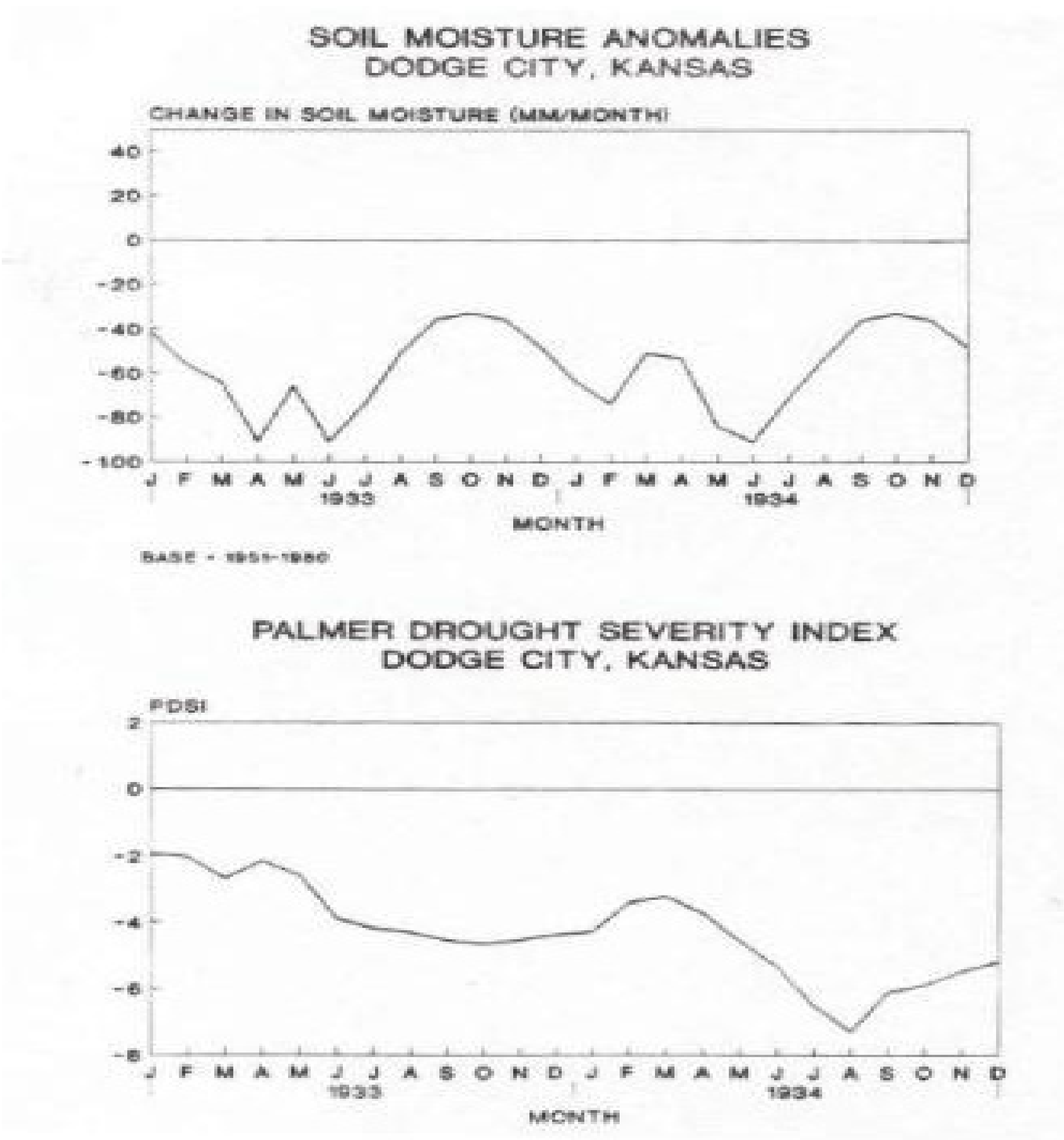

Figure 8: Difference in soil moisture and Palmer Drought Severity Index (PDSI) during 1933-34 from the mean values during 1951-80 for Dodge City, Kansas (after Rosenzweig and Hillel, 1993)

In the 20th century, records of rainfall and reports of blowing dust suggested a roughly twenty-year cycle, with the odd decades dry and dusty and the even decades wetter and not as dusty (Warrick et al. 1975; Warrick 1980). The 1990s did not show a return to the presumed cycle. Strong El Nino events, improved land management practices and soil conservation programmes apparently combined to keep the overall prevalence of dust storms in the Southern High Plains of the US well below the extent of those in the earlier dusty decades (Gill et al. 2000).

A recent study indicates that the climate over the last two thousand years in the Great Plains area of North America may have featured many periods like the Dust Bowl drought period that afflicted North America in the 1930s (Laird et al. 1996). The area had periodically suffered droughts longer and more intense than the 1930s Dust Bowl Era. Droughts of greater intensity than the one that caused the *"Dust Bowl"* of the 1930s were more frequent before AD 1200. Increased severity and frequency of droughts is one possible consequence of future increases in atmospheric CO_2 concentrations, and a return to the climate variability seen before AD 1200 in this region of North America would have devastating consequences. Thus, we might expect an increase in frequency of sand and dust storms in the US as atmospheric CO_2 concentrations continue to rise.

3.3. Soil properties

In the Great Plains of the US, a combination of natural processes and conditions makes the landscape vulnerable to wind erosion with accompanying dust storms. Deposition of new sediments from infrequent but inevitable floods, combined with lack of vegetation cover and seasonally high winds, yield conditions ripe for dust generation. For many thousands of years, such eolian (wind-borne) dust has been emitted from desert areas to be deposited in nearby desert soils perhaps as much as thousands of kilometers away. The presence of eolian dust in desert soils thus renders them extremely vulnerable to future wind erosion, under climatic change or human disturbance, if vegetation dies or if the protective, stabilizing desert skin is removed.

For example, dust storms are often generated in the White Sands region of New Mexico, and can affect the city of Alamogordo, located just southeast of the White Sands (Gill et al. 2000). Some major dust events can transport mineral aerosol out of the basin, usually towards the northeast. The White Sands are an unusual, thick sedimentary layer of gypsum (CaSO4) sand which covers the basin of former Lake Lucero, in the Tularosa Basin between the Sacramento and San Andres mountain ranges, south-central New Mexico. It is considered one of the largest gypsum dune fields on Earth. The bright white sands are an easy landmark to pick out on satellite images. On the ground, they are sculpted into a myriad of dynamic dune forms in the White Sands National Monument. High winds can cause the shifting White Sands to become a prodigious source of fine dust aerosols.

4. REMEDIES FOR COMBATING DUST AND SANDSTORMS IN THE US

In the early years of the 1930s, the extent of the damage inflicted upon the southern Great Plains by drought and dust storms was little noticed outside the region. The nation, led by its newly elected president, Franklin D. Roosevelt, was desperately trying to pry itself loose from the grip of the Great Depression. The plight of a band of usually well-off farmers was beyond the immediate concern of most citizens.

Certain individuals within the Roosevelt administration however, had realized that the lot of the average American was closely tied to that of Dust Bowl farmers. Hugh Hammond Bennett, who was known as *"the father of soil conservation"* in the US, had been leading a campaign to reform farming practices with the intention of preserving the soil well before Roosevelt became president. In the mid-1930s, desperate Dust Bowl farmers took little solace in hearing from Bennett that *"...Americans have been the greatest destroyers of land of any race or people, barbaric or civilized."* Further, he went on to call for *"a tremendous national awakening to the need for action in bettering our agricultural practices."* Despite such statements, Bennett was not insensitive to hardships faced by Dust Bowl farmers. Rather, he urged a new approach to farming in order to avoid similar catastrophes in the future.

In April 1935, Bennett was on his way to testify before a congressional committee when he learned of a dust storm blowing in from the western plains. At last, he would be able to present tangible evidence of the results of shortsighted farming practices. As a dusty gloom settled over the nation's capital and blotted out the midday sun, Bennett exclaimed, *"This, gentlemen, is what I have been talking about."* Congress responded by passing the Soil Conservation Act of 1935. In turn, the Roosevelt administration put its full weight and authority behind improving farming techniques.

Convincing farmers to approach the land in a new manner would take much effort and a bit of old-fashioned bribery. The federal government paid out USD $1 per acre to farmers employing planting and plowing methods aimed at conserving the soil. In 1933, the government, under the Agricultural Adjustment Administration, had begun to pay farmers to reduce their production of surplus crops, such as wheat. Proud and defiant as they were, many farmers nonetheless found themselves accepting the government's offer. From 1933-37 such payments provided many Dust Bowl farmers with their only source of income.

An array of New Deal programmes and organizations was devised to meet the needs of Dust Bowl residents: the Federal Emergency Relief Administration, the Federal Surplus Relief Corporation, the Works Progress Administration, the Civilian Conservation Corps, and the Drought Relief Service, which purchased cattle from destitute farmers. The cattle, poorly nourished and often sickly, were nearly all immediately destroyed. Most Dust Bowl farmers were immensely appreciative of Roosevelt and his New Deal programmes. For many, only infusions of federal aid made it possible for them to wait out the blistering years of drought and dust. When the rains finally came at the tail end of the decade and the Southern Plains once again yielded a bountiful harvest, the relationship between the farmer and the federal government remained entwined. Henceforth, a complex and sometimes controversial system of price supports and subsidies emerged to form the backbone of federal farm policy.

Beginning in 1935, federal conservation programmes were created to rehabilitate the Dust Bowl, changing the basic farming methods of the region by seeding areas with grass, rotating crops, and using contour plowing, strip plowing, and planting *"shelter belts"* of trees to break the wind. Farmers were defensive when outsiders criticized their farming methods. Only when they were paid did they begin to put the new farming techniques into practice. The dollar per acre they earned often meant the difference between being able to stay a bit longer or having to abandon their land.

Of all of Roosevelt's New Deal programmes, the Works Progress Administration (WPA) was the most famous, because it affected so many people's lives. Roosevelt's vision of a work-relief programme employed more than 8.5 million people. For an average salary of USD $41.57 a month, WPA employees built bridges, roads, public buildings, public parks and airports. The Civil Conservation Corps (CCC) was another one of the most successful programmes of the New Deal's remedies. It addressed the pressing problem of unemployment by sending 3 million single men from ages 17-23 to the nations' forests to work. Living in camps in the forests, the men dug ditches, built reservoirs and planted trees. The men, all volunteers, were paid USD $30 a month, with two thirds being sent home. The Works Progress Administration (WPA), Roosevelt's major work relief programme, would employ more than 8.5 million people to build bridges, roads, public buildings, parks and airports.

5. CONCLUSIONS

Sand and dust storms were serious in the southern part of the United States, especially during the 1930s. These storms caused serious economic and ecological losses to US people.

Misuse of land (destructive farming, overgrazing by cattle and sheep, etc.) prolonged droughts and special soil properties of the Southern Plains region were the major causes of the sand and dust storms in US. Active remedies, such as better farming approaches, intensive plantings of windbreak plants and governmental subsidies for farmers when necessary, effectively decreased the outbreak frequency of sand and dust storms in the 1930s. More recently, strong El Nino events improved land management practices and soil conservation programmes apparently combined to keep the overall prevalence of dust storms in the Great Plains well below the extent of those in the earlier dusty decades.

6. REFERENCES

Bonnefield, P. 1979. *"The Dust Bowl: Men, Dirt, and Depression."* University of New Mexico Press.

Ci, L. J. 1997. *Land Evaluation and Expert System for Combating Desertification*. China Forestry Publishing House, Beijing. 201.

Gill, T.E., Westphal, D.L., Stephens, G., and Peterson, R.E., 2000. *Integrated assessment of regional dust transport from west Texas and New Mexico, spring 1999*. Preprints of the 11th Joint Conference on Applications of Air Pollution Meteorology with the Air and Waste Management Association, American Meteorological Society, Boston, MA, pp. 370- 375.

Howarth, W. 1984. *"The Okies: Beyond the Dust Bowl."* National Geographic 166, 1984.

Hurt, R. D. 1981. *"The Dust Bowl: An Agricultural and Social History."* Nelson-Hall, Inc.

Laird, K. R., et al., 1996. *Nature*. 384:552-554.

Lee, J.A., Gill, T.E., and Mulligan, K.R., 1999. *The 1930s Dust Bowl: The Relative Roles of People and the Physical Environment*. Geological Society of America Abstracts and Programmes 31(1): A11.

Rosenzweig, C. and Hillel, D. 1993. *The Dust Bowl of the 1930s: analogue of greenhouse effect in the Great Plains?* Journal of Environmental Quality, 22: 9-22.

Svobida, L. 1986. *"Farming the Dust Bowl: A First-Hand Account from Kansas."* University Press of Kansas.

Wang, L. X. 1994. *Combating desertification in China*. China Forestry Publishing House, Beijing, pp. 408.

Warrick, R. A. 1980. *Drought in the Great Plains: A Case Study of Research on Climate and Society in the US*. In IIASA Proceedings Series: Climate Constraints and Human Activities, ed. Jesse Ausubel and Asit K. Biswas. Permagon Press: New York.

Warrick, R. A., Trainer, R. B., Baker, E. J., and Brinkman B. 1975. *Drought Hazard in the United States: A Research Assessment. Programme on Technology, Environment and Man*; Monograph #NSF-RA-E-75-004, the University of Colorado.

Worster, Donald. *"Dust Bowl: The Southern Plains in the 1930s."* Oxford University Press, 1979.

Zhu, Z. D. and Chen, G. T. 1994. *Land sandification and desertification in China*. China Academic Press, Beijing, pp. 250.

Part III

Case studies of sand-dust storms in Africa and Australia

A case study approach is used to explore the nature, extent and impacts of sand-dust storms on people and property in two contrasting economies.

Australia, a sparsely populated industrialized nation occupying a large continent where desertification is not so serious, represents one end of the spectrum among the more than 170 signatories to the UNCCD.

By contrast, Mali, a developing country in sub-Saharan Africa, has a small population, scarce resources, poor infrastructure and a lack of institutional capacity to cope with the serious impacts of desertification, including sand-dust storms. Its experience is typical of many less-developed countries in Africa that are facing serious challenges to combat desertification, alleviate poverty and fight the scourge of sand and dust. The interactions between natural and human-induced factors in causing desertification and sand-dust storms are explored in these two articles.

Chapter Six

SAND AND DUST STORMS IN THE SAHELIAN REGION OF AFRICA – CONSEQUENCES AND ACCELERATION CAUSED BY HUMAN FACTORS

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Key words: Africa, land degradation, nomadic, human factors, dust particles, Mali, Sahelian, herders, cereals, restoration, livestock, steppe, woodland, conservation, natural resources, agriculture, cultivation

SYNOPSIS

The African Continent is one of the regions most severely affected by drought and desertification in the world today. Of course, the author does not agree with the opinion some people hold that "Africa is a land of hopelessness" or "severe danger is in front of Africa." On the contrary, the author[7] *holds an optimistic view of the Sahelian Region in Africa. It does not matter how serious desertification develops in the region or even if land degradation will further be enlarged in some parts of Africa; there is a high potential for development. This article aims to describe the manifestations of desertification, including dust storms, through a review of known facts. The main objective of this article, and indeed the entire book, is to focus on generating wider concern and to drawing attention to this particular issue. Therefore, the author attempts to stress the close relationship between sand-dust storms and land desertification.*

KEY POINTS

1. *Sand and dust storms are most commonly the consequences of human activities that leave the soil surface bare of vegetation.*
2. *The richness and/or scarcity of sand material (sources of sand-dust storms) are closely related to soil conditions on land surfaces.*
3. *The immediate cause of desertification and the devastating African famine was the consequence of drought. However, the root cause is the misuse of land-use, deforestation and irrational agricultural policies over past decades.*
4. *Desertification in Africa was not only an ecological calamity, but also caused social disasters.*

[7] The author has worked in Mali-Sahelian region with a UNDP Chinese Expert mission. This article is written on the basis of interviews with local experts, administrators and citizens that he saw, and heard. The opinions represent those of the author himself. Information, data and local stories, including economic statistics and livelihood, are perhaps out of date. The photographs in the article were taken in 1988. Images at the same sites perhaps have been completely changed.

5. *Poverty is one of the key factors causing desertification and poverty forces farmers and herders to give up their traditional cultivation and herding systems*
6. *Measures aimed at controlling sand-dust storms and combating desertification, namely "what and how should we do it?" are not aimed at controlling sand-dust storms itself, but are aimed at wiping out the social causes of land desertification and establishing a national functioning system to fight desertification. This ideal long-term objective should be gradually realized in the future.*

1. INTRODUCTION

1.1. Sand-dust storms in Africa, wind regime, phenomena of sand-dust storms, transport and deposition of dust particles

Sand and dust storms are a visible natural process on the African Continent. The vast areas and distribution and extent of the desert landscape, including the Sahara Desert, indicate that this region is the very source of material for sand and dust storms in historical time. There is considerable anecdotal evidence concerning the severity of such storms (*Box 1*).

Box 1: Some anecdotal accounts of severe African sand and dust storms

Cloudsley Thompson of London University, in his book *"Sahara Desert"* described one sand-dust storm he experienced during the 1940s in Libya and recalled that the light of a torch was invisible beyond three steps. In the morning of one summer day in 1969, he and his wife traveled by jeep into the centre of the Sahara Desert, and they had to switch on the car lights during the daytime. There was no dust on the surface, but dust clouds shadowed all the sky (Sahara Desert, 1990).

As facts show, such wind-sand-dust disasters happen frequently on the African Continent. Powerful wind is the dynamic force causing sand-dust storms. At the southern fringe of the Sahara Desert, a special dry and hot wind, locally termed *Harmatta*, brings impacts to Mali and other countries in the Sahelian region. These NE or E winds normally occur in the winter season under a high atmospheric pressure system. When the wind force of Harmatta is beyond the threshold value (*see Chapter 1*) sand particles and dust particles will be blown away from the land surface and transported for several hundreds kilometres to the Atlantic Ocean. People often report sand particles and dust particles falling aboard ships in the Atlantic Ocean. Sand-dust storms have even stopped air flights crossing the affected region. Travelers aboard both ships and planes could observe clearly the overlap between the blue sky and dark dust clouds as the dust storm rolled out of Africa.

At the northern fringe of the Sahara Desert, strong windy weather often occurs in the winter and spring seasons. This wind is locally termed *Hamson*. When a low-pressure system occurs in the north of the Sahara Desert or above the Mediterranean, the turbulence takes place from west to the east. Strong winds will transport *"hot sand particles and dust particles"* from the Sahara Desert to the Mediterranean coasts and the delta of the Nile. This wind can blow for 50 days without stopping and reduce visibility to a few metres. It is locally termed *"Wind Hilleck"* in Algeria or *"Sirocco"* in southern Europe.

In Sudan, the strong wind is locally called *Haboob*. It was reported that the wet-warm strong winds in the Northern Sudano, at the southern fringe of the Sahara Desert, normally associated with sand-dust storm and thunder can last, on average, three hours and can flatten sand dunes and accumulate new barchan dunes. Haboob dust winds often appear in the summer season and movement direction is unstable. The air mass moves like a thick wall in a height of several hundreds metres. Haboob windstorms sometimes originated from the Northern Sahara Desert and are related to the lower atmospheric pressure in the Mediterranean. It blows with dense contents of sands and dusts (*Photo 1*).

Photo 1: Sand and dust storms plague cities

Sand-dust storms are closely related to human activities. The military disasters from 1940-43 caused the rapid increase of frequencies of sand-dust storms in the Nile Delta region. During the Second World War, vast areas in North Africa have been the sites of military battles and huge amounts of tanks, vehicles and fighting forces have trampled the fragile desert land surface. As a consequence, the sand surface was exposed without any protection of vegetation or biological crusts and fine sand/dust materials were formed. Sand-dust storms in this region are clearly one of the direct results of military activity.

1.2. Dust storms and dust devils

Dust events are also a common phenomenon in Africa. There are two broad categories: those associated with winds and those that rely on the heat transfer from the soil surface to generate an updraft. In the desert areas in Mali, Chad, Niger and Sudano in the Sahelian Region, one can sometimes observe strong wind in a conical formation. This is related to the tropical climatic turbulence in a restricted area. In Western Africa, this wind cone is locally termed *Tornado*. Tornadoes sometimes occur individually and sometimes appear in groups. The general diameter of tornadoes varies from several metres to several tens of metres and height varies from less than a hundred metres to less than a thousands metres. Tornadoes can disappear within minutes and can move only a short distance, but their force is powerful, velocity is high, direction is unstable and suspension is non-oriented. Tornadoes moves around in an anti-clockwise direction. Local people describe this tornado as *" wind comes along the sunrise"* (*Photo 2*).

Photo 2: Tornado

Dust devils, locally called *El-Bris*, often occur during the daytime without any winds because of the sudden raising of heated air currents. This wind blows sand- and dust and uplifts weathered plants (litter) from one place to another.

Dust devils are mostly caused by the interaction of uneven heat effects on surface and strong air circulation (*see Chapter 9*). This kind of dust bowl moves over a small area and usually disappears quickly. At a visible height, the dust devil is shaped as an elongated cone.

2. REASONS FOR CONCERN ABOUT SAND-DUST STORMS (THE RELATIONSHIP BETWEEN LAND DESERTIFICATION IN THE SAHELIAN REGION AND SAND-DUST STORMS)

We aim to comprehend not only natural factors, including environmental conditions causing sand-dust storms, but also to understand how human economic activities have accelerated this process.

The ecological disaster that took place in the 1970s in the Sudano-Sahelian region was one of the most harmful calamities of the last century, excepting the two World Wars. It was estimated that hundreds of thousands of people died and nearly half of the entire livestock herds and two million heads of wild animals were killed due to the severe droughts and land desertification at the southern edge of the Sahara Desert. More than six million ecological refugees were forced to emigrate from their homeland to other regions. The whole world was shocked by these disastrous events, and as consequence, the United National Conference on Desertification (UNCD) was sponsored in Nairobi in 1977.[8]

Desertification in Africa caused not only ecological calamity, but also social disasters. Droughts and land desertification have brought more social issues than we can imagine. Theoretical *"academic research"* and concentration on technical solutions are not enough. Integrated methodologies have to be utilized to investigate the issue. More attention has to be paid to what kind of approaches can be practiced and what real actions can be implemented while developing the optimum strategy and approaches to control land degradation. The application of science and technology, know-how and application of rehabilitation techniques is one of the key measures.

3. A CASE STUDY OF THE DESERTIFICATION PRONE DISTRICTS OF MALI

It was reported that the population growth rate in Africa was 3% per year (the population growth in Mali was 1% before 1914; 1.4% from 1928-59; 2.3% from 1960-78 (UN Population and Vital Statistics Report, 1979). According to the census of population in 1976 and 1987, the average population growth rate in Mali at that time was 1.7%.

Population growth and food security are intimately linked. In the 25 communities where we worked the food guarantee was less than 300 days (the FAO's requirement standard is 224 kg per man per year). There were only four communities that had 60 to 120 days food supply and thirteen communities had food supply for 60 days only or less.

It was found that there was a phenomenon of negative growth of population in 50 counties in Mali. Some villages, for example, such as Agamor Village, saw almost all the men and younger people immigrated and some even some fled to Algeria and Libya as ecological refugees. These immigrants were mostly out-of-work labourers who suffered considerable anguish. Some were reduced to committing crime. Consequently, serious social and political issues were a result. Therefore, only women, children and elders were kept in the village. In Sukenuo County and Napala County of Nioro Community, some villages were almost empty of population. It is difficult to explain our moods and feelings when we entered these less populated or empty villages. We were deeply impressed by the sad images of infertile soil and desertified lands around these villages. An analysis of precipitation in the Sahelian region showed that the phenomena of drought (such as in the 1970s) occurred four times in the 20th century (1910-15; 1940-44; 1968-74; and 1979-?) Meteorological data of weather stations at Tombouctou, Kayes, Gao, Kidal and Nioro (up to 1987) were used in our analysis. The first two droughts in the first half of the century did not cause serious social disasters. However, the latter two droughts have led to severe land degradation and desertification. The African famine is a consequence of drought. However, the root cause is the misuse of land-use, deforestation and irrational agricultural policies of the past decades.

[8] Before the expert mission came to Mali, one Chinese expert mission was entrusted by UNEP to survey the issue of land desertification in Ethiopia and Tanzania from December 1985 to January 1986. A great amount of information, literature and research papers on droughts and ecological disasters that took place in the Sudan-Sahelian region in the period from 1972-74 and in 1984 have been referenced.

Egyptian desert researcher, Prof. Kassas has said that *"land desertification was caused by three main factors: over-cultivation without traditional fallow systems, over-grazing and salinization caused by irrational irrigation systems."* Poverty is one of the key factors causing desertification and poverty forces farmers to give up their traditional cultivation and herding systems.

In the Sahelian region, areas with 400 mm of rainfall are regarded as appropriate areas for dry farming and these areas can be defined as the marginal areas. Local traditional shifting cultivation that has a history of thousands of years characterizes the dry farming on the marginal area. Abandonment systems of dry farming, swidden cultivation, spot cultivation, rotation cultivation, or shifting cultivation are all nearly the same term of this traditional cultivation system.

In the whole Sahelian region, privately owned small pieces of crop cultivation comprise the agricultural sub-sector. There are a few state-owned farms with an irrigation system. *Sorghum* and *Panicum,* traditional aboriginal crops of Africa and key foodstuff of the continent, are the main crops, which they harvest only once a year. There were some cases where local people sold their farming produce, but mostly the harvest is used for subsistence. On the perimeter of their fields, local farmers ploughed woodlands or grassland. These *"wastelands"* are in fact groves or savanna and some are even rangeland with high quality grasses. Trees, bushes and grasses were deforested with fires. They open and flatten the field with primitive farm tools and turn over the soil with a plough (it was estimated that there was only one plough for 12 ha of cropland in 1977).

Weeds are the main problems on newly cultivated fields and three to four times of weed cutting is needed. However, some farmers harvested crops together with weeds, as they did not cut weeds at any time during the growing season. Because of lack of input (2-4 kg of fertilizer per ha.), productivity and output of these newly cultivated fields is very low. After two to five years, along with reduction of soil fertility and unvarying practice of such a land-use pattern, farmers abandoned them and searched for new fields to open. These abandoned fields can be naturally revegetated in about 20 years. In these regions, the rate of abandonment of fields and field cultivation is 1:4 up to 1:5 times. In the 1930s and 1940s, farmers of Mali cultivated only one fifth of their dry-farming fields. In the 1960s, the duration of abandonment of field cultivation was reduced to ten years and even in some areas declined to five years due to the burgeoning population and lack of arable land. This shortening of the fallow period has led to a rapid decline in soil fertility.

With this rough cultivation system, the output from 1.2 million ha of *Sorghum* and *Panicum* from 1954-56 was 700,000 tons and the average yield was 583 kg per ha. In 1974, the mean yield of *Sorghum* and *Panicum* was only 480 kg per ha (calculated on the basis of data from FAO Production Yearbook, Rome, 1970, 1980). Yet the productivity of these crops in the Mali-Sahelian region was 30-45% lower than the mean unit yield of the whole country. It is evident that the productive efficiency is this low in the country.

In the marginal land areas, remarkable examples of wind deflation can be seen clearly if you search carefully. After sand-dust storms, the ploughed dry-farming lands were eroded and cultivated topsoil was blown out and transported away. In the marginal land areas where precipitation is 400 mm, wastelands caused by sand-dust storms are widely distributed. There is in fact a record of misuse of land resources in past decades. We witnessed vast areas of deflated dry-farming lands in the Sahelian region. Some deserted villages are mostly located on the north and south sides of the isohyet of 400 mm of precipitation.

4. CLIMATIC EFFECTS – DROUGHT FREQUENCY AND SEVERITY

As in Western Africa, annual precipitation in the Sahelian region increases gradually towards the south at a rate of 1 mm of rainfall/km. The rainy season lasts July-September, but rainfall variability is high (*Table 1*). In comparison with rainfall in the late 1920s, the annual rainfall in 1984 was 300 mm lower.

Table 1: Variation in the annual precipitation in the Nala districts of Mali in selected periods

Year	Rainfall (mm)
1932	600.7
1933	766.3
1934	644.7
1935	755.3
1936	699.6
1949	681.4
1962	648.0
1979	290.5
1980	294.3
1983	276.1
1984	198.7

The 400-mm rainfall isohyet moves back and forth in a south-north direction. It was recorded that the isohyet has moved southwards 200-350 km in 1913. The isohyet has moved northwards from 1945-68 and farmers of such dry farming have moved northwards and settled there. In the 1970s, the isohyet has moved southwards again and farmers were not able to immigrate southwards, as they disliked abandoning these virgin lands they had opened and cultivated for two decades.

The northward immigrants of dry-farming farmers have also forced the herdsmen to move northwards. For instance, from the 1940s to 1950s, Fuerbe tribes in Niger-Sahelian never moved beyond the line of 15 degrees North latitude. According to the population census in 1963, there were 18,000 Fuerbe farmers in the Tawa District and 25,000 Fuerbe farmers in the Agadez district (18 degrees North Latitude). Fuerbe Tribes moved northwards 200 km from the southern part over the last 30 years.

Crop cultivation (particularly the rough system of extensive cultivation with low yield) in the areas with less than 400 mm of rainfall, contributed to wind erosion on a large scale. Without rainfall, the ploughed fields can be exposed and can easily be eroded when wind forces causing sand-dust storms prevail; thus farmers will have zero harvest from their cultivation. During the last 30 years, the isohyet line of rainfall moved 100 km southward from the north (*Figure 2: Change of isohyet of 400 mm of rainfall from 1951-84*) and dry-farming production among this strip area has been heavily reduced.

Some scientists have calculated total productivity of cereals (*Panicum, Sorghum* and Maize) in the Kal and Yelimanel districts (*Table 2*). On the one hand, these data indicate a severe impact of drought on cereal production. On the other hand, these data show that productivity has not regained its previous level, even in later years with higher rainfall.

Table 2: Total production of cereals *(Panicum, Sorghum* and Maize) in the Kal and Yelimanel districts of Mali

Year	Yields (millions of tons)
1970-71	402.25
1972-73	8.79
1973-76	25 (approx.).
1979-80	25 (approx.)
1980-81	28.16
1981-82	19.38
1982-83	23.05
1984-87	27-32 (approx.)

5. AFRICAN HERDERS AND THEIR ROLE IN DESERTIFICATION

Half of the total herdsmen of the entire world live in Africa, and animal husbandry is the main agricultural practice in the Sahelian region. Animal populations are higher than the human population. In the Sahelian region, the possession of livestock (mainly sheep, goats and cattle) is a sign of wealth and degree of social status and, of course, animal husbandry is the herdsmen's source of livelihood.

Nomadic grazing was once a traditional animal breeding practice that fed animals on the one hand and still maintained rangeland on the other hand. In its traditional form it preserved grazing land. It was based on ecological principles and was an optimum practice to use natural resources in a sustainable manner. Nomadic grazing is a method to breed and multiply animals in a definite circumstance of time and space on the basis of natural resources, such as plants, water and minerals. This method caters and fits the repeated instability of nature. Nomads always head to where there is rich water and grasses and depart in time where there are insufficient resources. Because of its dynamic advantage, nomadic grazing plays a great role in ecological benefit in the long practice of livestock breeding. Nomadic grazing gets along with the environment, resources and utilization under certain conditions. In the past, vegetative cover on the previous migration route was better than in other locations. The development of a traditional nomadic grazing system was mainly determined by local natural and ecological conditions. On the vast desert steppe, temporal and spatial change of water supplies and grass growth and other natural resources can only be fully utilized when animals travel far away.

5.1. Knowledge of migration routes

The migration route is not a simple passenger corridor; it is in fact a grazing field. There are periodic migrations of animals and they are grazing/browsing while travelling. The feed intake and quantity is determined by the moving speed on the migration route. Water supplies, quality of grasses on the migration route and health conditions of the animals are key factors for herdsmen who control the migrating speed of animals. The degree of vegetation destruction on the migration route is directly related to the size of the transiting animal population and the migrating speed.

When the animal population on the traditional migration routes rapidly increased, intensive grazing and dense trampling loosened the stability of the land surface and destroyed the vegetative coverage, causing severe soil erosion. The migration route was desertified and sand-dust storms became frequent and the grazing land lost its productivity, finally becoming just a path.

While we were interpreting satellite images, we noticed many wriggly and tortuous strips on the image of the rangeland. These strips were identified as severely desertified areas without vegetation protection. We compared the vegetation degradation with the migration route desertification in the northwest of Suokeluo on the SPOT image and briefly graphed the following: *Photo 6*.

The northwest oriented animal-migration route in Suokeluo in *Figure 3* is the migration route to come and go to Mauritania and the Delta of the Niger River. On this 10-km wide migration route, the annual animal immigrant was around 380,000 UBT[9] during recent years. Such a great number of livestock, including 300,000 heads of cattle from Mali and 60,000 heads of sheep and goats from Mauritania, travel, bite and trample on this migration route year by year. This unceasing destruction brings damage to the vegetation and soil along the route. The vegetation was degraded and soil surface was disturbed in the central part of the route and became the sand source of sand-dust storms. This is the inevitable consequence of high stocking rates.

Nomadic grazing is a traditional grazing system in Mali. About 10-15% of the total nomadic and semi-nomadic herdsmen posses 70% of the total cattle population and 80% of the total population of sheep and goats. This means that 2.1 million to 3.85 million heads of cattle and 5.6 million to 9.6 million heads of sheep and goats moved along the migration route in the section of Mali during the period of the 1940s to the 1970s.

Nomadic grazing has a long history in Africa and is a traditional animal husbandry practice closely linked with livelihood customs and mode of production of the Bangbala and Moore tribe. In different seasons, herds of animals along the migration route come and go to arid desert steppes, the delta of the Niger River and other strips with water supplies.

Nomadic grazing in Mali moves to the south in the drought season and returns to the north in the rainy season. Animals migrate to the south in January (drier); temperatures are higher in February and animals will be concentrated in the river valley or watershed areas. The hot season comes in March and nomadic herdsmen graze animals in watershed or depression areas and shear the sheep of their wool. In dry April and hot May, animals are concentrated in the Niger River Valley. The Rainy season starts from June and nomadic herdsmen are ready to move northward with their animals. July and August are the rainy season and animals occupy the desert steppes in the north. Rainfall becomes less and less and the dry season comes in September and October, but the desert steppe is still available for nomadic grazing. November and December are drier and comfortable months and animals start to migrate to the south because grazing the quality of desert steppes becomes very low in this season. Nomadic grazing on desert steppes is characterized by free grazing while migrating and this is termed *"dwelling around grass and water."*

Some critics conclude that the ignorance of nomads has caused desertification along the migration route. This is an incorrect conclusion. Nomadic herdsmen have excellent skills and are one part of human wisdom that is worthy of praise. The shepherds, herders and camel herdsmen's wisdom and knowledge personally impressed me. First, they travel thousands of kilometres to accompany hundreds and thousands of livestock. They have no maps, no compass, and some even have no watch with them, but they have high self-confidence and an ability to recognize directions. Their surprising memory and their ability to recognize their own animals (livestock are often mixed at water-drinking spots) help them to find their lost livestock from vast desert steppes even by hearing the sound and observing the animals' foot prints!

[9] UBT is a basic unit of tropical cattle determined by the French Institute of Livestock and Veterinary for the Sahelian region. One UBT is equal to a cattle weight of 250 kg. For 60% of the cattle, horse and camel populations, each animal is equal to one UBT. The rest (and baby animal) is equal to 1/2 UBT; one sheep or one goat is equal to 1/10 UBT; one donkey is equal to 1/2 UBT.

Livestock are living bodies and any animal big or small has minimum requirements. They are fidgety and have a natural wildness. African herdsmen rush from one place to another without a settled location and endure fluctuations of weather from sunrise to sunset. They experience burning sun or drifting sands. African nomads have never enjoyed the free and easy life of pastoral songs, as shown on TV or in the movies. In both dry and rainy seasons, they start work from early morning till night and they know clearly what should do and how they should do it. These herdsmen have long experience that allows them to survive in a harsh environment and they are the witnesses of long-term rangeland degradation. In comparison with researchers, consultants and other strangers, the herdsmen have a better knowledge of the consequences of high carrying capacity on fragile rangelands and over-grazing. Herders accept responsibility for not only hundreds of thousands of animals, but also bear a heavy burden of anxiety about the resource base. Rangeland degradation and unpredictability of drought disasters are the pressures dominating their moods. It is incorrect to criticize the nomadic grazing system, because it is a traditional feeding animal practice with a history of several thousands years.

Except for soil and water conditions, transiting animals have played roles in promoting and strengthening the growth of vegetation. Livestock, particularly animals with hooves, trample the hard crust underfoot in the dry season and loosen the topsoil. Such trampling can improve the ventilation of the soil and bury seeds into the soil (just like hoeing soil and sowing seeds).

Appropriate utilization of fresh branches and leaves gets rid of excessive biomass. Animals are consumers in the ecosystem and their excrement and urine are useful in the recycling of nutrients. Nomadic grazing is a cheaper way using natural resources as the biggest input is the care of animals on rangeland. Yet under new conditions and when the animal population is doubled, the natural growth of vegetation and restoration capacity will be limited and the issue of over-grazing will need to be addressed. Not all regions report such big increases in livestock numbers.[10]

5.2. Feed requirements of livestock

In commercial ranches it is normally assumed that one mature cattle beast (bovine) on the temperate grazing land needs 0.4-0.5 ha of pasture. Yet there is no such pastureland in the Sahelian region. Research in Africa shows that one bovine of 100 kg body weight needs 2.5 kg of dry forage and that the annual requirement of dry forage for one bovine is 912.5 kg. There is no high yield forage grazing land in the Sahelian region. Under the common situation, one bovine needs 6-10 ha of grazing land in the Sahelian region. In extremely dry years, one bovine needs 30 ha of such shrub grassland to survive.[11]

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[10] In Dilei Community, the total number of cattle in 1982 increased up to 63,000 heads and suddenly decreased to 18,000 heads in 1986. The total amount of cattle in Tonbutu and Gao was 775,000 heads and 460,000 heads in 1982 and was reduced to 239,000 and 117,000 heads in 1986 respectively. The reason for such cattle population reduction is complex, but the degradation of the ecological environment and soil deterioration caused by sand-dust storms are key factors. Not all regions report such big changes in livestock numbers.

[11] The African Plant Ecology and Productivity Research Dept. of the International Livestock Farming Centre has made long term observations on the bush steppe of the Sahelian region and concluded the total above ground biomass of the sparse wood land (pioneer shrubs including *Guiera senegalensis, Balanites aegyptiaca, Acacia senegal, Grewia bicolor, Boscia senegalensis*) and relatively stable grassland is approximately 2,000 kg/ha when the density is 130 individuals of shrubs per ha, in which fruit, nuts and leaves is 120 kg/ha. and protein is 10-20%.

Over-grazing takes place when utilization rate exceeds plants growth rate. Edible plants will decline and eventually disappear if over-utilization occurs. The structure of the plant community changes gradually and inedible plants or poison weeds will gradually increase on a large scale. The land surface is less vegetated and exposed under the heavy trampling of transiting animals. Without much grazing grass and plants, transiting animals will migrate in a hurry and, as a consequence, loose sand materials are formed on the migration route. The frequent occurrence of sand-dust storms accelerates desertification processes on the migration route and thereafter the condition of rangeland vegetation is completely changed and vegetation degradation is further deteriorated. The degraded vegetation with low productivity on the migration route plays a feedback function to promote the process of desertification on the migration route. In dry years, sad images and the calamity of huge numbers of dead animal bodies can be seen everywhere on the migration route.

Desertification circles around drinking well areas are well-known phenomena in Africa. On the dry rangelands, huge numbers of animals gather around the locations where there are drinking wells. Intensive utilization and serious trampling on the land surface accelerate wind erosion. After several sand-dust storms, a desertification circle around a drinking well will be gradually enlarged. Herdsmen describe this situation as *"drinking water is more than before but forage is less;" "sheep and goats are more in numbers today but weight is less than before;" "cattle are more in number today but produce less milk than before."*

Under the impact of over-grazing, most areas along the migration route have been desertified and many herdsmen move to open new grazing land. After their careful interpretation of satellite images, some European scholars discovered that there were vast pieces of dry steppes among the space between two parallel migration routes. Due to lack of water supplies, few herdsmen used them. From the end of the 1960s to the 1980s, some developed countries, including European ones, collected USD $625 million to help improve water supply and control animal diseases. When the international supporting programmes were implemented, many drinking wells with modern equipment and advanced technology (some are solar-energy operated) were installed on the previously unwatered rangelands. To meet donor countries' requirements, some permanent livelihood service facilities (health clinics, veterinary clinics, etc.) were installed around the drinking wells according to foreign expert designs.

In the past, due to insufficient rainfall and lack of artificial drinking water wells, a vast area of vegetation in drylands was not utilized. This was regarded as *"wasteland"* or *"virgin land."* When man-made reservoirs, water dams, pumping wells and runoff catchment were installed, the vegetation around the water bodies was quickly destroyed and disappeared. Local administrators and even the decision-makers were not able to monitor and control the situation. Animals concentrated where there were water supplies. Vegetation around drinking wells was intensively grazed and topsoil was heavily and repeatedly trampled. As a consequence of such grazing, soil deterioration occurred and mobile dunes developed. Dr Robert Lange, an Australian ecologist, termed this desertification circle taking place around drinking well a *"Piosphere"* (Lange, 1969). The diameter of the desertification circle around a drinking well is normally 10-12 kilometres, which is equal to the distance that one bovine can travel in one night.

The installation of a drinking well on dry steppes is the start of land degradation. On satellite images, desertification circles appear around drinking wells on the river terraces of the Mur Kabu River and the Amu Darya River and the diameter of these circles is normally 7-10 km, with average diameter being about 2 km. In fact, the size of the desertification around a drinking well is closely related to the outlet quantity of pumping water, water use intensity, grazing season and the geographic location of a drinking well and wind erosion conditions. After the severe drought of 1968-73, the diameter of the desertification circle around drinking wells in the Sahelian region enlarged for several km and the centre position of the circle became bare sand land without any vegetation.

The change of nomadic nature and the settlement of herdsmen reflect the change of livelihood and mode of production. The settled herdsmen cut fuel woods around drinking wells. We did not see woodlands or shrub lands existing around drinking wells. In the dry season, cattle can drink water every two days and they can graze only in a radius of 15 km from wells; small animals drink water every five days and they can graze in a scope of 30 km apart from water supply; camels can drink water every 11-15 days and they can graze in a distance of 60 km away or longer from water catchment. Stable or concentrated grazing adjacent to drinking wells has enlarged year by year and so too has the size of the piosphere. Local herdsmen described that *“water supply is increased but grasses decreased; the number of cattle is doubled but the milk production two times reduced.”* Experts of European donor countries have recognized this undesirable consequence and some international organizations took immediate action to stop the further implementation of digging-well programmes in 1987.

Scientists from Russia, surveyed and observed the piosphere around drinking wells. They noted that there would be no over-grazing if the distance between watering points is 4-6 km. They observed that sandy land was trampled and some blowouts appeared on the windward slopes of fixed sand dunes (longitudinal dunes) in the windy season. The blowouts of wind erosion will naturally recover if there was continuity of rainy years. Such steppe can be classified in the first grade of degradation.

Second grade steppe degradation took place at a location nearby the drinking wells (2-3.5 km in diameter). Intensive grazing caused this degradation. More than 70% of herb grasses on the mentioned degraded steppe was utilized and topsoil was exposed under wind force on a large scale. As a consequence of wind erosion and sand-dust storms, blowouts cover large areas. Aboriginal vegetation declined and weathered and barchan dunes developed in some parts of land surface.

Because of the disappearance of trees, shrubs and some edible plants, the plant community has changed. Inedible or poison plants have replaced palatable species. The ratio of biomass above and under ground has changed and the latter reduced significantly. All these are indicators of degradation of desert steppes and land degradation.

The third grade of steppe degradation took place in a range of 0.5-1 km radius from the drinking well. This is a direct consequence of dense livestock concentration. Under the impact of wind blowouts, the sand materials at the exposed location start to move and accumulate nearby as sand sheets or *“sand tongue.”* Plain sandy land will gradually develop into barchan chains, and longitudinal dunes and transverse dunes will be formed. This evolution will completely change the growth conditions for plants. Shrubs, bushes, semi-bushes and edible plants will disappear and a monoculture of psammophyte will survive as pioneer community with very low plant productivity. Such significant degradation can be found in a circle 0.5-km apart from the water well. This has been designated a sacrifice area as nothing survives here. The degradation process can be seen within 5-8 years if the rangeland around the water supply is intensively grazed.

Restoration and revegetation can occur if livestock are removed. The second grade of rangeland degradation can be revegetated in about 6 years when the appropriate measures are taken. The third grade of steppe degradation is unlikely (even impossible) to be entirely recovered even if 17-years of preservation was arranged, because the seed banks for trees, shrubs and grasses have been destroyed. Physical sowing would need to undertaken and the area protected for a long time.

6. STEPPE AND WOODLAND BURNING ON A LARGE SCALE IS A WIDESPREAD PRACTICE

While interpreting SPOT images we found evidence of large areas of burnt land. Burned areas several tens of km long were clearly seen on SPOT images as dark patches. For instance, on December 10 1986, 10,000 km² of vegetated ancient dune areas in the north of the Nagu district was burned into bare land. We had interviews with local people and they understood that these fires were caused due to cooking in the field, refinery of bee-honey and smoking of cigarettes. In fact, steppe fire is also related to mode of production. The function of the fire was well recognized and used in old times. Reports indicate that early mariners saw fire and smoke from the West Coast of Africa as long ago as 300 BC.

Decomposition of weathered branches, leaves, straw and stalks is slow in this dry environment and they always impede the growth of new sprouts. Setting fire to weathered grasses can stimulate the growth of new growth and promote grass sprouting in advance. These fresh plants in the later period of the dry season provide significant benefits to local herdsmen. Such steppe fires can also clear most of the shrubs, bushes and young seedlings. Fire burning is unavoidable while practicing shifting cultivation, because it is a means to clear land. Of course, fire disasters will take place if no proper control measures are adopted. We have watched such fire disasters during our field investigations. Under the influence of strong wind, steppe fire will be out of control and spread widely. In years with less rainfall, wind erosion takes place on these burnt spots and then sand-dust storms prevail as a secondary process. Local governors and community leaders worry not only about the destruction of vegetation, but also about the disappearance of their villages in bush fires. Their grass-huts are so easy to be swept away in bush fires. Bush fires are legally prohibited, but regulation is not enforced.

6.1. Over-collection and cutting of fuel woods

Wood is the only source for cooking and heating. In the Sahelian region, three pieces of stone can make a simple stove and one bundle of tree branches can cook a dinner. This is a regular living style. In cities, people can use natural gas, but in rural areas, farmers and herdsmen rely on fuel wood. Savanna and bush steppes can harvest only 0.05-0.1 cubic metre of timber per ha. In areas where mean annual rainfall varies from 400-600 mm, average timber storage of natural forest is 3.9 cubic metres per ha. The mean productive capability is 0.13 cubic metres per ha per year. Yet the daily consumption requirement for livelihood is about 1.8-2 kg per person.

Investigation shows that, on the bush steppe with less than 200 mm of rainfall in Mali, average annual lack of fuel wood for each person is approximately 0.47 cubic metre. In this region, the desertification process was unceasingly accelerated. The nomads and seasonal migrating herdsmen dwelling in the areas with 200-400 mm of rainfall have an annual shortage of 0.45-0.55 cubic metre of firewood per person. Over-grazing has obviously occurred and land is desertified. In areas with 400-500 mm of rainfall, annual shortages of fuel wood per person are around 0.3-0.42 cubic metre. Along with the enlargement of the scale of arable land, daily requirements of fuel wood are doubled day by day. In general, the total amount of firewood can meet the need of 16-38% of total consumption. As a consequence, woodland was blindly deforested, wind erosion was accelerated and sand-dust storms became more frequent.

According to research published in 1986, *"Africa lost 3.5 million ha of forest annually (about 3.5 %) but in the coastal areas of Western Africa, the annual loss of forest is 5%. There were 15 million ha of forest in the Ivory Coast in the 1950s, but only 2 million ha has remained." "Senegal consumes 1.7 million tons of timber and 223,000 tons of charcoal every year (equal to 1.1 million tons of wood)."*

6.2. What should we do? Strategic consideration on controlling sand-dust storms caused by human factors. Approaches to control measures and tactics to fight desertification. Questions and some viewpoints

A sand or dust storm is a manifestation of the process of land degradation. On the typical mega-dunes and in the Gobi desert, fine materials that can be drifted and transported have been already blown up and transported to other regions in historical times (*see Chapters 10, 11 and 12*). Coarse sands and gravel remaining on the surface cannot be blown up to the air current in the atmosphere. Most severe dust storms have never taken place in arid desert zones, but on the steppes or arid steppe zones. For instance, in wheat cultivation areas in Canada at the end of 19th century and in USA in the 1930s, Black Dust Bowls have swept areas (*see Chapters 4 and 5*). After the disasters, a series of agricultural approaches were adopted to fight against wind erosion, including strip-shaped reclamation and strip-shaped cultivation, rotation cropping and mulching systems, soil fallow systems, et al. Specific governmental agencies were instituted, such as the Soil and Water Conservation Service, to prepare legal instruments and improve monitoring and supervision bodies. Landowners, producers or researchers gained valuable lessons from the disasters and fulfilled their mandates. Such approaches have yielded significant results (*see Chapters 1 and 11*).

Natural conditions and socio-economic development levels in the Sahelian region are different from North America and posses their own particularity. Whether the approach is to control wind eroded areas or take measures to combat the causes of sand or dust storms, the adaptation to local conditions should be considered the first priority. The issues of whom will execute and how to put the plan into practice needs to be resolved. It probably will not work if we copy the methods of North America or Europe mechanically, or just raise a general principle, or even develop some concrete and even well-done designs on paper. If there are no real initiatives on the ground, it is difficult to evaluate the practical value and advantage/disadvantage of these copied approaches and measures. In view of this consideration, we have to treat the question of *"what shall we do?"* scientifically on the basis of specific conditions and real facts under the principle of *"seeking truth from fact."* Cai Decheng summarized the scientific consciousness under the following five points:

i. Objective evidence.
ii. Rational questions.
iii. Dimension thinking.
iv. Equal arguments.
v. Practical inspection.

We have to analyze all sorts of versions and recognize a variety of actions. We already have lessons from previous failures. For instance, the *"Action Plan"* and *"action goal"* of the United Nations Conference on

Desertification (UNCD) (1977, Nairobi) are less effective or negative after more than 20 years. Therefore, we have to deal with the issue of *"what shall we do?"* with an opposite and cautious attitude.

On April 7th 1988, accompanied by a Mali national consultant, we invited leaders and members of the Local Development Committee in Gongdamu to discuss and share their comments and suggestions on the control of desertification. At beginning, the expert mission was requested to explain *"what they should do?"* Mr. B. Diallo, national consultant and project coordinator of agro-pastoral productivity of Mali explained some approaches in a very general language. His presentation basically focused on:

1) To face up to the existing facts of steppe desertification at different grades.
2) To strengthen steppe and grazing management, including determination of livestock population according to steppe and forage supplies and limitation of animal breeding.
3) To find out the status of steppes and adopt corresponding measures to restore the degraded steppes of different grades, including ejection of free grazing, natural enclosure and fence-preservation, reverse/reserve grazing and rotation grazing system.
4) To improve the commercial value of animals.
5) To avoid over-grazing and high carrying capacity.

A senior man criticized Mr. Diallo with a serious tone and he said *"this young man's presentation is so familiar to us and his language and terms are the same as what French colonists taught us in the past decades."* And then all participants had widespread comments. A woman committee member, being the only female, talked for such long time with such fluent eloquence and summarized that *"fishes swim in water, birds fly in sky, women produce babies, cattle, sheep and goats graze in wood land. These are a matter of course and nobody is able to change their freedom, nobody could change the existing state."* There was no elbowroom for further discussion and exchange of views and we had to listen carefully to their serious concerns and firm opinions.

In regard to this region, we consulted a document issued by Bauche, supervisor of forest and water on April 15th 1947. In this document, the physical geographic information and plant community of a piece of land, in size of 25,300 ha in the north of Gongdamu that was planned to establish a natural reserve, were recorded. The expert mission made two investigations to the field and assessed the existing vegetation. The mission surveyed the region two times, once while the Chinese petroleum minister was visiting Mali. The mission gained a macroscopic impression of the region. According to the Mali national consultants, we are *"strangers"* that have a lack of living experiences here. We are specialized in science and technology, but we have insufficient knowledge to deal with the difficulty people face while changing the traditional mode of production and the new economic order. We were superficial in recognizing such difficulties, we did not notice local historical changes, and thus we did not know what and how people think. Recalling that the people in the Sahelian region can graze their livestock beyond a national boundary without settlements, the methods of wire-fencing and rotation grazing system are merely *"empty words"* and it goes without saying that finding a huge budget for constructing these facilities to fence the steppes will not be easy. Moreover, it is dangerous to erect a wire-fence or vertical barriers on the steppes where there is migration of wildlife.

Livestock number is a sensitive question in the steppe areas. The number of animals is a sign of wealth and it reflects the social position, status and dignity that are worth more in value than any pearls or treasure. Reduction of livestock and limitation of animal numbers or species are very serious issues. Inappropriate policy on this issue will bring about social instability. Le Houerou (1977) wrote that local herdsman explained that *"I had 100 heads of cattle before the 1968-73 droughts and now I have only 50 heads. I will try my best to* *increase my cattle up to 200 heads."* One of my Mali friends said his father has 2,000 heads of cattle and when he tried to persuade his father to sell those overgrown animals he was strictly criticized. When talking or discussing the entirety, long-term and ecological benefits, the private, short-term and economic issues are quite prominent.

In addition, any measures to prevent land from erosion possess technical limitations in the areas practicing the method (for instance, farming tools and machines suited to humid areas are unsuitable to arid areas). There is no winter and no snow in the Sahelian region and the mulching materials can easily bring about an increase in plant diseases and insect pests. Any effective measures that are suitable to other regions perhaps will not work in the Sahelian region because of different social backgrounds, habitats, customs and economic growth status.

An Algerian, (Slimane, 1991) analyzed the causes of desertification while developing an approach to combating desertification in Algeria. There was a significant shift from tribal order to colonized disorder. Algerians practiced migrating nomadic and agro-pastoral systems long before the French occupied the country in 1830. After the territory was occupied, the colonial authority confiscated arable lands and forests and local people were forced into poverty. In order to seek a livelihood, local people had to damage or even destroy the ecological environment. In 1863, decrees had classified the grazing lands into state-owned, private or household and tribe collective territories. The boundary of each sector was legally limited. *"The legally designated herdsmen of any tribe are permitted to use the steppe/rangeland to graze their livestock within the order of number and variety of livestock formulated by the citizen committee."* In 1975, the Rangeland Law defined rangeland, steppe and grazing lands as belonging to the state. Steppe and grazing lands are public lands and now any people can use them without limitation. Therefore, some peoples' prediction in the early 1950s have been turned into reality (Monjanze: *"because of lack of careful attention on land-use, all grazing lands will be slowly turned into deserts. In Algeria, about 10 million ha. of grazing land will be desertified."* Bedrani concluded that the first step of future measures to control land degradation is to return all grazing lands to those tribes who had ownership of the land. The creativity and energetic enthusiasm will be brought into full play to manage their grazing lands with active assistance from state technical agencies.[12]

In October 1985, the Mali Government developed a National Action Plan to Combat Desertification and Control Sand Movement (NAP). The NAP was designed to *"establish a material Barricade to Stop Sand Movement – the Green Dam."* The Green Dam is 1,055 km long and 5 km wide, and covers an area of 5,275 km² (or namely 527,500 ha.) The first phase of the project lasts 15 years. We were informed that this NAP, developed with the assistance from international experts, is basically formulated on the basis of E. P. Stebbing's (a German Professor) scheme. Prof. Stebbing raised a plan to establish an unbroken forest belt in Nigeria and the desert edge of adjacent countries for controlling sand invasion. However, most serious scientists and researchers recognized that this design of the green belt is not reasonable scientifically nor economical feasible and is a practical impossibility. Some people titled it a *"visional cloud-castle"* or *"Utopia."* Yet many people, particularly those who hold power, insisted on carrying out the project. *"The whole nation is filled with confidence and consciousness."* These decision-makers kept in their minds a high ambition and planned to gain great achievements. According to Stebbing's design, it was calculated that the establishment of a green belt in a width of 25 km and a length of 6,000 km, from the Atlantic Coast in the west to the Red Sea in the east, would cover an area of 15 million ha. Even if the seedlings of plantation cost USD $100 (10 times more input is needed to plant the seedlings in the soil), USD $1.5 billion was needed for

[12] Editors' note: This may be easier said than done. So much damage has been done and so many former nomads have settled that this proposed remedy may be too simplistic.

implementing this project (Sahel Green Belt Transnational Project, UN Conference on Desertification, Nairobi, 1977). It should be pointed out that in the Sahelian region, the data of 400 mm mean rainfall cannot be used to design the plantation project, because rainfall variation each year is 30% or more than the mean annual rainfall. The dry season lasts 9-10 months and artificial plantation is very difficult under such harsh conditions.

We were informed in Macina that termites ate the cuttings of plants and destroyed seedlings. To observe this phenomenon, the expert mission traveled several hundreds km of area with termite-mounds and we were deeply convinced with the foresters' information.

During the field excursion, special arrangements were made to visit the existing projects for obtaining important knowledge and information (it was reported the World Bank has completed 994 projects from 1974-84, of which 14 % failed). The rate of failure was highest in the agricultural sector (30% in West Africa, not less than 51% in East Africa and 5% in South Asia).

This article is based on field experience and speaks louder than any summary and report form. The advantages, mistakes and reasons of failure of the various approaches can best be understood in this way. It is not always possible to visit the site of past attempts to combat desertification nor to speak directly with those involved.[13]

Before I wrote this article, I looked over the photographs taken during my field investigation in Mali and the scenes of tree plantations are clearly in my mind. In the mid-1980s, Germany opened plantation areas in suburban Gao district and made a plantation in a depression area with rich underground water. After their first year's trial, they summarized lessons and continued their efforts. Three years later as Mali friends explained, the German experts quietly left and this site was carefully fenced with wires. I stood by the fenced field and could not understand the reasons for such an outcome. I visited so many very well-managed artificial forest lands in Germany and these forested areas are some of most advanced artificial plantations where trees are mixed in optimum density, maintaining skill is reasonable and their growth is almost the same as the natural forests. The forest is better arranged and productivity is higher. Why was the German experience for planting so weak in Gao of Mali? I met some German experts in Aoluo Lake and their clothes are so simple and they worked here physically and mentally. They successfully cultivated so many trees of *Acacia* and *Eucalyptus* spp. Yet why were they not successful in the Gao district?

On the other piece of artificial plantation field we saw some huge steel tanks. Trees in spots were mostly weathered and those that remained were in poor condition. Mali national consultants asked me what impression I had. I explained *"it can be seen that many foreign foresters worked here as we saw so many used empty cans on the ground. Wild* Hyphaene thebaca *trees have not been cleared out and the imported* Eucalyptus *trees*

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[13] During my mission to Ethiopia to investigate the desertification issue, a request to visit an existing project in the country was submitted to local administrators. The answer was negative and I was informed that there were no donor-aid projects. This information was clearly wrong. I introduced local administrators to the project numbered DESCON-2/15, titled *"Restoration of forest, grazing lands and arable lands"* that was planned to be completed in a span of five years from 1979-83 with a total budget of USD $62.6 million. The project was aimed to restore 13,500 ha. of degraded area in the mentioned sectors through construction of terrace farming, runoff plantations, wind erosion control approaches, forest protection and seedling cultivation. Several days later, I was informed that in-situ visiting was impossible. *"The project is under implementation, although it failed at the beginning because local farmers were not the beneficiaries and did not accept the project."* In this project area, farming and grazing were not integrated and priority consideration was therefore focused only on a mono-element. I was satisfied even if I received this limited information.

cannot survive." Local administrators have told us that foreign experts left after the plantation was completed. Local villagers, due to lack of financial sources, could not afford gasoline and were unable to irrigate these seedlings. They have to wait and see what happens naturally. Mr. Diallo who graduated from France and Belgium, (with two Ph D. degrees) laughed and described frankly that *"it is my regret to say that both the donor countries and beneficiary country are not willing to obtain lessons from the failure."*

I had an unexpected meeting with a college-mate who graduated from the Leningrad Forest Engineering College, a younger African engineer. During my interview with him, I understood that the effect of plantations are effective if suitable varieties are selected and more attention is paid to native species and selection of plantation sites. In the rainy season, natural seedlings can be seen everywhere, but in the dry season, particularly in years with less rainfall, all lands will become dry soil. I praised his excellent work and his artificial plantation survives with a high survival rate. He smiled and said that local people grow trees much better than he does and lessons he learned in college are not useful in practice. I asked him why there were no trees around villages and no farmland protective shelterbelts. He replied that local farmers could easily answer this question.

I raised the same question in another interview with local people and I was answered with big arguments. Later, I understood through help of Mali experts, that there are so many mosquitoes and flies that carry serious contagious diseases, that if they plant trees around their houses the plants will provide shelter for the insects and even wind cannot blow them away in the evening. These insects disturb people's sleep. In addition, there are so many birds that make their nests on (even) small trees. These birds (guelea) spoil crops in the harvest season. It is a stupid idea to plant trees around farmlands and villages. Of course, there are many agroforestry systems aimed at preventing fields from eroding. Around corn, sorghum or *Panicum* fields some trees of *Acacia* spp. or *Butyrospermum parkii* were preserved. It is not right to say that all farmers and herdsmen are against plantations. Yet it is not easy to encourage people to plant trees; they must be made aware what the purpose of plantation is.

The southern edge of the Sahara Desert is characterized by traditional livestock production systems. Crop cultivation is, relatively speaking, rather weak. This structure and form supports people's opinion for tree plantations. Trees and sparse woodlands, for shepherds, are *"grazing fields"* and green umbrellas.

During the rainy season in the inland delta of the Niger River, nomads graze animals on rangeland far from the river course. *Echinochloa stagnina* is a kind of wetland grass with high nutrient status and it is favourite forage of livestock. In more than a half-years' dry season, main forage includes *Aristida mutabilis, Eragrostis tremula, Schoenefeldia gracilis*. On some pieces of rangeland, deep-rooted bushes and small trees are green in colour. Most mimosa varieties, like *Acacia* spp, *Leucaena* spp, *Prosopis* spp are protein and nutrient rich forage with a high value. We noticed that herdsmen hold a small stick of one metre long in their hands. It is used for knocking down the bean pods to allow grazing for their sheep and goats.

Pterocapus erinaceus is also favourite forage that small animals like. Herdsmen dislike high growth of the tree. We saw some high trees without any branches and herdsmen and farmers especially preserve this. Yet for most trees, herdsmen and farmers will cut branches before they grow up for feeding animals and for cooking.

Is the objective of reforestation in arid zones really similar to the aims of forest-covered regions? Is the arid zone forest aimed to harvest timbers? Can the arid zone forest not be used for forage purposes? Many areas in Africa are suitable to tree growing. About 150 years ago, a missionary introduced species of *Eucalyptus* spp. to

Africa from Australia. In Ethiopia, vast areas of *Eucalyptus* forest cover the mountainous areas around Addis Ababa. In Kenya and Tanzania, *Eucalyptus* trees grow high. In the Congo, a French group established a piece of *Eucalyptus* woodland by using tissue culture techniques and its annual growth is two metres in height and they are currently grown up as forest. Local people and even Mali colleagues dislike this species, even when I mentioned that there are more 500 species of *Eucalyptus* trees and some contain fragrant oil that can be used for medicinal purposes, to expel mosquitoes and flies and some contain raw materials for producing Palm Essential oil that Africans likes very much. Plantations of tree species are related to the purpose of the plantations. The native people in the desert always cherish water and treasure green plants. They do not use the tree branches with green leaves to cook. These green plants are indispensable for life. There is a link between them and their livestock. The urgent need of native people is green forage, not timber.

S. Milas, an English observer, observed in 1984 that in last two and half decades, human population in the Sudano-Sahelian region has doubled, but cereal production has decreased 50%. The average arable land per capita was 0.31 ha and was reduced to 0.15 ha per capita. *"The key point to improve the environment situation in the Sudano-Sahelian region (19 countries) is the policy on population quantity and density."* Allan, a well-known researcher of traditional African animal grazing, borrowed Thomas Moore's words and wrote in 1965 that *"if African people do not eat their own superfluous animals, then they will be killed by the superfluous animals."* The total population in Africa was 219 million in 1950, 285 million in 1960 and 551 million in 1985. The population of Egypt was 7.5 million in 1882 and rapidly increased to 47 million after 103 years. Half of the total population in Tanzania is below 15 years of age. Therefore, the rapid population growth is regarded as the trap of social development in many research conclusions (Ambio Vol.23, No.4-5 July 1994).

Population growth brings about pressures on land-use and results in over-cultivation, over-grazing and irreversible collection of fuel wood. Deforestation and thus land desertification are closely related to both human and animal population growths. Based on this recognition, in January 1986, I explained this truth gently with an analogy to Ethiopian officials while presenting at the HQ of the Economic Commission for Africa (ECA). Exempting China's family planning strategy, I mentioned a story from south China. A village leader told his villagers and said *"all of our villagers are on a boat and if you have some people more on the boat, we all will be submerged."* One Ethiopian official responded with a direct mood and said *"Japan and Hong Kong are highly populated and economic growth is very fast. Population in Africa is far from their density."* I explained and answered the questions made by local officials with facts of development levels of productivity and historical background and I tried to defend myself that I was aiming to criticize any people through telling the village's story. I was interested in briefing people of our experiences, because I think population is a priority issue that needs to be seriously addressed.

In many areas of Africa, especially in the Sahelian region, the diversity of race of people and tribes cannot be found in other continents. In the Mali-Sahelian region, there are Arabs, Cypriotes and black peoples. They have different religious beliefs (Islamic, Christian, and fetishists). They have their own living styles and modes of production (nomadic, migrating herd, fishery, and settled farming). They have combinations of religious beliefs and modes of production. Almost all tribes, big or small, advocate large numbers of population. In this region, the control of birth is regarded as a crisis of race and any attempt to lessen pressure on land-use by extending this population policy is an unacceptable solution that other regions practice successfully.

7. Conclusions

7.1. What to do and how to do it? Respect nature, advocate biodiversity, apply advanced new technology, utilize natural resources wisely and sufficiently and draw up an ideal blueprint

In fact, measures aimed at controlling sand-dust storms and combating desertification are aimed not only at controlling sand-dust storms themselves, but at wiping out the social causes of land desertification and establishing a national functioning system to fight against desertification. This ideal long-term objective should be gradually realized in the future.

Searching for approaches and solutions that can either preserve natural heritage and traditional relics or can feed the increasing population is possible. Except for emphasis on conservation on a large scale, the adaptation of advanced techniques for developing desert agriculture should be practiced and a high-input, high-output intensive economy should be created in some regions with favourable conditions.

We are used to consider first the introduction of methods, approaches and technology from other developed economic regions and other rich countries while we are designing our plan. By doing so, local traditional practices, living style and customs have been of less concern. Natural forces, powerful vitality of the nature and the self-restoring and self-recovering abilities of nature have often been neglected. Even some place hope on *"artificial geographic operations"* to nature, such as changing the flow direction of river water, rebuilding species, gene-splicing, etc. They put human will in opposition to nature's physical laws. This is a mentally stupid opinion that many people believe.

There is no necessity for choosing one strategy but also we should not seek far and wide for what lies close at hand. The native plants, diversity of variety and delicateness and effectiveness of the regeneration ability of nature are really the fountainheads to create modern civilization.

Another point of my personal experience is that there are so many intelligent people with wisdom in Africa, and those local people must be the main ones to offer ideas, search for solutions and undertake the necessary measures. They may need help. These intelligent people include local elder leaders and senior practitioners and most are educated scholars. They deeply understand their people and land and are not limited by old ideas. They are able to find out the path to enter globalization from the rapid advancement of modern civilization and technical progress. Of course, strangers can explain their own opinions too.

When I was in Africa, I finally understood the truth of life. The operation of social matters is the same as the natural phenomena. Both are the reflection of objective regularity and cannot be arbitrarily changed. Human life, particularly the extension of a thousand years of life style, habit, customs, economic and productive activities, contains elements of human wisdom and should be equally protected.

7.2. Key ideas for actions to combat desertification

As the breakthrough points transit to long-term objectives, key ideas for planning action should be focused on the following points.

7.2.1. *Enlargement of nature conservation in a planned way*

Conservation and preservation are two distinct concepts. Preservation is *"keeping things as they are"* while conservation implies *"wise use."* Nature conservation, as discussed here, is not a limited narrow-definition and means not only the scope of *"prohibited areas"* or *"National Park.*" There is a need to protect the natural environment, to maintain diversity and to prevent resource degradation in the Sahelian region.

There is no parallel in any region of the world to the diversity and value of natural heritages, the scarcity and fragileness of natural landscapes, the particularity of human cultures and land-use patterns found in the Sahelian region. For the sake of the whole of mankind, the reservation of the Sahel's aboriginal resources and the protection of its landscape on a large scale are the strategic steps to avoid the phenomena of *"infertile land produces a poor population and poor people make unproductive land."* Unceasing spread of desertification destroys not only the *"neglected civilization."* but also the natural heritages and relics. These cannot be replaced once lost. Mankind will be the beneficiary of protecting the Sahelian region and then, in consideration of the responsibility and obligation, the donor countries must make their contributions and efforts. Certainly the affected countries in the Sahel region ought to do their best to try not to lag behind in their efforts to bring land under a conservation strategy.

A public awareness program should be established for the purpose of effective conservation. The necessity, urgency, functions and significance of nature conservation should be recognized at all levels, from governors to landowners and donor countries to project beneficiaries. Determination of an effective social functioning organization system is a guaranteed measure to conduct publicity/education, to implement projects, to strengthen legal institution building and to practice system monitoring. At the moment, the key issue is that people, both the local cooperator and development partners, focus their main interests on the surface phenomenon of land desertification and sand-dust storms and pay less attention to long-term consequences and strategic measures to control the substantial underlying issues.

7.2.2. *Integration of potential development and utilization of natural resources*

The omnipresence and mystery of natural forces are an erudite domain that human beings are unable to know. All shapes and colours and useable value of natural resources are the greatest latent capacity that humankind depends on. In this context, the African Continent possesses maximum potential. The African Continent is the vastest virgin land on our planet, just waiting to be uncovered and used.

There were historical records in this field long time ago. Priestley in 1775 pointed out that small animals, and even big animals in the desert that will not drink water. *"I was surprised and found in my experiment that mice can unexpectedly survive without water. I fed them for 3-4 months and I offered them drinking water many times, but they did not try to taste it. They lived in good health."* Chapman's data from 1921 shows that Antelope, Oryx, Gazella, Adda and Ariel do not drink water some time. Some wild animals can survive for a long time without drinking water in the desert if they can live on the vegetation that Arabic people call *"Janzue." "Janzue"* steppe is typical desert vegetation composed of scarce and scattered plants of *Indigofera berhautina, Indigofera hochtetteri, Neurada procumbens, Tribulus longipetallus, Fagonia bruguieri, Cyperus conglomeratus and Stipagrostis acutiflora*. It is well known that water does not only occupy the most space and weight. No water means no life. Water moves in organic bodies and water changes the distribution in different organs. Depending on water, blood, lymph and tissue of organic bodies can continue their normal exchange and metabolism. The digestion, assimilation of food and excrement of harmful matters from the body needs water. Some animals in the desert obtain water through taking food, but not through direct drinking of water (research shows that some chemical reactions inside the animal body can produce water, which is not a big amount and not the main components) Animals need water to breathe, to perspire and excrete stool and urine. This is a lively mystery of survival of the fittest in the world.

Native African people do not only understand the characteristics of these wild animals in nature deeply, but also make full use of outstanding latent substances. The mixing of cattle herds with Oryx is depicted on ancient Egyptian sculptures. In Kenya, Tanzania and Niger, people have experience in cross breeding and in management of mixed species grazing. Wild ungulates have potential for domestication and/or for game ranching. It has been shown in Kenya that Oryx can produce 14 times of meat than cattle breeding in a unit area (Desertification Control Bulletin No. 9 December 1983).

These big wild animals cannot only resist diseases but also do not need periodic drinking water. Hunting the harvestable surplus of these wild animals on the steppes (and not butchering them in a meat-processing factory) will lead to win-win objectives of economic returns and steppe protection.

Non-African people have recognized the value of some African plants. For instance, the resin of *Commiphora myrrha* is widely used as the traditional Chinese medicine for curing swellings and fractures. Local street vendors sell it in odds and ends as a native product. I asked my friends of Mali whether there is *Aloe vera* var. *Chinensis* cultivation in Mali. I was told that they do not know this plant. But one-day later, a local expert asked me what plan I have for the *Aloe* plant. Actually, many natural resources in Africa, including a variety of plant resources, are very much valued by scientists in the world. For example, the fashionable edible miniature algae (*Spirulina platensis*) originate from some alkalinized water bodies in the Sahelian region, including Chad Lake. Local women around Chad Lake have eaten these miniature algae in drought years and it provided nutrition to local citizens; from then on wide attention was paid to the algae. During the recent decade, artificial cultivation of miniature algae is recognized and annual production of dry powder is 2,000 tons (in total 300 farms in various sizes are the main pool-type production). The FAO, World Bank and UNESCO have proved this health food, but there is no production or artificial cultivation in the Sahelian region, which is the original place of these algae. It runs its course in the Sahelian region and is not even harvested. Some alkalinized water lakes are subject to industrial pollution and the plant is becoming locally extinct.

The aim of referring to the above-mentioned animals, plants, and microbiology resources is to demonstrate a faith that human beings should pay great attention to the African desert land that has such a high potential. The excellent advantage of this desert-like land (*"without winter season"*) should be recognized from a viewpoint of long-term strategy. In the natural resources, sunshine in Africa is sufficient. Development of the knowledge and skill to develop and utilize solar energy is a key to future development in the region.

7.2.3. Development of intensive modern agriculture with advanced technology

Our forefathers summarized in a historical document that the *"tree will be regenerated if roots were kept."* No matter where and how, land desertification and sand-dust storms cannot be completely controlled if people cannot find a series of concrete measures to meet the basic requirements of food, shelter, or approaches to solve the issue of starvation and housing and means to help local people alleviate poverty. Any single measure is unable to fight against land desertification and control sand-dust storms. The active adaptation and full utilization of the achievements of modern science and technological advancement is the only way to attack this issue. This could be done by:

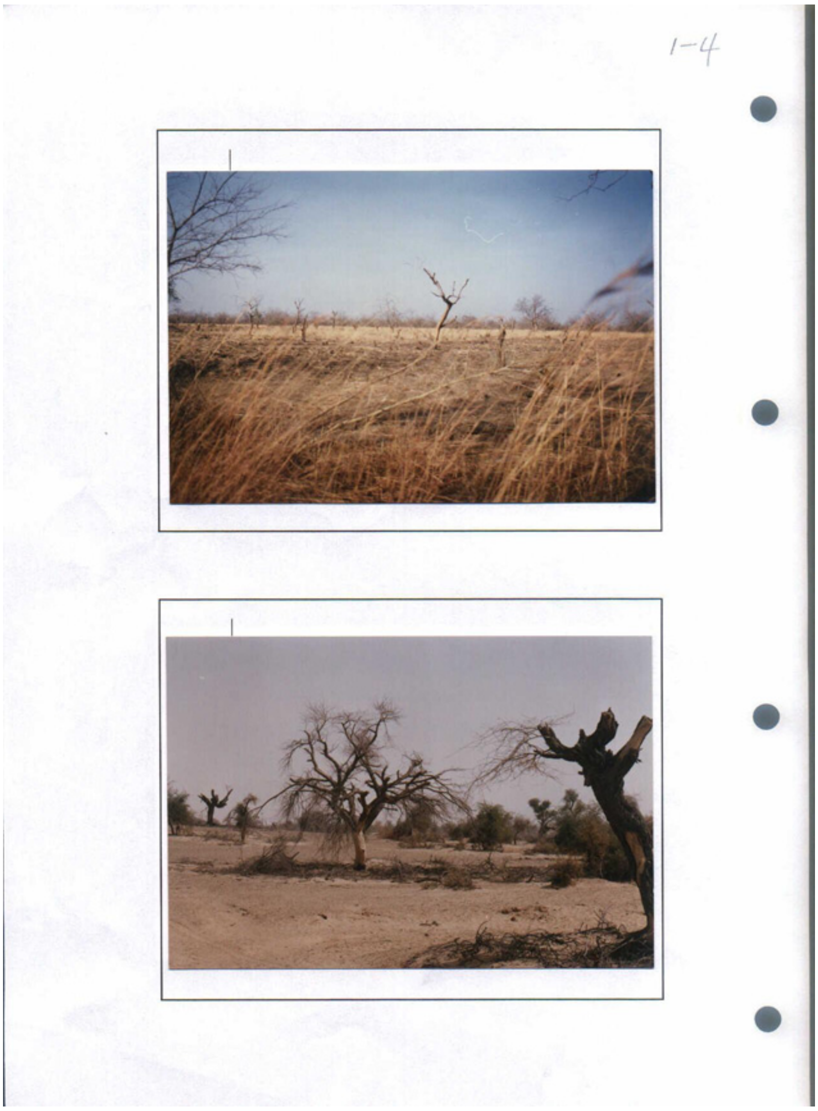
- Developing and utilizing sufficient solar and thermal resources.
- Raising and creating high-quality and rich-yielding products per unit area under conditions of photosynthesis, and establishing modern agricultural civilization.
- Meeting people's survival needs.
- Promoting further economic development.

The so-called modern agricultural civilization contains many quantitative characteristics, including:

- Advantages of harmony between human and nature; follow-up of sustainable strategy; win-win objectives in both economic development and protection of ecological environment.
- Breakthroughs in methodology and viewpoints of traditional agricultural and animal husbandry resources; creative thoughts for *"searching truth from fact"* and *for "striving for thoroughness of down to earth;"* adaptation and extension services of advanced agricultural technology (such as human-controlled agricultural facilities, industrialized plant production, bio-technology, non-soil cultivation, miniature algae cultivation, three-dimensional plantation, water saving irrigation techniques, shed-feeding of animals and poultry, non-abandonment agronomy, *"green production"* etc.).
- Creation and operation of entities (private, collective, state-owned, joint venture and foreign invested); priority consideration to new mechanisms readjusting structures of agriculture and animal husbandry, step by step in different phases; establishment of an industrialized commodity economy; development of specialized new products; growth of big industry characterized by special local features and global significance and effect.
- Present global market; utilization of transnational group's technology and investment; introduction of international operational regulations; practices of standardization for production, processing and trade exchange.
- Assessment of plan, design, programme; concerns on all matters, small interest and mini-initiative; action instead of words; be flexible and suitable to local conditions rather than *"impose uniformity on all."*
- Resources are insufficient, conditions are limited and experience is short, but the wisdom will not end and talents are everywhere. I do not believe the saying *"Africa is a hopeless case."* A delightful prospect will come true.

Appendix 1: Photographs

The following series of photographs tell the sad story of sand-dust storms and land desertification processes.



Photograph 3: Aboriginal landscape before opening up and cultivation. This region is a typical picture of bush land and savanna (*Acacia* spp. and *Balanites aegyptiaca*) (woody species including: *Balanites aegyptiaca, Acacia raddiana, Acacia senegal, Commiphora africana, Boscia senegallensis, Leptadenia pyrotechnica, Guiera senegalensis, Euphorbia balsamifera, Boscia angustifolia, Acacia loeta, Zizyphus mauritiana*; herbage including: *Cenchrus biflorus, Aristida* spp., *Schoenefeldia gracilis, Cymbopogon proximus*). It is estimated that the annual area of deforestation in Mali is round 300,000-400,000 ha.

Photograph 4: Opening up of *"wasteland"* for shifting cultivation. This is a household scale of cultivation (households occupy more than 10 ha, covering only 7% of total cultivation; 44% of farmers hold only 1.9 ha cultivation land or less (Annuaire statistique du Mali, 1967). To facilitate cultivation, farmers normally cut trees and bushes and clear the fields with fires.

Photograph 5: Wind erosion on newly opened land. Sahara Desert has enlarged 400-km southward beyond the existing southern boundary of the desert 15,000 years ago. The ancient dunes in Segu-Gongduo are witnesses. The existing cultivation areas are the East northeast-West southwest oriented ancient dunes that were connected as vast dune fields. These ancient dunes were formed over 2,000-1,800 years ago (M. Sarnthein, 1978). Because of long-term stability of the surface, these ancient dunes were vegetated and some soil layers containing fine soil particles were formed. However, the mechanical composition of these ancient dunes is the source material of present day sand-dust storms.

Photograph 6: A wind regime with dynamic force prevails from March-June and this is the dry season. All the dry-farming lands are exposed in this season. The coincidence of dry season and a strong wind regime brings soil erosion. Sand and dust storms swept the surface and transported the topsoil. In some areas with rich sand sources, annual herb and perennial grasses will be naturally revegetated on the loose layer under the cultivation layer in rainy seasons if no more human disturbance takes place. Yet those wind-eroded areas, because of harsh soil conditions, are not easily rehabilitated and an exposed surface will remain. They will be turned into barren lands.

Photograph 7: Small and fine clay particles were lifted by wind and sand particles moved under wind force accumulated on the surface to form sand mounds. In the Sahelian region, high sand mounds are distributed over large areas. Plain sand sheets will be revegetated soon in rainy seasons and sand movement no longer prevails.

Photograph 8: The occurrence of *Leptadenia lancifolia* is an indicator of infertility of soil and development of desertification. This desertified crop field will be abandoned. The Psammophyte (*Leptadenia lancifolia*) will spread on further desertified land. On-site observation shows that such desertified land *"needs 30 years to be revegetated as woody grassland even under strict enclosure."* More years will be needed to restore the soil layers. Analysis of satellite images in different ages shows that the most farmlands are concentrated around settlements with shifting distribution. The farmlands are exposed to wind at most times of the year and land degradation is manifested in the form of spot-shaped circles.

8. REFERENCES

Cloudsley-Thompson, 1984, *Sahara desert*, Pergamon Press.

FAO Production Year Book, 1970, Rome.

FAO Production Year Book, 1980, Rome.

Gerasimov I. P. 1986, *Arid Land Development and the Combat Against Desertification: An Integrated Approach*, UNEP and USSR Commission for UNEP, Moscow.

Kashkarov D. N. and Korovin E. P., 1936, *Life in the Desert*, Moscow.

Lange, R. J., 1969. The Prosphere: Sheeptrack and Dung Patterns, *J. Range Management*, 22: 396-400.

LeHouerou, H. N., 1977, Biological Recovery versus Desertization, Economic Geography, 53 (4), 413-420.

Lusigi W. J. and Korovin E. P., January-March 1984, Desertification and Nomadism: A Pilot Approach in Eastern Africa, *Nature and Resources*, Vol. 20, No. 1.

Qian Ning et al.; 1983; *The dynamics of the sands*. Beijing: Science Press.

Radtchenko G., 1983, *Countries in the Sahel*, Moscow.

S. Milas, 4-5 July 1994, *Ambio* Vol. 23, No.

Sanford W. and Wangari E., July-September 1985, Tropical Grasslands: Dynamics and Utilization, *Nature and Resources*, Vol. 21, No. 3.

Slimane Bedrani, 1991, *Legislation for Livestock on Public Land in Algeria, Nature and Resources*, Vol. 27, No. 4.

Tucker C. J. and Nicholson S. E*.,* 1998, *Variations in the Size of the Sahara Desert from 1980 to 1997*, Ambio, Vol.28, No.7.

UN Population and Vital Statistics Report, 1979.

Chapter Seven

DUST STORMS AND DUST DEVILS IN SOUTH AUSTRALIA – THE DRIEST PROVINCE OF THE DRIEST CONTINENT ON EARTH

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Key words: arid, semi-arid, dust events, suspended, dust devils, dust entrainment, transport, deposition, off-site effects, Australia, El-Nino

SYNOPSIS

The major dust storms only occur in Australia where human-induced disturbance occurs in drylands under conditions of severe drought. Climate is beyond human control but the adoption of land management practices that give more soil protection is the key to reducing the extent and severity of dust-related events.

South Australia, a large region in Australia, is used as a case study and data is presented to show that both the frequency and severity of dust storms has been reduced. The number of days of wind erosion fell from a peak of over 180 per year to less than 20 per year in the past 30 years.

KEY POINTS

1. *Wind erosion and dust storms are both a naturally occurring and human induced phenomenon. Moreover, unlike many other land degradation processes they are extremely episodic in nature. The wind erosion system is made up of a multitude of interacting meteorological, pedological and vegetational parameters. The situation is further complicated by mankind's ability influence these parameters.*

2. *It is clear that land management is a contributing factor to dust storms. Evidence of this comes from the differences in soil loss from individual fields, depending on the management regime.*

3. *Greater awareness by land users, provision of good technical advice by government extension agencies, good policies and strong legislation hold the key to Australia's success in reducing the frequency and severity of dust-related events over the past 100 years.*

1. THE PREDISPOSING FACTORS

Australia is a dry place, with over 75% of its land surface classified as arid or semi-arid dryland. Sand and dust storms are natural events that occur widely around the world in arid and semi-arid regions, especially in subtropical latitudes. It is not surprising then that Australia should be subject to dust storms and other related phenomena that are so common in other mid-latitude regions.

Rarely is Australia considered in the context of world climates, but it occupies a corresponding position in the Southern Hemisphere to many of the driest parts of the Northern Hemisphere as *Figure 1* shows.

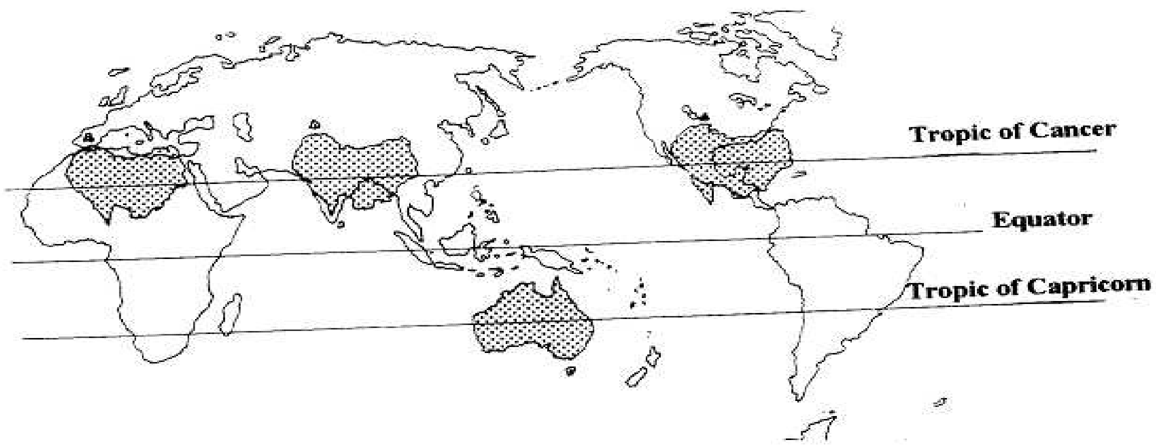

Figure 1: Australia lies in the mid-latitudes and has a climate that is similar to that experienced in Northern Hemisphere regions. In this map an outline of Australia is superimposed on Asia, Africa, and North America

2. DUST STORMS AND RELATED PHENOMENA

The major dust storms occur where anthropogenic land disturbance occurs in drylands under severe drought. Major storms occur when prolonged drought causes the soil surface to lose moisture and there is a co-occurrence of strong winds. This allows the mass entrainment of fine particles into the air through suspension. It is the smallest soil particles (usually <50 mm) and organic matter that are lost in dust storms. Suspended particles, usually <100 mm in diameter, may be transported at altitudes up to 6 km and over distances of up to 6,000 km. An Australian example of this was in 1902 (*see Box 1*).

Dust events (defined as any one of the phenomena listed in *Box 2*) can occur throughout most of Australia, with only the coastal pockets remaining free. Dust storms however, have a limited extent (McTainsh and Pitblado 1987). The affected regions lie within the 400 mm isohyet. Dust storms occur most frequently in Central Australia and coastal Western Australia, with an excess of 5 storms per year. They are markedly seasonal in their occurrence, and appear to be a feature of the late spring (September-October) and summer (February-March) months (Middleton, 1984). However, the dryland cropping regions in South Australia and in the adjacent province can create a dust event hazard in late autumn (May) before the winter rains set in.

Dust storms can be hundreds of kilometers wide and up to a kilometer high. Australia's best-known storms wreaked havoc in the cities along the eastern seaboard and in regional towns and cities in 1983 and 1994.

2.1. Dust storms and drought

El Nino, a seasonal warming of water off the South American coast, occurs every three to eight years and often brings drought to Australia. Most of the severe dust storms have been associated with El Nino droughts. A major dust storm in 1993 occurred in the plains east of South Australia (*Figure 4*). It is widely regarded as being due to the El Nino induced 4-year drought and poor agricultural practices. A massive amount of soil was eroded by winds and deposited over eastern Australia and New Zealand (about 1,800 km away) The fine fraction of soil was entrained in the atmosphere, resulting in dust to be circulated around the globe three times in the jet stream.

Similar problems occurred in 1994. Dust storms swept across Western Australia, South Australia (*see below*) and western New South Wales. It is estimated that 10-15 million tonnes of topsoil was removed from the major cropland areas in these provinces and transported across much of the continent.

3. SOUTH AUSTRALIA: A CASE STUDY

South Australia, a large province of over 984,000 km^2, will be the principal focus of this chapter. It lies between latitudes 26^o S and 38^o S and longitudes 129^o E and 141^o E, and shares its borders with four other provinces (*Figure 2*). The northern parts are arid with mean annual rainfall as low as 125 mm whilst the southern regions support extensive areas of dryland crop production (principally wheat and barley). Farming practices vary with the climate. In the north of South Australia livestock production on extensive rangelands is the principal form of agriculture but in the south cereal cropping with long periods of bare fallow over the hot dry summer is the norm.

Figure 2: South Australia is a large province of almost 1 million km^2. It shares borders with five other provinces and is often described as the *"driest state [province] in the driest continent on earth"*

Conditions are often conducive to the formation of dust storms and the more localized phenomena of dust devils. The South Australian climate is perfect for the development of the sort of vortexes that cause dust devils. There is very little rain in the hot months (*Figure 3*) and many of the region's dryland cropping areas are in bare fallow and are grazed by sheep. The soil surface is devoid of vegetative cover and sheep's hooves cause local dust to rise (*Figure 4*).

In the last 20 years, there have been two severe dust storms in South Australia. The first occurred on 16th February 1983 and the second on 24th May 1994. There was a further large dust storm across most of the Eyre Peninsula in the west of the State on 7th November 1988. On average, South Australia can expect 0.1 severe wind erosion days per year (*Table 1*).

Table 1: Estimated annual frequency of wind erosion events in South Australia

ABS* Region	Wind erosion category+		
	Severe*	Moderate*	Dust in the air**
Adelaide	0.10	0.22	8.18
Barossa	0.10	0.22	8.18
Kangaroo Island	0.05	0.10	3.83
Onkaparinga and Fleurieu	0.10	0.22	8.18
Yorke	0.10	0.30	8.95
Lower North	0.10	0.19	7.41
Riverland	0.10	0.37	12.01
Murray Mallee	0.10	0.37	12.01
Upper South East	0.05	0.10	3.83
Lower South East	0.05	0.10	3.83
Lincoln	0.10	0.57	17.13
West Coast	0.10	0.57	17.13
Whyalla	0.10	0.57	17.13
Pirie	0.10	0.65	19.17
Flinders Ranges	0.10	0.19	7.41
Far North	0.10	2.27	60.58

- Estimated from 20 years of Bureau of Meteorology Data on visibility ** Estimated from 17 years of Environment Protection Agency data when Total Suspended Particulate matter (TPS)>150μg/m^3/hr.
- Australian Bureau of Statistics classifies regions based on geography and demography.
- + See text.

In Australia the Bureau of Meteorology recognizes four types of wind erosion events:

1. Severe wind erosion days when visibility is reduced to less than 200 m, over very large areas.
2. Moderate wind erosion days when visibility is reduced locally to less than 1,000 m, but not over extensive areas.
3. Days when there is some *"dust in the air"* as defined by the Environment Protection Agency as periods when the total suspended particulate matter (TPS)>150μg/m^3/hr.
4. Zero wind erosion days TPS<150μg/m^3/hr.

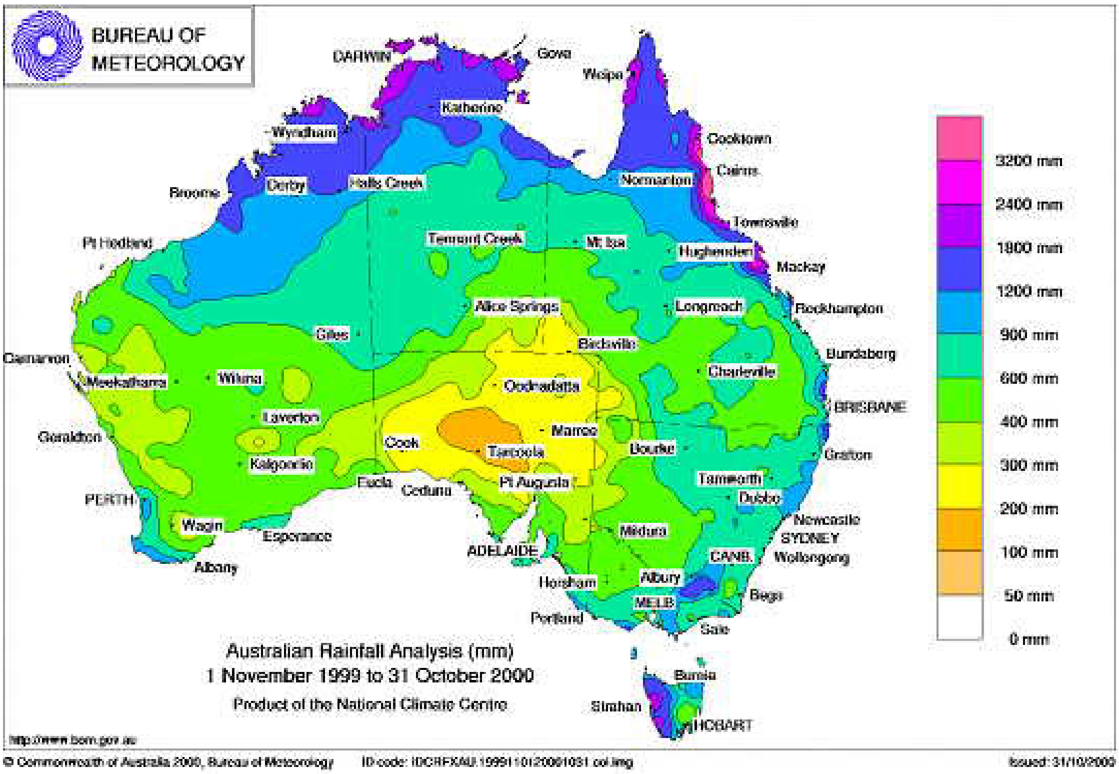

Figure 3: Rainfall in the hot dry spring months is low over much of South Australia. Dust events are more frequent in spring

Figure 4: Dusty conditions are often associated with large concentrations of livestock in the hot, dry months

Every summer hundreds of thousands of dust storms and related phenomena *(see Box 1)* travel across the arid and semi-arid regions of South Australia. Only a small fraction of them are observed however, because generally these dryland regions are sparsely inhabited.

3.1. Dust swirls (dust devils)

Dust devils (*Figure 5*) are usually most active over dryland regions in the early afternoon, 12.30-2.30 PM, local standard time. These times precede by several hours those at which the maximum air temperature recorded in standard shaded instrument shelter, 1.5 m above the ground. This is probably because the soil surface attains its peak temperature earlier than the air temperature at the 1.5-m level. The main energy source is the heat flux from the hot surface, although under certain circumstances, dust devils can be formed in moderate temperature environments, provided that other necessary meteorological conditions are fulfilled.

Research in the USA has shown that a heat transport flux of 0.7 calories/cm²/minute can be expected on dry soil in summer. For a circular area of 10-metres in diameter this translates into a net upward heat transport of about 50,000 watts. A dust devil moving over a heated surface utilizes this energy to maintain itself. When dissipative forces such as surface friction and eddy interaction with the environment exceed the available energy, the whirlwind is destroyed.

Figure 5: The duration of a dust devil varies from several seconds to many hours; most probably last less than five minutes, and only a few persist more than one hour

4. THE DUST STORM EVENT OF MAY 24-25 1994

*At midday May 24 1994, much of southern South Australia was covered by a dust storm. In Adelaide, the provincial capital (population 1 million), visibility was reduced to 400 m (*Figure 6*). Whilst it was the biggest dust storm to reach Adelaide in 1994, it was only one of several that rolled across South Australia in 1994.*

Figure 6: Adelaide and much of South Australia were hit by a major dust storm on May 24-25 1994. Dust storms like this were once more common in Australia but better attention to land management has meant that such events are now rare

The dust storm was quite extensive and covered about 800 km from west to east. Many communities were affected and widespread damage was reported in the press as visibility in some locations was reduced to 50 m. Some of the immediate effects were:

- Traffic accidents.
- Power failures, as distribution lines were destroyed.
- Closure of airports and diversion of planes.
- Closure of roads and railways.
- Loss of soil fertility.
- Distress to asthmatics.

4.1. Contributing factors

- **Rainfall:** Adelaide had a rainfall deficit of about 99 mm in the five months preceding the dust storm. Other centres further west had even greater deficits.
- **Wind speed and wind run:** Wind speeds in Adelaide on May 24 ranged from 30-45 km/hr and gusts of up to 70 km/hr were recorded. The average daily wind run for Adelaide in May is 195 km/day. On May 24, there was 320 km of wind run, indicating the persistence of strong winds. Wind flow data indicates that the wind speed and duration was among the highest 1% of events ever recorded in Adelaide.
- **Where did the dust come from?** An analysis of satellite imagery indicates that the dust that passed through Adelaide came from the agricultural (dryland cropping) districts to the west and north of Adelaide.

- **Faulty land management:** An analysis of the soil loss from individual fields suggests that land management was a contributing factor (see below).

5. ENVIRONMENTAL CONSEQUENCES OF DUST RELATED PHENOMENA

Recently published data from South Australia show that wind erosion and dust storms are likely to cost millions of dollars each year. Costs such as house cleaning costs, days lost from work because of illness (or an inability to get to the job), the cost to the aviation industry of diverted flights and so on, are among the costly affects. The most significant cost is that associated with the onset of asthma in susceptible people. South Australia, for example, experiences 8.5 days per year on average when the dust load is sufficient to trigger an asthma attack (Williams and Young, 1999). It was concluded that as much as 20% of the Province's asthma problem could be linked to the dust in the air.

At the broader level, it has been realized that wind action winnows the soil particles and leads to a loss of soil particles rich in nutrients and organic matter. Calculations based on visibility and wind speed records for 100 km wide dust plumes, centered on eight climate stations around South Australia, indicated that dust transport mass was as high as 10 million tonnes (Butler, Davies and Leys, 1995). Thus dust entrainment during dust events leads to long-term soil degradation, which is essentially irreversible (Yaping, Raupuch and Leys, 1996). The cost to productivity is difficult to measure but is likely to be quite substantial.

6. MEASURES TO COMBAT DUST STORMS AND OTHER WIND-RELATED PROBLEMS.

The big dust storm of May 24-25 1994, being an autumn event, meant that many fields were in bare fallow over the dry summer; some had already been cultivated in expectation for the autumn rains and in preparation for sowing of the cereal crop. Others were still protected by stubble and other crop residues, while others had been heavily grazed in preparation for cultivation (Butler, Davies and Leys 1995).

It is clear that land management was a contributing factor to the dust storm of May 24-25 1994 that affected much of South Australia. Evidence for this statement lies in the fact that not all fields were affected and that there were large differences in soil loss, depending on management regime.

To minimize the risk of wind erosion on South Australian farms, the following recommendations were made by Butler, Davies and Leys, 1995.

1. Develop a better monitoring system to improve understanding of factors leading to such events, the impact of the event and the impact of R&D and extension programs to induce changes in farming practices.

2. Develop agronomic extension programs that support farmers changing their seeding systems in accordance with land management principles. The programs should initially target farmer groups in areas where wind erosion potential is perceived to be the greatest. They should include greater focus on

soil conservation farming to achieve the maintenance of ground cover to prevent wind erosion in all fields, particularly during summer and early autumn.

3. Develop seeding system decision support systems for application in lighter textured soils.

4. Implement training for government officials, extension staff and others in the use and application of these decision support systems.

5. Collate and publish land management information relating to wind erosion control in suitable land management packages. Guidelines for critical residue cover levels on different soils and residue types should be included in these packages. Guidelines for residue management should be reviewed and updated.

6. Support and promote developments in weather forecasting and in particular the use of reliability indicators with forecasts.

7. CONCLUSIONS

Wind erosion and dust storms are both a naturally occurring and human-induced phenomenon. Moreover, unlike many other land degradation processes they are extremely episodic in nature. The wind erosion system is made up of a multitude of interacting meteorological, pedological and vegetational parameters. The situation is further complicated by human's ability to influence these parameters.

In the recent past, severe dust storms were relatively common. However, as indicated in *Figure 7*, since the early 1970s the frequency of dust storms across Eastern Australia has diminished considerably. The reasons for the change in the frequency of dust storms are not fully understood but are thought to be associated with a decline in the long period of fallow in summer and a general change in land management practices.

There is a growing awareness of the importance of dust entrainment, transport and deposition in the evolution of landscapes in drylands, which is perhaps best exemplified by the number of books, conference proceedings and scientific papers on the subject. Dust storms and their environmental consequences have received increased attention lately (Williams and Young, 1999). Off-site effects have come to be more fully considered recently. It has been observed that costs are not always a direct function of dust storm severity – a moderate dust storm can require as much to clean up as a severe dust storm, and the greatest returns come from reductions in widespread and severe but infrequent events.

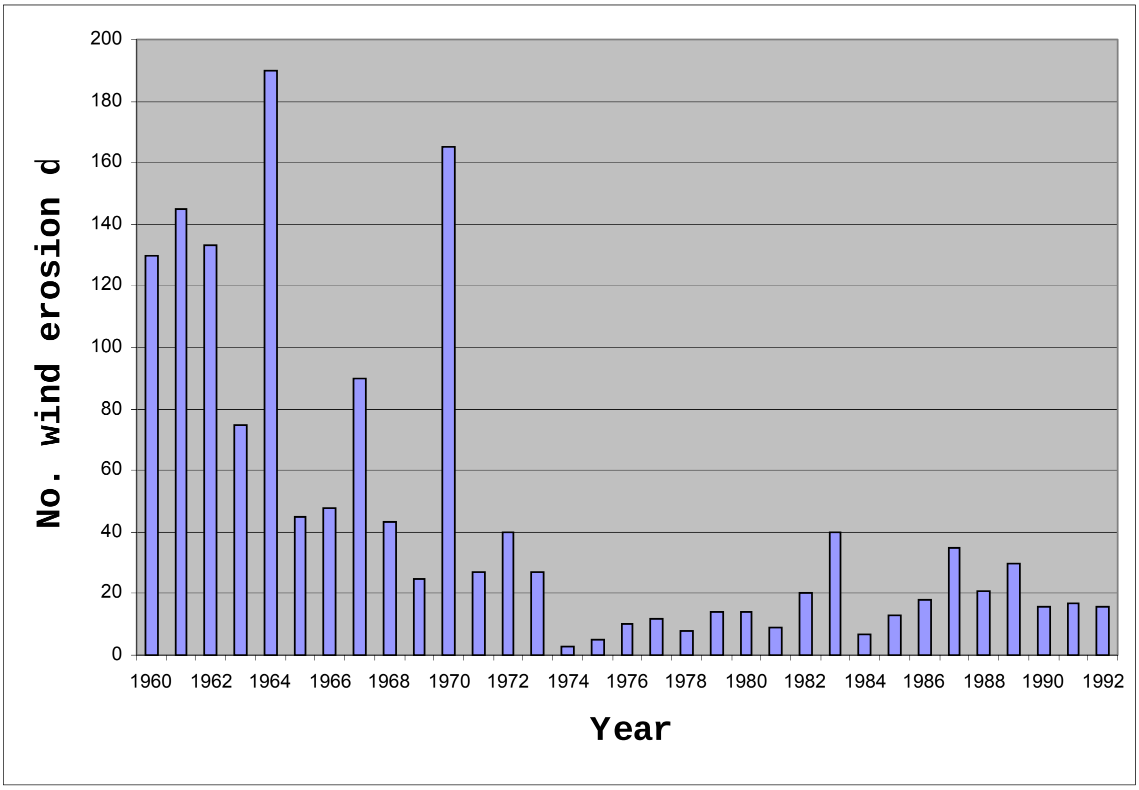

Figure 7: Total number of dust storm days from 41 Eastern Australian weather stations (adapted from State of Environment Advisory Council, 1996)

Box 1: The Great Dust-Up of November 1992

The year 1902 was one of appalling drought in eastern Australia. Whenever strong winds blew, desiccated soil was whipped into great dust clouds. On the worst day, Wednesday 12 November 1902, northwesterly gales caused exceptional dust storms to sweep across three states. The winds caused considerable damage in their own right, tearing roofs from buildings and uprooting trees across Victoria, South Australia and southwestern New South Wales.

The storm was first reported in South Australia, where it affected many parts of the state. Thick clouds of dust shrouded Adelaide from early morning, reducing visibility to 20 metres.

In Victoria and the Riverina district of New South Wales, gales and dust began in the morning and worsened as the day went on. Reddish-brown dust filled the air as the temperature climbed to 38°C. A squall line seemed to have crossed northern Victoria and the Riverina in the afternoon, because town after town reported a sudden terrifying increase in wind, and dust so thick that it put the town in total darkness for between 5-20 minutes. The winds blew down telegraph poles over western Victoria and it took days to repair the line from Melbourne to Adelaide.

The mail coach from Geelong to Portarlington, caught in the storm was halted for 20 minutes as the elements terrified horses and passengers alike. After the storm, sand 30 cm deep had to be shoveled from the railway line between Kerang and Swan Hill before trains could pass.

In some towns, *"balls of fire"* were reported. At Boort in central Victoria they reportedly fell into paddocks and streets, with showers of sparks as they hit the ground. In Chiltern and Deniliquin the balls were blamed for setting fire to buildings.

A possible explanation is that fast-moving blowing dust particles generated static electricity, which ignited organic matter carried along with the dust. The experience must have been truly frightening; the sky: a lurid red, a hot gale blowing, dust thick enough for almost total darkness, and balls of fire to add to the terror.

Box 2: Some definitions of dust storms and related phenomena*

Four definitions of the dust phenomena are the same as used by the Australian Bureau of Meteorology, which conforms to the worldwide standards of the World Meteorological Office (WMO). SYNOP present weather [WW] codes are included:

1. *Dust storms* (SYNOP WW code: 09) are the result of turbulent winds raising large quantities of dust into the air and reducing visibility to less than 1,000 m.
2. *Blowing dust* (SYNOP WW code: 07) is raised by winds to moderate heights above the ground reducing visibility at eye level (1.8 m), but not to less than 1,000 m.
3. *Dust haze* (SYNOP WW code: 06) is produced by dust particles in suspended transport which have been raised from the ground by a dust storm prior to the time of observation.
4. *Dust swirls* (or dust devils) (SYNOP WW code: 08) are whirling columns of dust moving with the wind and usually less than 30 m high (but may extend to 300 m or more). They usually dissipate after travelling a short distance.

- Dust events, a term used by McTainsh and Pitblado (1987) in their study of dust storms in Australia, refer to any event involving either dust entrainment, transport and deposition by aeolian processes (definitions 1- 4 above).

8. REFERENCES

Butler, P.R., Davies W.J. and Leys, J F. (1994*);* Dust Storms in South Australia on 24-25th May, 1994. Primary Industries, South Australia. *Technical Report Number 243.*57 pp.

Middleton, N.J. (1984); Dust storms in Australia: frequency distribution and seasonality. *Search* 12: 46-47.

McTainsh, G.H. and Pitblado, J.R. (1987); Dust storms and related phenomena measured from meteorological records in Australia. *Earth Surface Processes and Landforms* 12: 415-424.

McTainsh, G.H., Burgess, R. and Pitblado, J.R. (1988); Aridity, drought and dust storms in Australia (1960-1984). *J. Arid Environments* 16:11-22.

SOEAC 1996; *State of the environment in Australia*. CSIRO, Melbourne.

Williams, P. and Young, M. 1999. *Costing dust. How much does wind erosion cost the people of South Australia?* CSIRO, Policy and Economics Research Unit, Land and Water, Adelaide.

Yaping, S, Raupach, M.R., and Leys, J.F. (1996). A model for predicting aeolian sand drift and dust entrainment on scales from paddock to region. *Aust. J. Soil Res.* 34: 309-42.

PART IV

CASE STUDIES OF SAND-DUST STORMS IN ASIA

Asia is a vast region with a multiplicity of terrain and climates. Much of it is dryland, some of it is harsh desert. Many countries within the Asian region are experiencing severe and, in some cases, accelerating desertification. High population density, low levels of economic development, poor infrastructure and isolation exacerbate the problems. The interplay between natural and human-induced causes of desertification is strong here, as there is a delicate balance between the numbers of people and capacity of the land to provide food for them all.

Sand-dust storm events are frequent and serious and each year the death toll of humans and their livestock is high. Crops are lost, houses destroyed, transport and communications disrupted and human health put at risk. The economic cost is staggering.

Dust from these regions is often distributed beyond the national borders and this poses a problem for neighbours. Even within the national boundaries the annual losses from devastating sand and dust storms are staggering. Communications, infrastructure, agriculture and animal husbandry are affected. Human health and welfare are impacted.

In this section a *"transect''* from Southwest Asia through Central Asia to North Asia reveals the common features of regions affected by severe desertification and the plight of people at all levels as they try to mitigate the effects.

Many of the problems being experienced now are a direct consequence of poor policy decisions made at an earlier time.

Chapter Eight

WHITE SANDSTORMS IN CENTRAL ASIA

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Key words: Aral Sea, aeolian, salt, solonchak, deserts, socio-economics, health, disease, crop yields, atmosphere, climate change, water, irrigation, revegetation, wind, satellite imagery, meteorology, modeling, seasonality

SYNOPSIS

Central Asia is one of the regions with a high frequency of dust and salt storms. It is characterized by the presence of vast areas of sandy and solonchak deserts of natural and anthropogenic origin. The enhanced anthropogenic activity in the Aral Sea basin brought about the Aral crisis. As a result, the powerful basis of aeolian processes was formed, which favored the development of salt and dust removal from the dried up bottom of the Aral Sea and distribution of salt and dust over significant parts of the basin.

Atmospheric precipitation (seasonal distribution, amount, and kind of precipitation) influences seasonality significantly and contributes to the frequency of dust storms in Central Asia. Much of the dust has a high salt concentration. The salty dust affects not only climate and landscapes, but also the health and economic activity of the population.

This chapter analyzes research work conducted over the past 30-40 years, outlines the present situation, and gives some predictions of the likely future of the region.

KEY POINTS

1. *Removal, transportation and deposition of salty dust are some of the most negative phenomena experienced at present in Central Asia, especially in the Aral Sea region. The root causes are inappropriate human activity.*
2. *Salt and dust transfers and deposits affect the quality of environment: air quality, quality of the surface and ground water including drinking water, quality of the agricultural and livestock products. Consequently, the living conditions and health of the local population are getting worse.*

3. *The problem of the Aral Sea is not unique on Earth; it is a part of the general desertification process occurring in many areas of the world. Thus, the search for a solution to the Aral crisis has global importance.*
4. *The Aral Sea crisis experienced during the past 30-40 years has led to the realization that the implementation of adequate nature conservation measures requires a long period of time and significant capital investments.*
5. *There are measures that can be taken to ameliorate the situation and create a more stable and healthy environment, but the task is urgent and needs to be approached in a holistic way that deals with socio-economic as well ass ecological problems.*

1. INTRODUCTION

Sand and dust storms are phenomena particularly common to the Central Asian arid and semi-arid regions. The small amount of atmospheric precipitation, vast areas of sandy and clayey deserts, poorness and scarcity of vegetation cover, and strong winds all cause dust storms.

Despite the fact that sandstorms in Central Asia are widespread phenomena, they had not been studied before the 1920s. The deep and systematic study of the dust storms in Central Asia started in the 1950s with development of the virgin lands in Kazakhstan. For the most part, this study dealt with *"black storms,"* formed as a result of deflation of ploughed chestnut soils, and served as indirect indicator of wind erosion of the soil. White or salty storms, caused by deflation of the solonchak, salty and other saliferous loose deposits saturating the air by salt particles before the 1960s, were rare. Starting with the intensive development of irrigation in the Aral Sea basin at the beginning of the 1960s and the irrational use of water resources, significant areas of secondary salinized lands and anthropogenic solonchak appeared. These areas are the sources of salt transfer that negatively affect the environment and living conditions of the local population. However, there is no comprehensive study of dust and salt storm frequency, distribution and seasonality in the Central Asia region, and this investigation is designed to go some way towards filling this gap.

2. GENERAL CHARACTERISTICS OF DUST STORMS IN CENTRAL ASIA

Dust storms (DS) in Central Asia have some general peculiarities and features. Systematic observations on dust storms began in 1936 in meteorological station networks. These observations are limited by visual estimation of storm duration and intensity, and horizontal visibility range. Meteorological stations do not carry out any instrumental measurements of amount, concentration and composition of solid particles in the airflow.

The first generalization of climatic observations on dust storms was done in the 1960s. N. N. Romanov (1961) presented the review on dust storms regime in Central Asia and southern Kazakhstan based on observations over a 5-year period. In addition to frequency and duration of dust storms for this period, Romanov gave a classification of synoptic pre-conditions of dust storms' onset and developed recommendations on their forecasting. He showed that in the major part of Central Asia, the northern, north-eastern and north-western winds cause the dust storms, while in the south of Turkmenistan – eastern and south-eastern winds favor the formation of dust storms.

N.S. Orlovsky's study (1962) deals with detailed spatial-temporal distribution of dust storms in Turkmenistan by observations in 1936-60 from 42 meteorological stations. At the same time several papers on characteristics of dust storms over different regions of Kazakhstan were published. After investigation of the main synoptic situations leading to the formation of dust storms in Kazakhstan, A. E. Seredkina (1960) drew attention to the great variety in seasonality of dust storms. A. S. Uteshev and O. E. Semenov (1967, 1972) carried out an analysis of the number of days with dust storms in northern Kazakhstan, while L.P. Fedyushina (1972) presented data for southeastern Kazakhstan. A description of spatial distribution and duration of DS in 5 administrative districts of Western and Southern Kazakhstan was done by A. P. Agarkova (1972). In 1978 the refined map of the average annual number of DS for Kazakhstan was published (Semenov and Tulina, 1978). S. A. Sapozhnikova (1970) divided the Central Asia and adjacent areas according to DS frequency based on data for 1936-64.

2.1. Frequency, distribution and seasonality

The spatial distribution of the average annual frequency of DS differs in the northern and southern regions of the area under research (*Figure 1*). Soil and climatic conditions could explain it. In this vast area, sandy deserts such as Karakum, Kyzylkum, Muyunkum, Sary-Ishikotrau, Taukum, Sundukli and some other smaller deserts, are situated. In Kazakhstan alone there are about 45 sandy massifs within the total area of 336,000 km² (Kurochkina, 1978). Besides the sandy areas the crushed-rock gypseous Upstart desert occupies the vast territory in the northwest of the region, and the stonnesy Betpak-Dala desert – in the north; the narrow strip of the loess deserts stretches along piedmonts, and solonchak deserts are embedded in the numerous separate depressions.

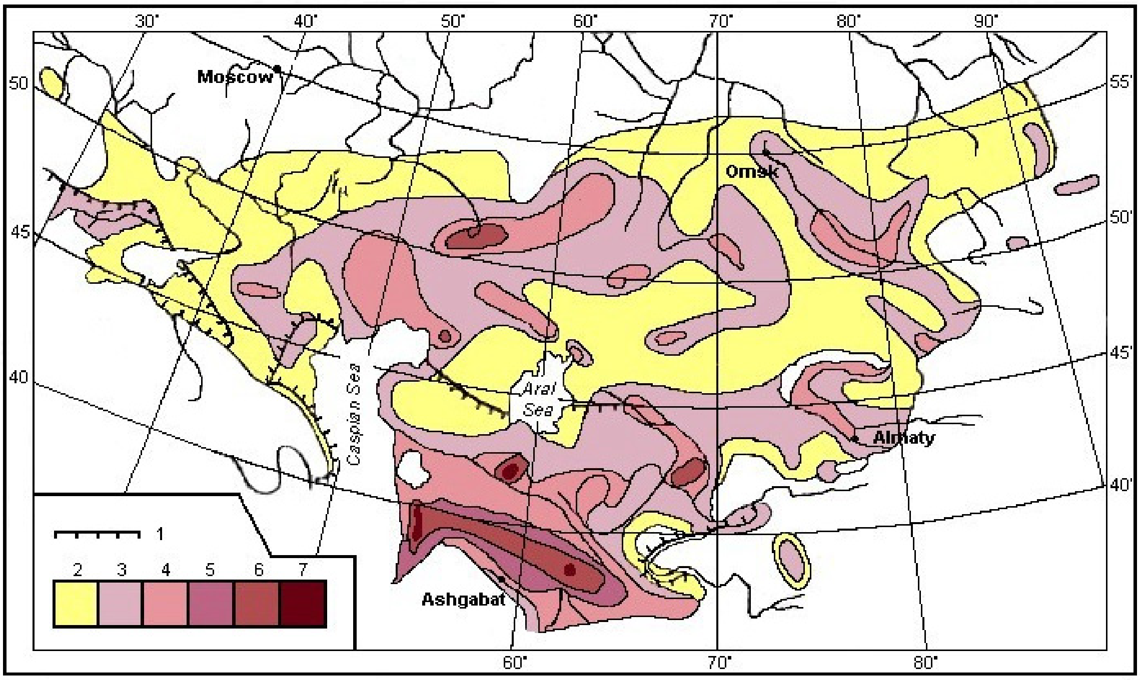

Figure 1: Spatial distribution of annual average DS frequency

Central Asia belongs to the arid and semi-arid climate zones. Latitudinal zonality and peculiarities of the regime of atmospheric circulation lead to significant differences between climatic conditions in the northern and southern parts both in the cold and warm seasons.

The northern area during the cold season is situated in the sphere of activity of the winter Siberian anticyclone. The severe and long winter with severe frosts and lasting snow cover in most years is typical for this area. In the southern part winters are mild with unstable snow cover and often with transition of temperatures above 0^0.

Peculiarities of atmospheric circulation significantly influence the regime of precipitation. The change of air mass takes place over the southern part of Central Asian deserts: the air mass of the temperate-zone prevails in winter and continental tropical air in summer. At the same time there is no pronounced seasonal change of the air mass over the northern regions, the air of the temperate latitudes prevails here round the year. Consequently, in the southern areas with intensification of cyclonic activity, the atmospheric precipitation gradually increases starting in October with the maximum in March-April. In May there is a sharp decrease of precipitation, and in July its amount is close to 0. In the northern areas precipitation are distributed more evenly: there are two small peaks – in late autumn and late spring.

Analysis of the yearly distribution of atmospheric precipitation over the area under research shows that summer precipitation jumps to an infinitesimal minimum in the region between 42-45^0 NL (Chetyirkin, 1960). Usually the boundary between northern and southern sub-zones of Central Asian deserts is drawn along this break: from the northern part of Kara-Bogaz-Gol Bay through Amudarya River delta and Bukantau mountains to the Karatau range.

The northern deserts' sub-zone (from Precaspian lowland in the west to Jungaria in the east) is characterized by dry climate with warm summer and moderately severe and insignificant snow cover winter. It includes the northern Precaspian area, Mangyshlak, northern Ustjurt, Muyunkum, the Pribalkhash area and Jungaria.

The southern sub-zone is characterized by dry climate with very warm summer and moderately mild winter. It occupies the southern regions of the Aral-Caspian lowland – south of Ustjurt, Krasnovodsk plateau, Karakum desert, and Central and southern Kyzylkum desert (Chelpanova, 1963).

In the northern sub-zone the distribution and frequency of DS is characterized by significant spottiness, in southern Central Asia its zonality is typical. The number of days with DS increases from northwest to southeast, and reaches its maximum in the Central Karakum Desert.

In the northern sub-zone distribution of DS over the area and its frequency is extremely heterogeneous and spotty. The sites with high frequency (20 and more days with DS per year) are situated in areas with higher wind speeds and soils with light texture, which are under intensive use, or in sandy areas with sparse vegetation. Such sites with a high number of DS days are in the Precaspian lowland, in the Volga-Ural sandy massif. The average annual number of days with DS here is 20-30 days, with maximum 67-108 DS in some years. In the south of Kazakhstan the number of days with DS is higher in the sandy deserts and river valleys. The average number of days with DS in Syrdarya and Ili Rivers is 28, maximal 67; in the southern shore of the Balkhash Lake these figures are 30 and 103 respectively.

In the southern sub-zone of the area under research, where the large sandy deserts are situated, the zonal distribution of the average annual number of days with DS is typical. The maximum was marked in the Central

Karakum Desert, where the number of days with DS is more than 60. The highest frequency of DS is observed in the area of sand dunes: it reaches 62 days in the eastern Karakum (Repetek) and 67 days in the west (complex of sand dunes and solonchak). In some unfavorable years, DS frequency in Central Karakum is as high as 106-146. It means that the Central Asian region is one of the main sources of dust that is transferred by air masses to other areas.

The atmospheric precipitation (seasonal distribution, amount and kind of precipitation) influences the seasonality and frequency of DS significantly. In the northern sub-zone atmospheric precipitation falls year-round, with stable snow cover in winter. Thus, in the northern part of this sub-zone DS occur mainly from April till October, rarely extending from March to November. In the south DS occur in all seasons of the year.

In the southern sub-zone of Central Asia most of the meteorological stations show that the maximum of DS frequency is in May (*Figure 2*). In the western and central areas this maximum is more diffused in comparison with northern areas, and extends into the summer months. Thus, in the western part of the sub-zone the maximum is equally probable to arise in June, July and August. In northern Ustjurt the main maximum is in April, and a smaller one in June and September. In the southeast of the northern sub-zone the highest number of days with DS is observed in June, and in the south in July and August.

Thus, in the northern sub-zone moving from the north to the south the maximum number of days with DS shifts to the later months. The distribution in the south does not agree with the yearly variation of wind speed. There is a maximum in spring (April-May). It could be explained by the yearly distribution of precipitation (Semenov and Fedyushina, 1970). In the south and southeast of Kazakhstan precipitation peaks coincide with higher wind speeds, but the maximum number of days with DS has been observed in the relatively dry summer period.

In the southern sub-zone of the area DS occur in all seasons of the year. The stable snow cover is absent here, and precipitation falls in winter-spring. Summer is characterized by a lack of rain and high air temperatures. The minimal frequency of number of days with DS is marked in January and December. The exceptions are mountain meteorological stations, where the minimal frequency of number of days with DS has shifted to summer. The maximum number of days with DS on the plains is observed mainly in summer (June and July); sometimes it shifts to the autumn (August and September), or there are two maximums: spring-autumn and summer-winter (*Figure 2*). In the mountain areas the maximum of DS falls in winter (Orlovsky, 1962).

Figure 2: DS frequency throughout the year

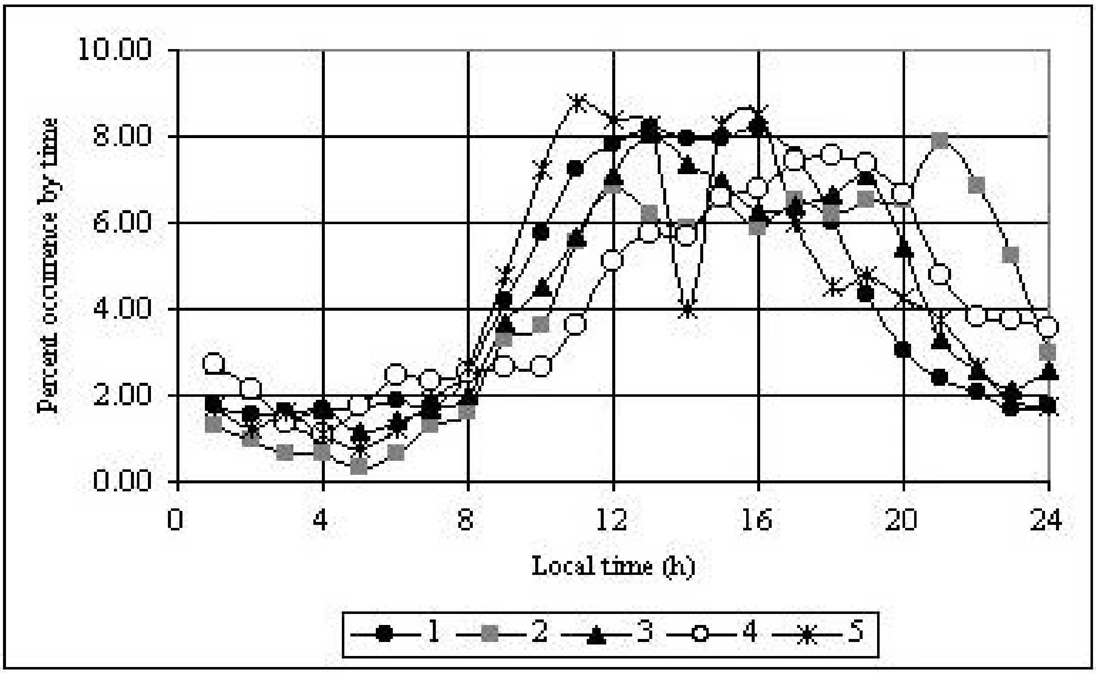

Figure 3: Diurnal march of DS in Turkmenistan for 18 stations from 1981-95

2.2. Diurnal variation

We defined the diurnal march of DS for 18 stations in Turkmenistan during the period 1981-95. Maximum DS occur (as a rule) in the daylight time (*Figure 3*). The number of DS events increases after 5 AM, reaching its maximum at 11-12 AM or 15 PM, after which it gradually decreases. In the piedmont areas it shifts towards later hours. It is connected with more active convections in the past morning time over the mountain areas.

The main factor, stimulating the diurnal variation of DS, is diurnal variation of wind speed with observed maximum in the afternoon hours, and drying of the soil in the daylight hours. Nevertheless, the diurnal march of the wind speed with maximum in the second half of the day and minimum at night and morning hours is observed mainly in summer and winter. In transition seasons, during cyclone discharge and cold front passage, the diurnal march of the wind speed and, consequently, the diurnal variation of DS are deranged. Thus, the great frequency of DS in the night hours is observed in spring and autumn.

It should be marked that clearly expressed diurnal variations of DS are connected with the southern and southwestern periphery of anticyclone and northwestern periphery of thermal depression that prevail over eastern Turkmenistan. Dust storms conditioned by thermal depression occur periodically in the afternoon hours and cease towards the night hours following the diurnal march of the air pressure (Synoptic processes, 1957).

2.3. Duration of dust storms

In the northern sub-zone of Central Asia the frequency of DS with a duration of more than 3 hours is rather high and changes in the range of 20-73%. In the north of this area and in the stonnesy semi-deserts and clayey deserts DS are short – not more than 1.5 hours. The frequency of DS with duration 5.5-10.4 hours increases sharply in areas with light soils. The frequency of DS with duration 12 hours and more is about 3%, and only in the narrow strip of Central Kazakhstan that is widening to the southeast in the Muyunkum sands and southern Balkhash, it is more than 3% (Semenov and Fedyushina, 1970). The largest duration of one DS event (116 hours) was observed only once, from 1936-72. DS with duration greater than 3 days were observed on three occasions (Semenov and Tulina, 1978).

In the southern sub-zone the largest number of hours with DS during the year occurs in the months with the largest number of days with DS. The average duration of DS in the plain and piedmont areas of Turkmenistan varies from 0.5-23 hours in January, and from 6-56 hours in July. Dust storms of short duration are typical for the southeast and south of Turkmenistan (Kara-Kala, Kushka) where their maximal average monthly duration is not more than 6 hours.

In many areas of Turkmenistan in some years the duration of DS for the year reaches the largest for Central Asia values. Thus, in western Turkmenistan (Molla-Kara, Nebit-Dag, and Aidin) and in southeast Karakum (Tedjen, Cheshme, and Repetek) the duration of DS more than 500 hours per year was observed, while the maximal duration of DS in Repetek is 721 hours. In July 1942 in Repetek the total duration of DS was 176 hours, with annual average about 6 hours.

In the most part of the Central Karakum Desert the maximal duration of DS is recorded in the spring. Thus, in Chagyl in March 1949 a dust storm lasted 39 hours, in Kyzyl-Atrek in February 1957 57 hours and in November 1952 in Nebit-Dag 60 hours. It is interesting to note that in Nebit-Dag maximal duration of DS less than 12 hours was recorded only in September. This means that duration of DS is longer in areas with more frequent DS.

In the piedmont plain of the Kopet-Dag mountains (Kyzyl-Arvat, Aidin) the maximal duration of DS is 24 hours and is likely probable in all seasons throughout the year.

Mean annual duration of DS varies from 350 hours in the west of Turkmenistan to 15 hours in the southwest. In the mountain areas the duration of DS is insignificant. Less than 100 hours with DS per year were recorded in the piedmonts of the Parapamiz and Kugitang-Tau mountains, in the Murgab oasis and along the Amudarya River valley. In central Karakum the mean annual number of days with DS is more than 200, and its maximal duration (350 hours) was marked in the west (Nebit-Dag) (Orlovsky, 1962).

2.4. Dust storm frequency over time

The annual variation of the frequency of number of days with DS for long periods is of certain interest for researchers. We studied the annual variation of DS for 60 years (1936-95) by 18 meteorological stations situated in different regions of Turkmenistan. The common observation for all areas is the sharp decrease of DS frequency after 1980-85 (*Figure 4*). There are two peaks of DS in northern Turkmenistan; in Central Karakum there is one clearly expressed maximum of DS frequencies. In some stations this maximum is not expressed.

The decrease in frequency of DS after 1980-85 was also recorded for other areas of Central Asia (Usmanov, 1998; Chube, 1998; Galaeva, 1998). Thus, in the region around the Aral Sea there was a threefold increase in the frequency of DS in the period 1960-80, and starting from 1980 it decreased significantly (Usmanov, 1998).

Such variation in DS frequency could be explained by periodic changes in global atmospheric circulation. The period 1930-60 is related to the first circulation period with enhancement of the frequency of the latitudinal circulation. In the second circulation period (1961-85) the frequency of latitudinal circulation type decreased, and the meridian type of circulation dominates. At present, we are witnesses to the activating latitudinal character of circulation and sharp decrease of meridian type circulation. Possibly, the period of 1986-93 was a transitional period to the new circulation epoch (Muminov and Inaganova, 1995). That can explain the observed increase in the frequency of number of days with DS in 1993-95 (*Figure 4*). It means that using such parameters, frequency of DS as criteria for desertification processes development, is not correct without considering other factors.

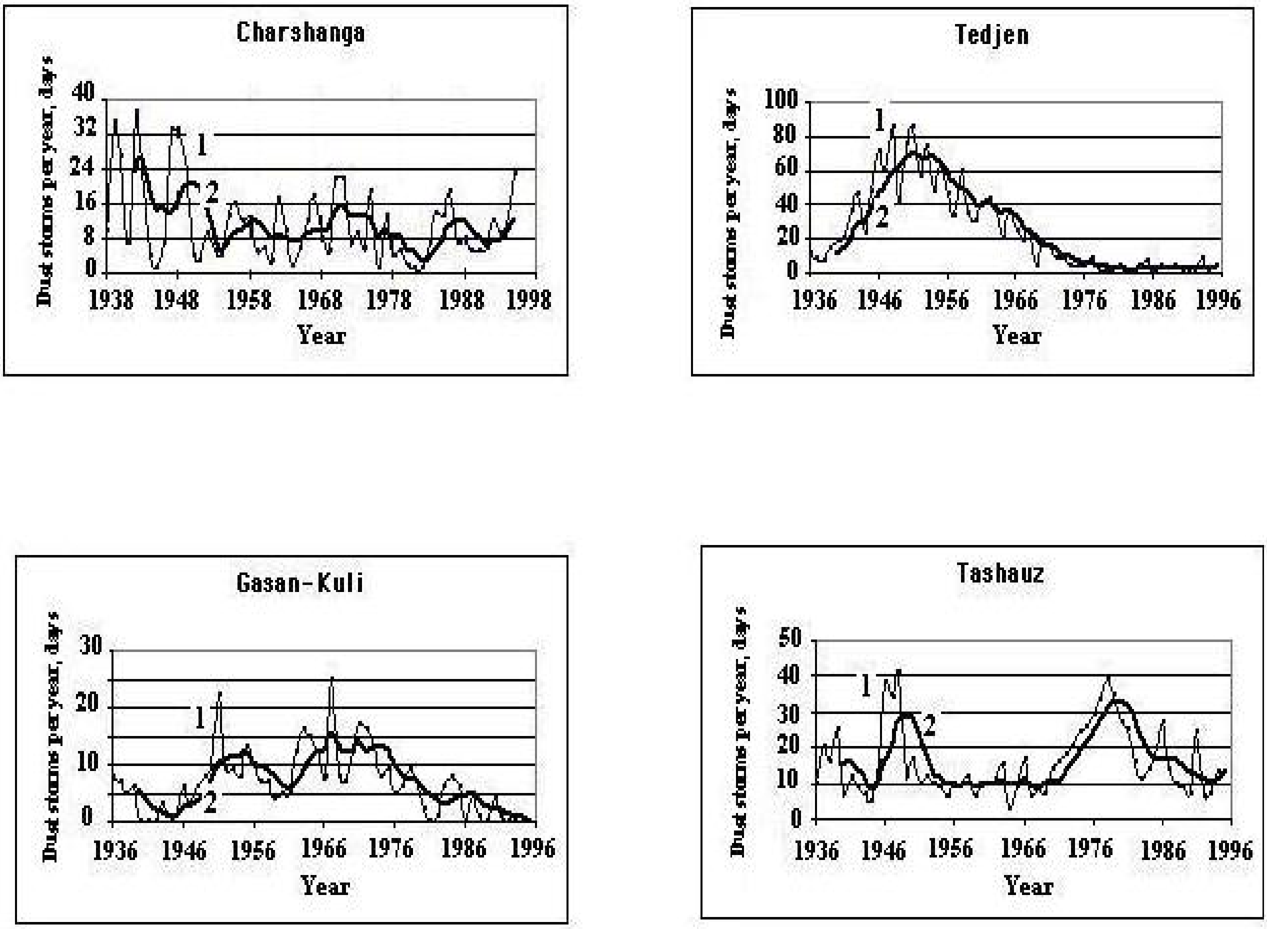

Figure 4: Decrease of DS frequency after 1980-85

3. WHITE DUST STORMS IN THE 1970S IN CENTRAL ASIA

Salt is an indispensable component and companion of dust. Dust-salt storms were observed over the giant solonchaks of Central Asia, in Iran, India and the western deserts of the USA. White dust storms consisting only of salt particles are relatively rare. They are characterized by white or grayish dust colour because of the big amount of salt particles (mainly gypsum and halite). White or salt storms are formed as a result of the deflation of solonchak, salt deposits or other loose rocks that saturate the air by dust particles.

Salinized soils are the typical landscape in deserts and occupy 14% of the total area of arid and semi-arid soils of the world (Lobova and Khabarov, 1977). Solonchak occupy an area of 868.9 thousand km²; about 50% of them are in Eurasia. The most active source of salts is meadow crusty and puffy solonchak, which comprise 10% of the total area of solonchak in arid and semi-arid zones.

In Central Asia solonchaks occupy more than 150,000 km²: 24,000 km² in Turkmenistan, 15,000 km² in Uzbekistan, 1,000 km² in Tadjikistan, and more than 110,000 km² in Kazakhstan (Pankova et al., 1996). These soils could be considered salt accumulators and places of aeolian blowout, or removal of salts. The main typical indicator of solonchak is a high salt concentration in the upper layer of soil. In spring and autumn the volume of readily soluble salts in the layer 0-10 cm of meadow crusty and puffy solonchak is more than 50% of its total content in the upper half-metre layer. The loose structure of the upper accumulative salt horizon and sparse vegetation favor the blowing off of salts by wind.

Solonchak of Central Asia occupy depressions where the intensive salt accumulation conditioned by close occurrence of saline groundwater takes place. Large areas of solonchak are found in the deltas of the Amudarya, Murgab, Kashkadarya, Zeravshan and Chu Rivers, the eastern part of the piedmont plain of Kopetdag, in the coastal zone of the Caspian and Aral Seas and Lake Balkhash.

Sand-salt storms were a rare phenomenon before the 1970s. With intensive development of the natural resources in the Aral Sea basin at the beginning of the 1960s the frequency of such storms increased significantly. It means that dust-salt storms have both a natural and anthropogenic character.

3.1. Natural white storms

Most of natural dust storms mixed with salts could be observed in Central Asia, southern and western Kazakhstan, and the northern Caspian region. Nevertheless, the natural white storms were recorded mainly in the low and middle part of the Volga River. This is because 1) these areas are more densely populated, and 2) they are situated in zones where dust and salt originated from the Aral-Caspian lowland deposit.

These events were observed in the Volga River valley in 1948 (Sakharov, 1948), in spring 1950 (Motorin, 1954; Zamorsky, 1952) and 1955 (Kravchenko, 1959). During these events the deposition of white salty or bitter-salty powder on the windward side occurred only by eastern and southeastern winds. In April 1950 a salt storm event occurred in the lower Volga River valley. The accumulated layer of dust was very small – less than 1 mm, but all the objects looked gray, and the vegetation looked as though it was covered by hoar-frost (Zamorsky, 1952). These dust-salt deposits were caused by dust storms that occurred from April 4-7, 1950 over the Aral-Caspian lowland and the northern Caspian lowland with many solonchak. The distance of salt and dust transfer from the places of their origin reached 400 km during this event (Zamorsky, 1952). The haze was observed at a distance of 500-600 km from its origin.

More intensive white storms were observed in this area in April 1955 (Kravchenko, 1959). The first storm started on April 10 1955 over the Aral-Caspian lowland. The wind speed reached 15-20 m/sec from eastern and southeastern directions. At a height of 3 km it was as high as 50-60 km/hour. These air streams raised dust and salt and transferred it to the middle and lower parts of the Volga River. Several meteorological stations on April 11-12 recorded the dust and salt as a dry haze.

In Elista town (Kalmyk Republic) the dust appeared at 6 AM on April 11, and reached its maximum at around 4 PM. The storm stopped the next day, April 12 at 5 PM. The windward side of the objects and plants had been covered by an ashen-gray deposit about 0.1 mm thick. Chemical analysis revealed that 47.4% of the deposit was soluble salts, and 52.6% insoluble residue. From the total amount of salts, sulfates accounted for 90.6%, chlorides for 7.4% and bicarbonates for 2%. According to approximate estimations, each hectare of soil received about 25 kg of sodium sulfate. An even stronger storm occurred from April 18-22, 1955. Such cases of salty dust sedimentation should be classified as rarely observed phenomena by their intensity and extension. On April 18, 1955, wind speed in the west of Kazakhstan reached 15-20 m/sec, and even 20-25 m/sec, i.e. almost hurricane force. The raised mass of dust moved to the northwest and north, to the middle and upper Volga. On

April 19 the dust reached Gorky City and brought about haze with visibility of 1,000 m. According to aerial observations the upper boundary of the dust reached 3-4 km. Soon after, dust appeared from the southeast in the form of a dense cover of dry fog. A whitish deposit with a bitter taste covered the soil surface, ground objects, vegetation and animals. The deposit was 1-2 mm thick, sometimes even 2-4 mm. Chemical analysis demonstrated that the deposit consisted mainly of sodium sulfate, sodium chloride, salts of magnesium, particles of gypsum and silica. As mentioned above, the white salt storms were observed earlier, but the storm of April 18-22 1955 was exceptional and spread over an area of more than 500,000 km².

Dust-salt transfers to the Volga valley could be seen on satellite images (*Figure 5*). There is a traveling depression in Central Asian deserts – from the eastern part of the northern Caspian Sea between the Krasnovodsk peninsula and the Ural River mouth; storms carry large amounts of salts and dust through this area. The prevailing southeastern and eastern winds often turn into storms and even hurricanes here. These storms raise huge volumes of salts and dust when passing the old channels of Uzboi and solonchak of the Karakum desert and the Caspian shore, and move them to the Russian platform. In the vast Volga valley salt sediments on insulators and supporting structures damaged the electric power lines. These phenomena confirmed that salt dust was transferred by strong southeastern winds from the northern Caspian and Aral-Caspian lowland.

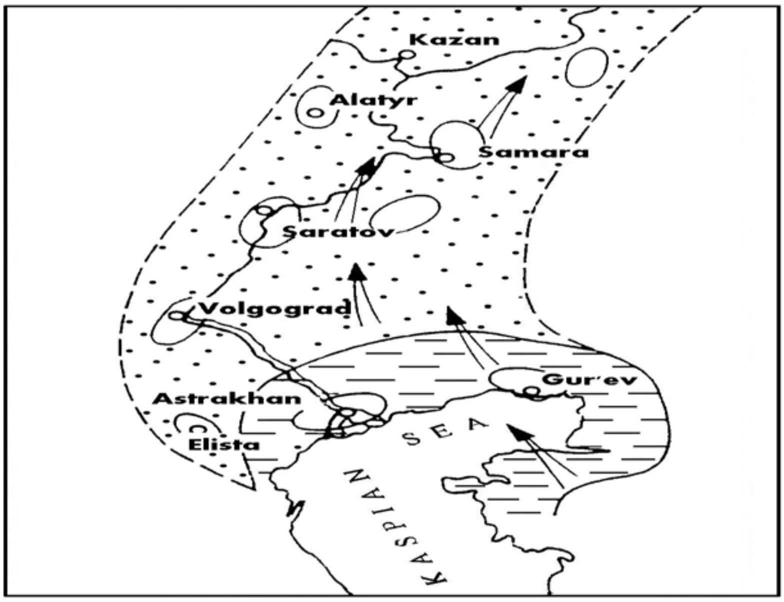

Figure 5: Dust-salt transfers to the Volga valley

The approximate volume of aeolian removal of salts from the meadow crusty-puffy solonchak is 5,000-7,000 tonnes/km² per year (Orlova, 1983; Kozhevnikova, 1959). About 728 tonnes/km² of salts are blown from the territories with spotty salinization where the soils are hydromorphic with high salt content in the surface layer (Orlova, 1983).

According to these estimates about 109.2 million tonnes of salts per year are blown out from the solonchak of Central Asia. This estimation is very approximate, because the salt transfer from solonchak is significantly larger. By M. A. Orlova's estimation (1983) meadow crusty-puffy solonchak, which occupy 86,890 km² in the world, could supply the atmosphere about 520 m tonnes of salts annually. From the rest of the desert area (45,308.81 km²) including less dynamic solonchak, salt removal is 780 m tonnes, and from all arid areas of the world about 1,300 m tonnes per year. Thus, according to very modest estimations the solonchak of Central Asia contributes about 10% of the salt removal of all solonchaks of arid and semi-arid zones.

3.2. Anthropogenic white storms

The distinctive feature of the ecological situation in 20th Century is that the human pressure on nature is not limited to small territories, but spread over vast regions. In some cases the changes in the environment are not significant and do not threaten human health and activities. Nevertheless, in areas where the natural balance is disturbed by human activity, environmental changes threaten human health and activities, especially regions with an unfavorable ecological situation. Central Asia is one such region. Here, large-scale anthropogenic changes lead to the formation of dust-salt-raising places: 1) in the 1950s in connection with development of virgin lands in Kazakhstan, 2) in the 1970s with construction of the dam in Kara-Bogaz-Gol and 3) with large-scale development of the lands under irrigation in the Aral Sea basin.

3.2.1. Kara-Bogaz-Gol Bay

The total area of Kara-Bogaz-Gol is about 18,000 km². It decreased to 7,678 km² in 1980 with the decrease of the Caspian Sea level. In order to stop the decrease of the Caspian Sea level the dam separating the sea and the bay was constructed in the spring of 1980. It was the next *"victory"* over nature, and humans again started to struggle with the problems created by their actions. The dam separating the bay from the sea brought about the drastic shallowing of the bay, and later its complete drying. It took only 4 years for the total drying of the bay; in its place the giant, dead (and dangerous for the environment) salty desert was formed. As a result the anthropogenic source of salt transfer has appeared. The salts from Kara-Bogaz-Gol were recorded in the Pamir piedmonts. A bank of pipes was built in the body of the dam in 1984 for delivering water to the bay, and finally, in 1992 the dam was destroyed. In May 1995 the water level in the bay was raised by 7 m, and the bay was almost filled with water.

3.2.2. The Aral Sea

If the anthropogenic salt-transfer source in Kara-Bogaz-Gol was successfully eliminated, the activity of the second anthropogenic place of white storm origin in the Aral Sea region is increasing. Significant changes in the environment have taken place here; they have not only local, but regional character. These changes in ecology of the Aral Sea basin occurred because of regulation of the rivers and the irreversible off-take of river flow for irrigation.

The sharp decrease of the Amudarya and Syrdarya Rivers discharge started in 1961, and brought about the drastic drop of the Aral Sea level. During the last years the total discharge of these rivers decreased to 4-5 cubic km per year, while in 1960 it was 55-60 cubic km per year. Such intake together with atmospheric precipitation over the sea surface (9-10 cubic km per year) and insignificant groundwater discharge balanced the evaporation. The sea level at marks close to 53 m MSL had an average depth of 16 m, and area of the water surface was 66-67,000 km². By 1999 the sea level dropped more than 18 m, and to the mark of 33.8-m MSL. The width of the exposed and dried bottom exceeds 120 km, and its total area is about 40,300 km² (Breckle et al., 2001). The Aral Sea is disappearing from the Earth in the space of one human generation, and in its place the youngest of the world's sandy-solonchak desert *"Aralkum"* is forming (*Figure 6*).

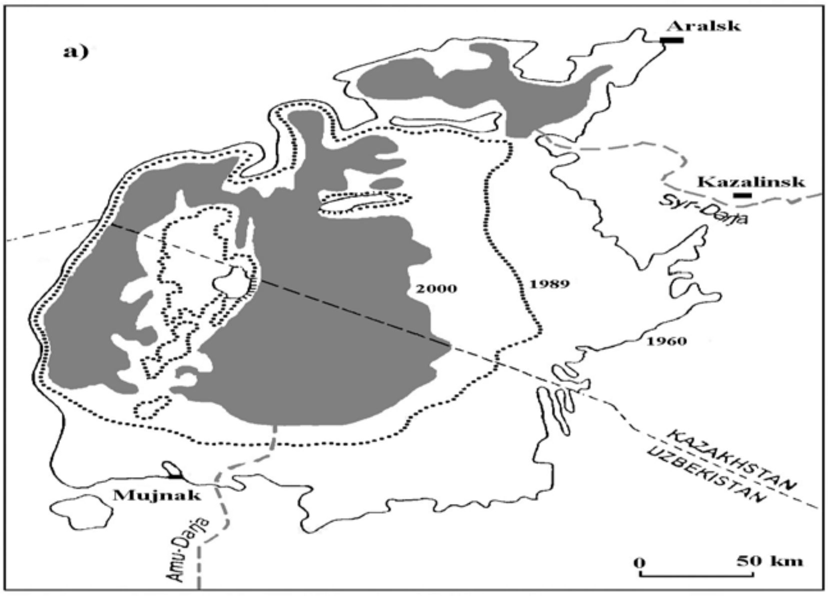

Figure 6 (a): Aralkum

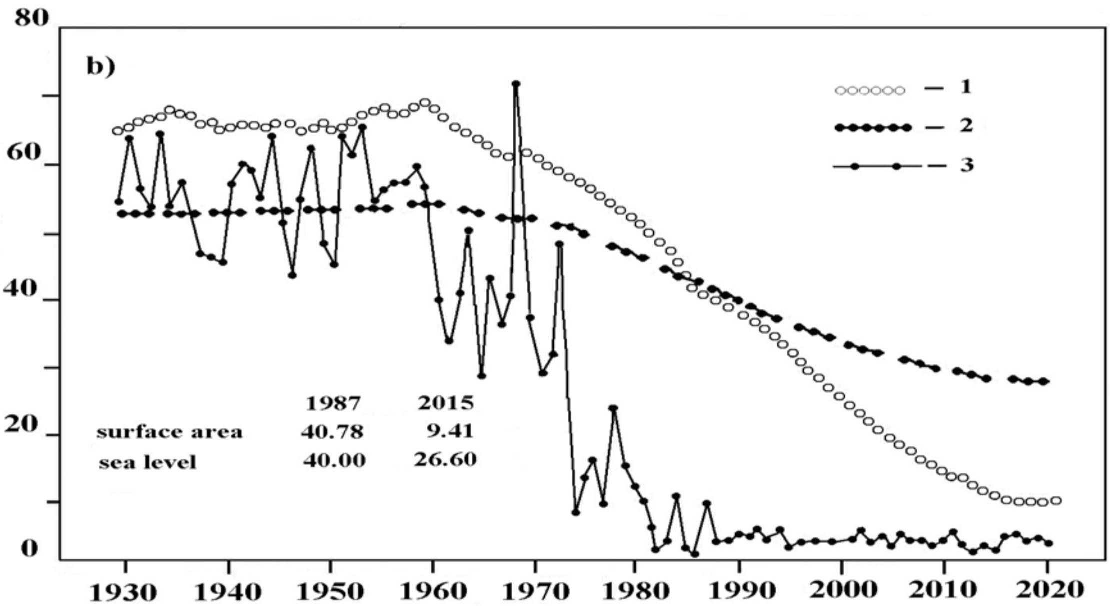

Figure 6 (b): Aral Sea level

The decrease of the sea level has led to a change in the halogeochemical process. Before the level decrease, the Aral Sea was a receiver of salts. About 23.8 m tonnes of salts per year came into the sea with the surface flow, and about the same volume with the underground flow (Chernenko, 1986). At present the drying coastal zone is a deliverer of salts for transportation to other regions, because the exposed bottom of the sea represents a giant solonchak surface.

By their morphological features the soils of the dried bottom are crusty and puffy solonchak. The marshy solonchak developed on an area of 2,000 km² (Rubanov et al., 1998). By chemical composition the soil is sulfate-chloride and chloride-sulfate, formed on the sandy and sandy loamy maritime soils. By salt content the soils are heavy salinized soils with 8-10% and more of sulfate and chloride salts. The store of the latter in the aeration zone of ground is 2,200 tonnes per hectare.

Predominance of the soils with light texture favors the development of wind erosion processes and formation of aeolian forms of relief. In aeolian massifs the sands of inter-dune depressions are slightly or moderately salinized. In small barchan massifs the store of sulfates and chlorides in the aeration zone is 180-270 tonnes per hectare and in the high dunes 104 tonnes per hectare. Salt content in barchan is not more than 0.1-0.3%, dusty fraction is 4-6% (Rubanov et al., 1998). Intense salt accumulation and aeolian transformation of the dried bottom of the Aral Sea led to the formation of a powerful site of salt and dust transportation aggravating the ecological situation of adjacent areas.

4. ARALKUM – NEW POWERFUL SOURCE OF SALT AND DUST TRANSFER

The dry strip around the Aral Sea started to form in 1961. However, the unusually strong dust storms were not observed here till 1975. For the first time a dust storm in the northeastern coast (to the south of Syrdarya River delta) was recorded by satellite imagery in 1975 (Grigor'ev and Lipatov, 1974; 1979). To this day, a dry sandy surface with a width of 20-25 km and a length of 100 km was formed here. Eight dust storms were recorded here in April-June of 1975: 5 events from April 2-May, and 1 in June (29 large dust removals with a distance of 200-450 km towards the west and southwest were recorded by satellite imagery from 1975-81). During the next five years (1985-90) an increase in the number of dust storms to 5.5 events a year was observed by satellite imagery together with revelations of new large dust-raising sites on the dried bottom near Vozrozhdenie Island and the Kulandy Peninsula. However, the low spatial and temporal resolution of the images and high cloudiness does not allow recording of all dust storms. On the whole, the number of events should be much higher than was recorded (Grigor'ev and Lipatov, 1982). Nevertheless, further observation from space made it possible to reveal the main sites of salt- and dust cloud formation, their size and main directions of salt and dust transportation (Grigor'ev and Lipatov, 1982; 1983; Grigor'ev and Djogova, 1992).

4.1. Areas of dust and salt transfer

Significant changes of both the site and structure of dust blowouts were noted during observations on the formation of dust storms on the northeastern coast of the Aral Sea. By decreasing the water surface the area of deflation and the number of dust-raising sites increased. In 1986 three powerful sites of deflation were observed: Vostochniy, Saryshiganskiy and Kokaral'sky. Presently there are four anthropogenic sources of aerosols in the Kazakh part of the dried Aral bottom:

i. In the north – the bottom of the former Saryshiganak Bay.
ii. Sandy beaches around the former Kokaral and Barsa-Kel'mes islands.
iii. In the east – the dried bottom of the sea from the outlet of the Syrdarya River to the Akpetkin archipelago.
iv. In the west – a newly formed large island in the place of the Vozrozhdenie and Lazareva islands (Galaeva, 1998).

Also the intensity of salt and dust blowouts changed with time. For instance, on May 22nd 1975, the dusty cloud over the Aral Sea had an area of 14,000 km². The dusty cloud observed on May 6 1979, by the same synoptic situation, had an area of 45,000 km². Analysis of the satellite images (Grigor'ev and Lipatov, 1983) demonstrated that the structure of the dust flow depends on the moisture content of the underlying surface. In 1975 the dust flow over the Aral Sea in most cases was divided into two big streams 30-40 km wide. Such division was determined by the structure of the dust-raising site. Both streams originated in places with dry sands. In 1976 the structure of dust removal changed; division into two streams is not experienced any more, and the dust is blown evenly from the whole coastal area.

4.2. Distribution of dust transfer

Transfers of salt and dust are usually directed to the south-south-west towards the Amudarya River delta and the Ustjurt plateau (*Figure 7*), but in some cases they stretch to the east-south-east towards the Syrdarya River delta (Grigor'ev and Lipatov, 1982). Analysis of space images for 1975-81 revealed that in 60% of all cases the salt and dust blowouts were moving to the south-west to oases in the Amudarya delta, in 25% of events to the west to the Ustjurt plateau, and in the rest of the cases to the south and southeast (*Figure 8*). In 1975 salt-dust transfers were mainly spread over the Aral Sea and rarely over adjacent coastal zones. In 1975 only one dust storm from the 8 recorded storms reached the opposite seaside. In 1979, by contrast, in 6 events from the recorded 7 salt-dust storms, dust reached the western and southwestern coasts of the sea. The average length of the salt-dust flow in 1975 was 180 km; in 1979 it increased to 300 km. On May 6 1979 a strong salt-dust transfer over the Aral Sea and Ustjurt with a length of more than 500 km was registered. The area of salt and dust deflation comes to 20,000-30,000 km²; raised and transported salt and dust affects the surrounding territory – more than 500,000 km².

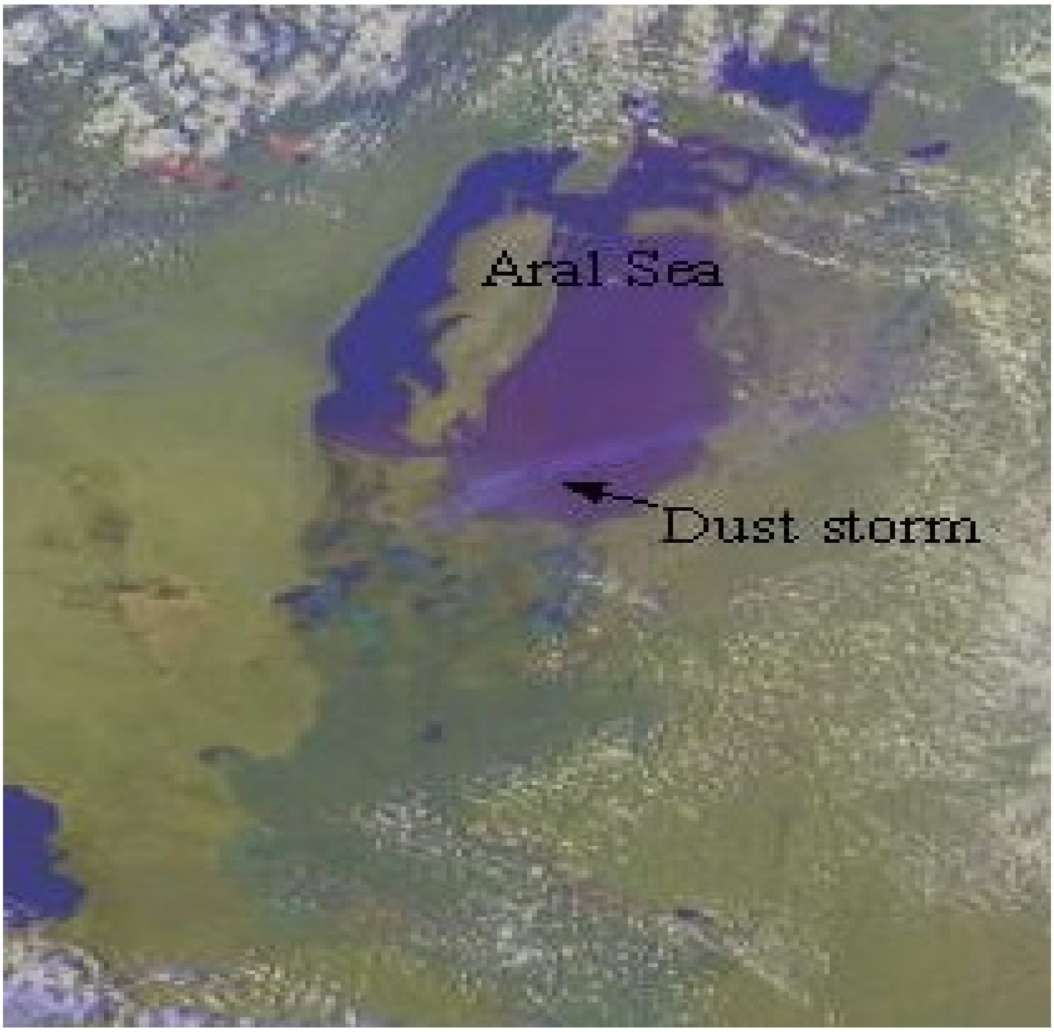

Figure 7: Transfer of salt-dust to the south-south-west

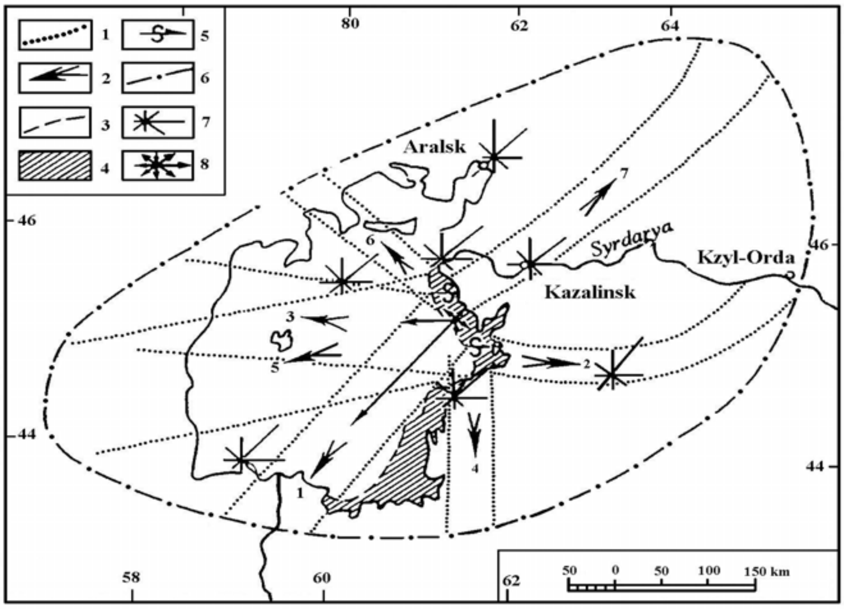

Figure 8: Transfer of salt-dust to the south-south-east

It should be recognized that the satellite images register only cases with very strong atmospheric turbidity so in reality dust and salt could be transported to a far longer distance than can be observed from space. Based on this assumption, Grigor'ev and Lipatov (1983) supposed that salt from the Aral region reaches the Caspian shore and spreads all over the Aral-Caspian lowland.

4.3. Volume of salt-dust transfer

The assessment of the volume of salt-dust transfers from the dried bottom of the Aral Sea and its composition, the directions of its transportation and areas of deposition is of significant importance to the scientific world as well as to the public. This interest is created because of the negative influence of salt storms on the environment and living conditions of the local population. The experimental and theoretical study of the processes of sand, dust and salt aerosol transportation is very complicated. Thus, studying the transportation ability of winds during storms we can estimate only the scale of the aerosol mass and the distance of transportation. Estimations by different researchers of the volume of salt and dust removal from the dried bottom of the Aral Sea are very contradictory. Analysis of satellite images for 1975 shows that the yearly removal of aerosols from the eastern coast to the southwestern direction is 15-75 m tonnes (Grigor'ev and Lipatov, 1982), for 1990 this figure is 90 m tonnes (Grigor'ev and Djogova, 1992). These figures for aerosol transfer are well known and have been quoted in many publications, but require critical analysis. According to our opinion, the estimation of aerosols as 75-90 m tonnes per year by satellite imagery is overstated. First of all, the authors take as a basis the assumption that the duration of each dust storm is 50 hours, and their frequency is 10 storms per year. Data from climatic reference books and the studies of dust storms do not confirm such a long duration of events with such a high frequency and intensity. Second, by such volumes of aerosol removal the denudation of the dried bottom of the Aral Sea should be about 20 mm per year.

In our opinion, more reliable data on salt and dust removal from the dried sea bottom was obtained by Kazakh researchers (Semenov, 1988, 1990, 1995; Galaeva et al., 1996; Galaeva and Semenov, 1997). Based on field measurements on the rate of flow of solid particles and wind speed in the near-ground layer during sand-dust storms and laboratory measurements in a wind tunnel, a climatic model of salt-dust storms was elaborated. This model allows monitoring of the transportation of sand by wind in the near-ground layer based on data of meteorological observations on dust storms. This model can calculate the volume of sand transported during one event, the yearly volumes of transported particles, and multi-year rows of these masses. Such a model, for the first time, allows the detailed estimation of the volume of sand and salt aerosol removal from the Kazakh part of the dried bottom of the Aral Sea, and development of a vector rose map of sand transportation in this region (Semenov, 1988; 1990).

The first assessment of dust and salt removal was done during the period 1969-79. The mean multi-year values of the volume of Aral aerosol transfer to different directions were calculated for two main sources – Saryshigonak Bay in the north, and the area between the Uyaly Island and Syrdarya river delta in the east (*Figure 9*). There is an obvious difference between aerosol transfer from the northern and southern parts. In the north aerosol transportation moves mainly in a northeast and east-south-east direction. More than 8×10^5 tonnes of aerosols per year could be transported in this direction. In the eastern dust-raising places the transportation is directed mainly to the west-north-west and south-south-east, and volume of aerosol reaches 3.4×10^6 tonnes per year.

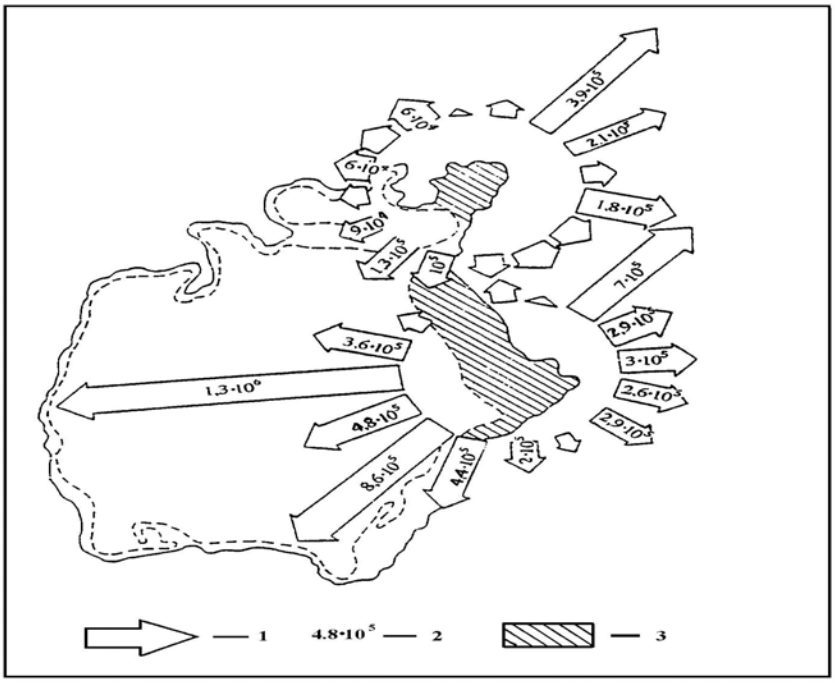

Figure 9: Mean multi-year values of the volume of Aral aerosol transfer in different directions

The total volume transported by airflow aerosol to the all directions from the Saryshigonak area is 1.5 x 10^6 tonnes per year and from the larger eastern area 5.8 x 10^6 tonnes per year. The total volume of transported material for both places for the period 1966-79 was estimated at 7.3 x 10^6 tonnes per year. Since the salt content is 0.7-1.5% of the total transported aerosol amount, the total salt removal from these places is 50-70 thousand tonnes per year (Semenov, 1990). This estimation should be seen as close to the maximum, because it is based on the relationship of the rate of flow of sand particles during the storms and the Frude dynamic number of 5% assuredness. For climatic estimations it is more reasonable to use 50% assuredness, closer to the mathematical expectation. Thus, if we depend on total sand discharge with 50% assuredness (Semenov, 1990), the maximal estimation of salt and dust transfer (7.3 m tonnes) is reduced to 1.6 m tonnes per year.

Monitoring over 27 years of the development of deflation processes on the dried sea bottom showed the cyclicity of wind transportation of the Aral aerosol (*Figure 10*). The first peak was observed in 1970-71 (for meteorological station *"Aral Sea"*) and comes to 9,302 tonnes per year; the second peak happened in 1983-85 and comes to 6,500 tonnes per year. Studying the whole 27-year-cycle, it is obvious that since 1986 there is a tendency for the amount of transported sand to decrease. According to the Uyaly meteorological station maximum sand transfer was observed in 1984, coming to 20,269 tonnes/year, which is two times more than the highest values observed in the northern part of the Aral Sea. There is the same stable decrease of amount of transferred sand from 1986 onwards.

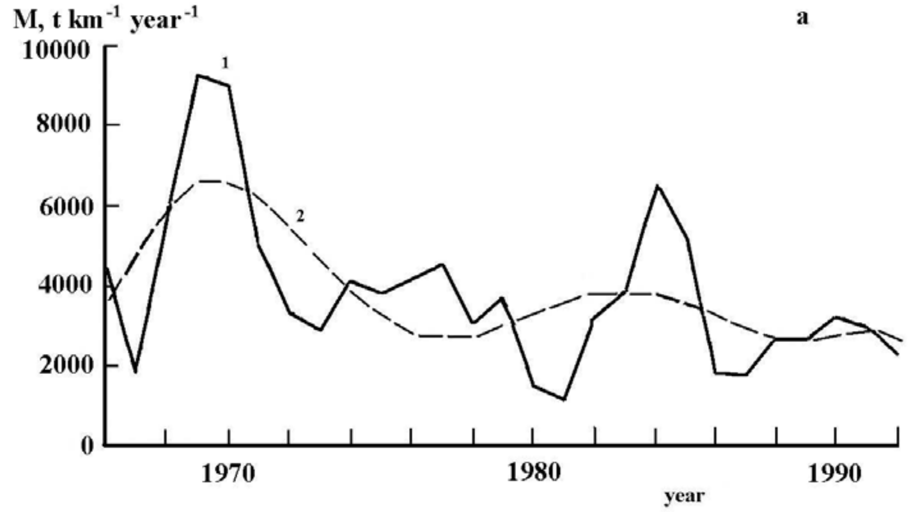

Figure 10 (a): Deflation processes on the dried sea bottom showing the cyclicity of wind transportation of the Aral aerosol

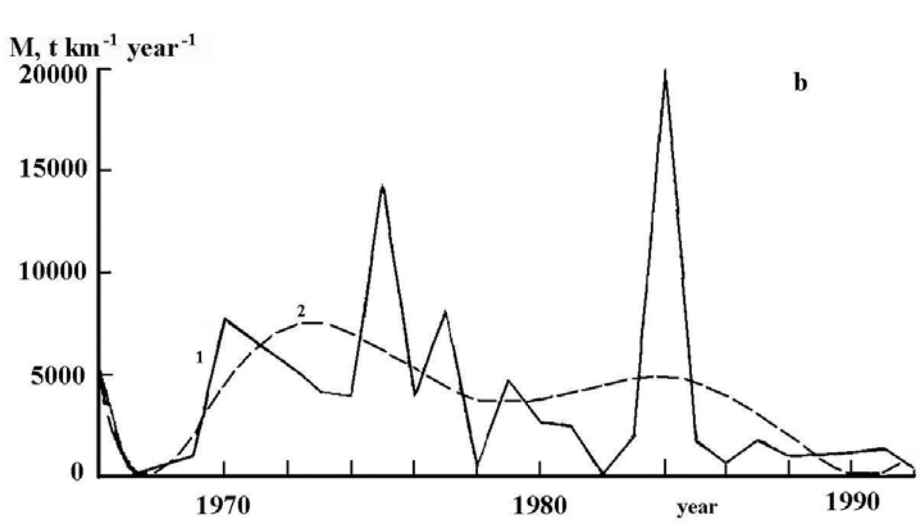

Figure 10(b): Deflation processes on the dried sea bottom showing the cyclicity of wind transportation of the Aral aerosol

In the 1970s, 7 years out of 10 saw the amount of transported aerosol exceeded the average annual value. In the 1980s, 1984 was a year with intense wind activity, while in the other 9 years the amount of removal reached 0.1-0.7 of the average annual value. Thus, in spite of the increase of the area of dried sea bottom the average annual transfer of salt-dust aerosol with 50% assuredness for the period 1966-86 decreased to 1.12 m tonnes per year as a result of the decrease in wind speed during dust storms (Galaeva et al., 1996).

By 1992 the Aral Sea level had decreased by 15 m, and four new sources of aerosols were formed in the Kazakh part of the dried bottom (*see above*). *Table 1* shows the estimated average annual amount of sand removal of 50% assuredness for these 5 places for 1966-92 (Galaeva and Semenov, 1997). The average annual vector roses of sand transportation from 5 meteorological stations (MS) were used for calculations. Data from MS Lazarev Island were used for assessing the new western source of dust/salt, MS Aral Sea for Saryshigonak and Kokaral deflation area, MS Uyaly for the most powerful eastern source and MS Barsa-kel'mes for the sandy beaches of the island of the same name. The removal of the sand was defined for 16 directions, which allowed an estimate of the amount of salt-dust aerosol coming to certain areas of the Aral region. In *Table 1* the total amount of solid particles raised from each source to all directions are presented.

Table 1: Average annual removal of sand (tonnes per year) from the main sources of deflation of the dried bottom of the Aral Sea by a sea level drop of 15 m (Galaeva and Semenov, 1997).

Direction of transportation	Source of dust and salt raising				
	Lazarev island	Barsa-Kelmes island	Eastern island	Saryshygonak	Kokaral
N	50	0	10,094	5,712	6,324
NNE	2,552	0	8,128	11,132	20,740
NE	2,520	0	2,263	21,021	30,261
ENE	1,488	77	15,402	21,157	25,110
E	5,775	255	37,862	16,215	11,280
ESE	2,940	331	29,827	13,764	9,213
SE	7,830	1,200	66,896	10,152	7,827
SSE	5,424	810	19,980	10,773	9,072
S	800	940	32,857	13,664	15,128
SW	44,856	31,080	92,418	14,514	20,894
WSW	101,742	7,130	44,394	13,604	16,146
W	20,895	1,887	55,576	10,235	7,120
WNW	1,050	0	22,116	8,246	5,519
NW	90	0	7,119	4,257	3,282
NNW	113	0	4,680	4,189	3,528
Total	**211,001**	**46,186**	**507,063**	**192,837**	**217,890**

It is interesting to compare this data with the data for the shorter period of time, for example 1986. According to observations of Uyaly MS the annual average of aerosol removal decreased from 690,000 tonnes in 1986 to 500,000 tonnes in 1992 in spite of an increase in the area of the Eastern source. The data for the Saryshigonak and Kokaral sites did not change significantly. The total amount of raised aerosols from the Kazakh part of the dried bottom (caused by a 15-m level decrease) is assessed at 1.17-m tonnes per year; i.e. it increased 50,000 tonnes per year.

Table 2 shows the predicted volumes of dust removal by a 20 m Aral Sea level drop. The calculation was done on the condition that the average annual vectors of sand transfer would be the same as at present. The further decrease of the Sea level will bring about the significant growth of the area on the eastern source, which will merge with the Barsa-Kelmes source. The Kokaral and Saryshigonak sources will merge into one northern source. The average annual removal of aerosols will increase up to 1.29-m tonnes per year because of the increase of the area of the sources. Most likely, this figure will be higher, since at the beginning of the 1990s the trend of increased sand removal was marked, and possibly, after the phase of decline in deflation processes intensity in the 1980s, the period of high wind activity starts.

Table 2: Forecast of average annual sand transfer (tonnes per year) from the main sources of deflation in the dried bottom of the Aral Sea by a 20 m level decrease (Galaeva and Semenov, 1997)

Direction of transportation	Source of deflation		
	Northern	Eastern	Lazarev island
N	13,056	16,758	56
NNE	29,737	11,648	2,882
NE	35,574	28,520	3,690
ENE	29,062	18,972	1,624
E	24,252	38,794	5,050
ESE	24,864	29,827	3,122
SE	20,770	69,299	8,486
SSE	23,490	30,192	7,344
S	31,232	54,549	896
SSW	37,927	53,144	14,541
SW	24,563	116,472	65,682
WSW	18,687	54,684	111,041
W	13,308	56,943	21,890
WNW	14,896	22,116	1,115
NW	8,710	8,253	97
NNW	9,135	7,072	153
Total	**359,263**	**617,243**	**248,666**

Thus, according to the most favorable conditions the amount of raised dust-salt aerosols can change from hundreds of thousands tonnes to 20-30 million tonnes per year (*see Figure 10*).

4.4. Volume of sedimented aerosols

For estimate of the volume of salt and dust sediments in the area adjacent to the Aral Sea areas we analyzed data obtained by Uzbek (Razakov and Kosnazarov, 1996; 1998) and Kazakh (Semenov, 1996; 1998) scientists. Sedimentation of salt and dust aerosols was studied from 1982-91 at 43 points situated in zones with different wind activity, vegetation density and anthropogenic activity: in the exposed bottom, coastal zone and in areas with and without irrigation in the Amudarya delta. Multi-year measurements demonstrated the dependence of the aerosol sedimentation on the orography of the area, dominant winds, vegetation characteristics, soil moisture content, etc. The total amount of deposited aerosols in the southern Aral zone is 1.5-6.0 tonnes per hectare; among them the amount of soluble salts comes to 170-800 kg/hectare, and sometimes even 1,600 kg/hectare (in the dried bottom of the Aral Sea). In the irrigated lands of the Karakalpakstan Republic this value is lower: 150-300 kg/hectare. The major part of dense residue consists of terragenous material where the amount of soluble salts comes to 2-30% with the highest value in areas close to the solonchak. The role of aeolian transportation in the salt balance in the dried bottom of the Aral Sea and the coastal zone is 6-26% and in the irrigated zone 1-1.5% (Razakov and Kosnazarov, 1996). The measurements of dry deposits in the Amudarya delta do not allow determination of the input of Aral aerosols to the ecological pressure in the region. Both aerosols of dust storms with strong winds and daily local aerosols originated from convective processes settle out on the catcher-boards. An attempt to separate Aral aerosol and determine the amount of dry deposits created by convective processes was done by Semenov (1996, 1998). He estimated the approximate average annual amount of dry deposits at 79 tonnes per km² in the Amudarya delta and 45 tonnes per km² in the Kazakh part of the Aral Sea region.

The models of transfer and sedimentation of Aral aerosols were elaborated based on field measurements of sand/dust profile flow during storms and dry deposits on the surface (Semenov, 1998). These models for the first time allowed an assessment of the input of dust-salt storms to the process of formation of dry deposits in the region.

The map of average annual amount of dry deposits from dust-salt storms plumes observed in the Kazakh part of the dried bottom of the Aral Sea is in *Figure 11(a)*. The map of the territory at scale 1:1,000,000 was divided into rectangles with 20'x 20' sides. For the centers of these rectangles the amount of dry deposits from each of the five sources of the aerosols were calculated. Then the sums of all obtained values of dry deposits in each rectangle were calculated. The calculations were based on area of the sources of aerosols formed by a 15-m sea level drop. *Figure 11(a)* indicates up to 150 tonnes per km² in a year of dry aerosol deposits in the eastern coastal zone of the Aral Sea. Moving 120-140 km away from the sources of aerosol transfer the average annual volume of deposited dust-salt aerosol decreased to 5 tonnes per km². In the Northern Aral region the amount of deposited aerosol is similar to that in the Amudarya delta (90-100 tonnes per km² per year). The average annual volume of deposits both of dust storm origin and convective raising of particles varies in the Kazakh part of the Aral region, from 50-145 tonnes per km² per year (*Figure 11b*). This amount increases in the Amudarya delta and reaches 179 tonnes per km² per year. By moving from the dried bottom of the sea, the input of convective local dry deposits increases.

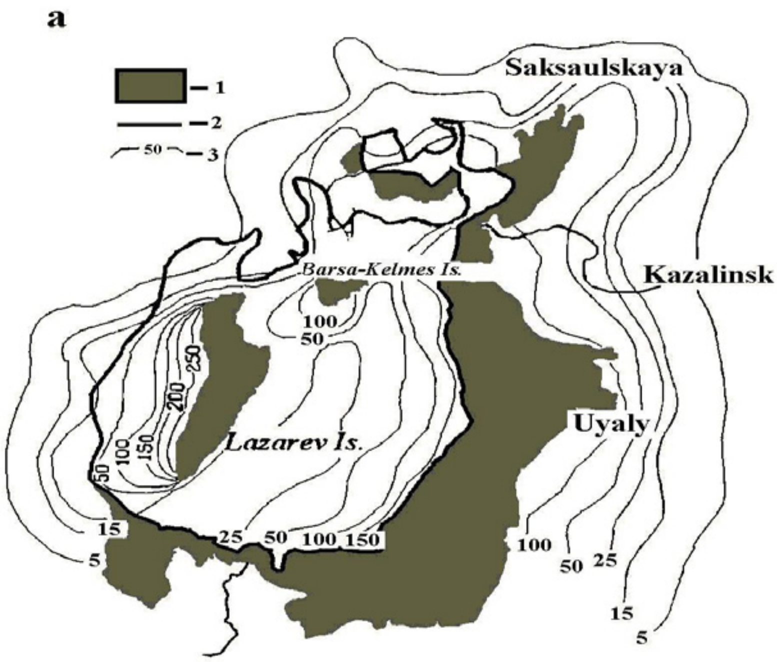

Figure 11 (a): Average annual amount of dry deposits from dust-salt storms plumes observed in the Kazakh part of the dried bottom of the Aral Sea

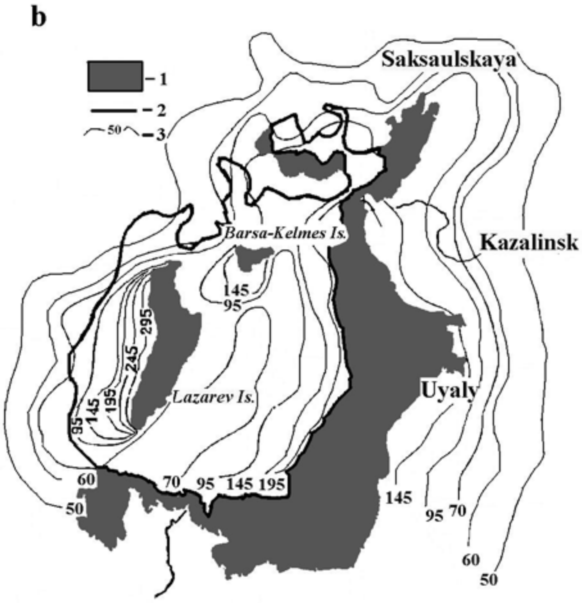

Figure 11(b): Indicates up to 150 tonnes per km² in a year of dry aerosol deposits in the eastern coastal zone of the Aral Sea

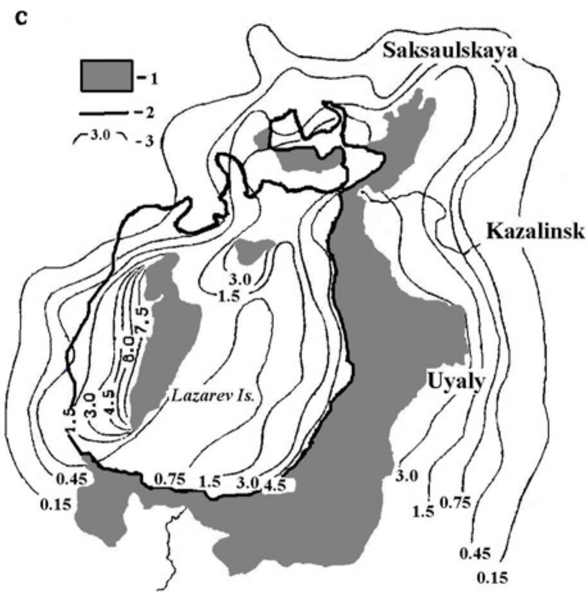

Figure 11(c): Spatial distribution of salts originating from the dried bottom of the Aral Sea

Figure 11(c) demonstrates the spatial distribution of salts originating from the dried bottom of the Aral Sea. The values were obtained based on the assumption that the salt content in aerosols is 3%. The value of the salt content in aerosols was estimated by field measurements (Semenov, 1998). As mentioned above, the salt content in deposited aerosols in the Amudarya delta was estimated at 5-6%; it increased to 20-30% in areas close to solonchak (Razakov and Kosnazarov, 1996). Thus, the volume of deposited salts in the Northern and Eastern Aral region is less than in the Amudarya delta. In the coastal zone of the Eastern Aral region the amount of deposited salts is 1.5-3 tonnes per km² per year. Deposits after individual strong dust-salt raising events can differ significantly from this average estimation. One should also consider that the process of salt transfer in the Aral Sea region has been going on for more than 30 years; thus, such an amount of deposited salt significantly affects the arid ecosystems of the region.

4.5. Range of aerosol transportation

Range of dust-salt transportation from the dried bottom of the Aral Sea was estimated by satellite images to be 300-500 km (Grigor'ev and Lipatov, 1974). Nevertheless, this estimation is uncertain due to determining the final destination of aerosol transportation. Thus, the synoptic method was applied for assessing the maximal distance of dust-salt transportation (Galaeva, 1998). It allowed determining the length of the trajectories of aerosols for observed strong dust storms events. The study of trajectories of aerosols of different size shows that the range of their transportation depends on the duration of the storm and wind speed at the height of transportation. The particles within sizes of 16 microns could be transported the largest distance, up to 900-3,200 km. The maximal range for 90 microns particles is between 170-1,300 km.

5. ECOLOGICAL AND SOCIAL CONSEQUENCES OF WHITE STORMS

Removal, transportation and deposition of salty dust is one of the most negative phenomena experienced at present in the Aral region, and brought about by human activity. The salty dust affects not only climate and landscapes, but also the health and economic activity of the population.

The increased content of aerosols in the atmosphere influences its optical properties and radiation characteristics. By absorbing the direct and diffused solar radiation the aerosols contribute to the heating of the atmosphere in places of its localization. Changing the radiation balance in the upper atmosphere, the aerosols affect the heat balance of the climatic system as a whole. These radiation disturbances cause variations in the atmosphere and ground temperature and changes in a number of climatic parameters.

Aerosol components play a certain role in the decay of solar radiation by decreasing the transparency of the atmosphere. The most intense decrease of solar radiation was recorded in the second half of the 1970s over the Ustjurt plateau and the Aral region. Together with an increase of dustiness of the atmosphere, the change of radiation properties of the ground surface brought about the increase of the continentality of the climate in the region (Muminov and Minagamova, 1995; Chub, 1998).

Influence of dust-salt deposits on vegetation productivity is first of all connected with changes in parameters of the environment, for example:

- Atmospheric transparency.
- Changes in relations between the components of radiation and heat balance.
- Decrease of photoactive radiation flow on the upper boundary of the sown crop and its redistribution in vegetation cover.
- Increase of salt content in the soil, and direct impact of dust and salt particles on the leaf area.

It was shown (Usmanov, 1998) that the intensity of transpiration from dust-laden leaf in the daylight time decreased to 62-69%, while transmission of solar radiation through dust-laden leaf to the lower strata decreased to 50-60%: the temperature of the leaf surface increased. Losses of cotton yields resulting from aerosols influence reached 5-15% and the yield of rice decreased by 3-6% (Razakov and Kosnazarov, 1996). Salinization of the soil in areas adjacent to Aral Sea regions sharply increased as a result of aeolian salt and dust transfers from the exposed sea bottom. There was a five-fold increase in the area of halomorphic geosystems during the last 30 years, changing the structure of the region significantly (Popov, 1998). The increase of halomorphic geosystems areas is an indicator of a decrease in the productivity of the land and their degradation and the onset of desertification in this ecologically unstable region.

From the beginning of the 1970s there was the steady decline in the productivity of pastoral vegetation. The multi-stratum grass stands have been replaced by single stratum ones; valuable palatable species are disappearing and have been replaced by less palatable or unpalatable species. This leads to the formation of additional sites – sources of the wind erosion, and to a decrease in the natural potential of these rangelands.

A characteristic feature of aerosols in the Aral Sea basin is the relatively high content of water-soluble salts. Annual salt deposits with atmospheric precipitation come to 150-300 kg per hectare. Salt content of precipitation in 1975 was 30-100 mg per liter; presently it has increased to 100-150 mg per liter. In springtime such rains create salty crusts, which prevent seed germination, damage the power lines, etc.

The intensive salinization of the soil shortens the lifetime of the supporting structures of high-voltage transmission lines. Often the wires break and even high-voltage transmission lines are destroyed as a result of salt deposits from the air. It leads to an increase in expenditures for repairing power lines. Additional expenditures for repair of transmission lines in the Raushan-Beiney of Kungrad railway section for the period 1981-90 came to USD $15 million. Property damage as a result of power breaks was USD $9 million for the same period. In total capital expenditures increased budgeted investments 2.8 times (Kamalov, 1998).

Salt and dust transfers and deposits affect the quality of the environment; first of all, air quality, quality of the surface and ground water, including drinking water and quality of the agricultural and livestock products. Consequently, the living conditions and health of the local population are getting worse: sickness due to viruses, hepatitis, intestinal respiratory diseases increase, especially among children. In the Karakalpakstan Republic, adolescent girls have lower characteristics of physical and puberty maturity than girls of the same age do in the Uzbek and Russian populations. There is a specific morphotype for the Aral region's children: short stature and low weight, wide chest and narrow pelvis. Only 28.5% of the girls from the Aral region are pubescent at the age of 17 (Kamalov, 1998).

The polluted air negatively affects the respiratory and cardiovascular systems (Radzinsky, 1994). It is expressed in the change of lung size and passibility of the trachea and bronchial canals. The oncology morbidity is also very high in the Aral region. It includes esophagus, stomach and liver cancer. The oncology morbidity is especially high in the coastal areas of the Aral Sea. Cancer morbidity in Karakalpakstan comes to 70-80 cases per 100,000 population, while in the coastal zone it is 2-3 times higher (Radzinsky, 1994).

6. APPROACHES TO COMBAT WHITE STORMS

The Aral Sea and its problems have attracted the attention of the world for the past 40 years. Important resolutions and projects were adopted to combat the negative phenomena in this region. In 1989 the USSR declared the Aral region a zone of ecological disaster. A system of actions in order to solve the social, economic and ecological problems of the region was foreseen in adopted decrees. *"The Concept of conservation and rehabilitation of the Aral Sea, normalization of hygienic, medical and biological, and social economic situation in the Aral Region"* was elaborated. In this document it was emphasized that the problem of the Aral Sea and the Aral region is closely connected with a solution to the complex ecological and socio-economic problems of the Aral Sea basin, and could not be studied separately. The decrease in the level of the Aral Sea and related processes of the Aral region's degradation (with salt-dust transfer among them), are caused by irrational utilization of water and land resources in the whole basin of the Aral Sea; e.g. zones of anthropogenic impact on the landscapes and their disturbances do not coincide.

The collapse of the USSR by the end of 1991 and further financing constraints did not allow start on the work for the planned scale. Nevertheless, for effective solutions to ecological and socio-economic problems of the Aral region, a group of international organizations was established by five Newly Independent Central Asian States: the *"International Fund of Aral Rescue,"* the *"Interstate Commission on Sustainable Development,"* and the *"Interstate Coordination Water Resources Commission."* Agreements of 1993, 1994, and 1997, Nukus (1995), Alma-Ata (1997), and Ashgabat (1999) signed by the leaders of the five Newly Independent Central Asian States have significant importance for developing the Aral region. The principles for financing the developed international programmes were defined, the strategy of rational water use was elaborated, and information systems on the management of water resources and hydrometeorological service were created.

In accordance with the programme *"use of the drainage water and cultivation of the salt tolerant crops,"* the following projects are under development: *"Assimilating of the dried up bottom of the Aral Sea," "Organization of the pilot site on growing of the salt- and drought-tolerant plants (halophytes)," and "Introduction of the new effective methods of irrigation."* It is envisaged to create protective forest belts on the dried-up bottom of the sea on an area of 500 hectares in the Mujnak Town surroundings. The programmes *"Monitoring of the Sand-Salt Storms of Aral," "Cultivation of the Salt Tolerant Plants"* and others were adopted. The aim of the strategy of water supply and nature conservation activities is not the rehabilitation of the Aral Sea in its initial status, but creation of a new ecologically sustainable Aral Sea with a stable level at a mark of 38 m MSL.

Besides the multi-purpose programme of the Aral Sea Basin, several projects have been implementing under the aegis of international organizations (UNDP, EC, UNICEF) aiming to create water supplying systems, solutions of hygienic and medical problems, and to increase population employment.

The Aral crisis experienced during the past 30-40 years has led to the realization that the implementation of adequate nature conservation measures requires a long period of time and significant capital investment.

Central Asian States do not possess at present and will not hold in the nearest future such means; thus, precisely addressed international financial donations are needed.

Preventing salt and dust removal from the dried bottom of the sea and its deposit in the Amudarya and Syrdarya Rivers delta, protective measures were elaborated. They include creation of the *"green protective belt,"* consisting of shallow mark dyked systems, phyto-amelioration of the dried areas in the 1960s, and cultivation of halophytic plants (*Figure 12*). For total expenditures of 21-22 cubic km of water artificial cultural landscapes could be created for prevention of desertification and removal of salt and dust material, formation of microclimate, improvement of biodiversity, and for forage and firewood production. The first experiments on phyto-amelioration in the southern part of the dried bottom were carried out from 1981-84 (Koksharova and Isakov, 1994). The local large shrubs – indigenous to the Aral region, growing on the coast and taking part in the process of natural overgrowing of the sandy strip of the dried bottom, were chosen for afforestation experiments. About 70 species are recommended for phyto-reclamation and afforestation (Dimeyeva, 1998). Ecological evaluation and elaboration of phyto-ameliorative measures should be realized in two aspects: ecosystems of the dried bottom and ecosystems of populated areas.

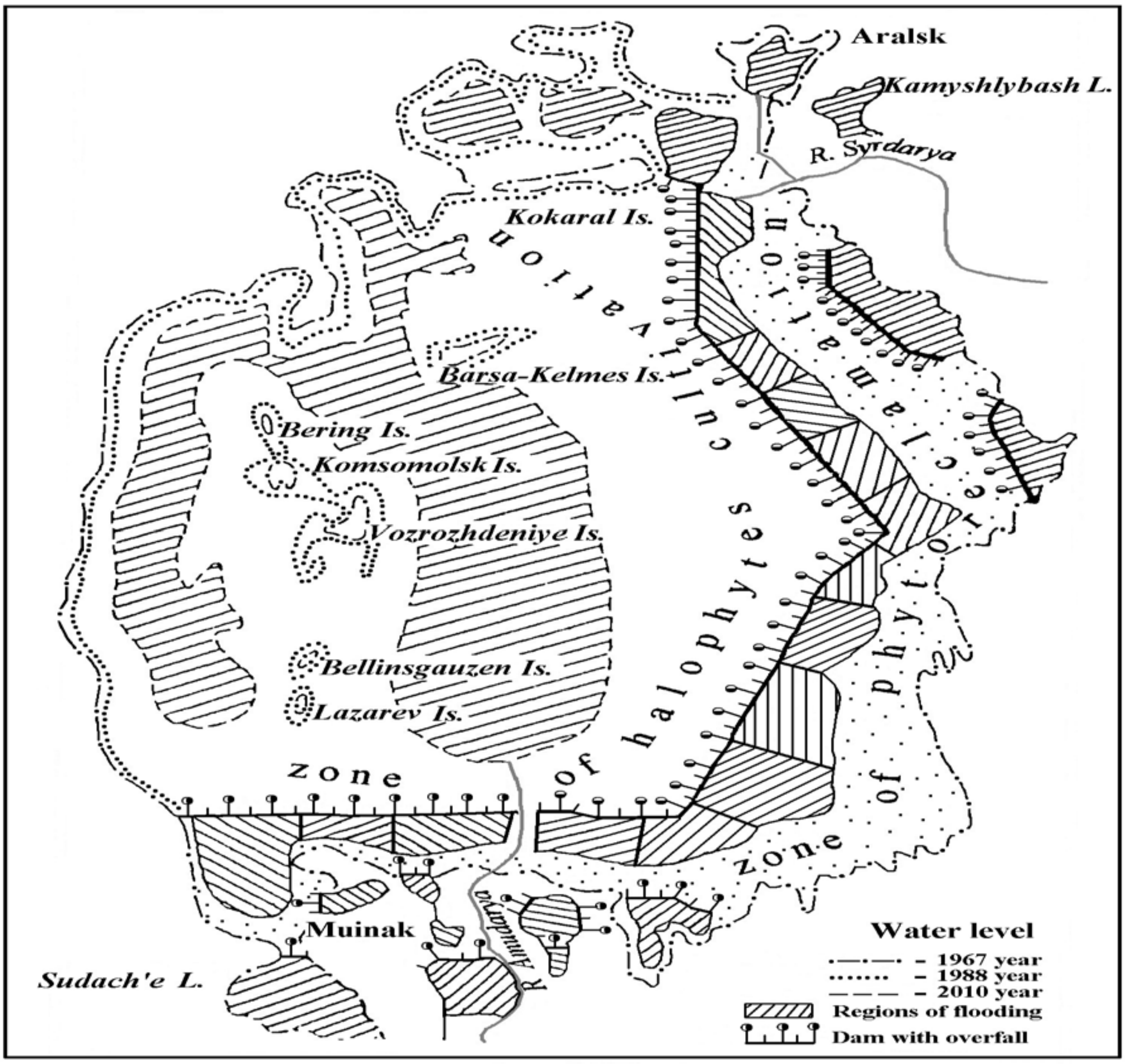

Figure 12: Shallow mark dyked systems, phyto-amelioration of the dried areas in the 1960s, and cultivation of halophytic plants

The main purpose of phyto-amelioration on the former bottom is recovery of the natural overgrowth and establishment of germplasm banks for further planting. The list of perspective phyto-ameliorates for the dried bottom and desertified surrounding areas is based on such properties as desalinization, landscape stabilizing and sand fixing ability. Forest belts near settlements protect against strong winds, transport of salts, dust devils and fixate shifting sands. Local trees and shrubs species (*Haloxylon aphyllum, Atraphaxis spinosa, Ammodendron bifolium* and *Calligonum aphyllum*) are recommended for forest reclamation and biological fixation of shifting sands.

The species *Tamarix* and *Kalidium* are preferable for saline soil. Planting of 1-2-year-old seedlings gives the most effective results. For towns and villages the following trees and shrubs are recommended: *Ulmus pumila, Acer negundo, Fraxinus excelsior, Salix alba, S. caspica, Elaeagnus oxycarpa, E. angustifolia*, and *Lonicera tatarica*. These species are heat resistant and tolerant of the slightly saline soil (Dimeyeva, 1998).

The following types of phyto-reclamation are suggested (Kurochkina and Makulbekova, 1984):

- *Haloxylon* sp. sowing in sand-accumulation furrows within a depth of 10-15 cm and a width of 0.7-1.2 m where the depth of the ground water is less than 2-4 m.
- Sowing of *Haloxylon aphyllum* and *H. persicum*, and other psammophylic shrubs (*Calligonum, Astragalus, Ammodendron karelinii*) in the furrows of sandy-solonchak surfaces where ground water depth is not less than 3 m and salinity is 10-80 g per liter.
- Aerial sowing of *Haloxylon* sp. and psammophylic shrubs in barchan-hillock sands on the coast of the 1960s.
- Rehabilitation of *Haloxylon* and *Artemisia* communities on the former coast by creation of sand accumulation furrows around separate groups of *Haloxylon.*
- Re-cultivation of drying solonchak by deep-ploughing and sand spreading, with further sowing of halo- and psammophytes.
- Sowing of halo- and psammophytes in drainage canals.
- Creation of cultural pastures of *Kochia, Agripyrum sibiricum* and *Eurotia ceratoides* in oases.
- Autumn sowing of salt tolerant pasture halo- and xerophytes (*Salsola orientalis, S. arbuscula, Kochia*) in oversanded solonchak.
- Sowing of the psammophytes and halomesophytes with use of anti-deflation protection on sandy dunes.
- Phytoamelioration by sea water irrigation: sowing of *Elaeagnus* sp., *Tamarix, Prosopis* and *Amorpha* on relict beaches.

After measures to increase the discharge capacity of the Syrdarya River in the winter period the water level in the Small Aral Sea was stabilized. Since the mid-1990s there is a dam between the former Kokaral island and the eastern shore of the Aral Sea. As a result the Small Aral Sea in the north and the Big Aral Sea in the south presented different scenarios of development. The Syrdarya River flows into the Small Aral Sea. By the annual inflow of 4-5 cubic km to the Small Aral Sea its level in 2010 will stabilize at the mark of 42.9 MSL, and the area of the water surface will come to 3,820 km². In May 1998 its level reached 41.8 m, and its area increased to 3,700 km² (Breckle et al., 1998). Thus, if the future of the Aral Sea at the beginning of the 1990s seemed hopeless, today we can look at the Small Aral Sea with cautious optimism.

7. CONCLUSION

Central Asia is a region with a high frequency of dust and salt storms. It is characterized by the presence of vast areas of sandy and solonchak deserts of natural and anthropogenic origin. The enhanced anthropogenic activity in the Aral Sea basin brought about the Aral crisis. As a result the powerful basis of aeolian processes were formed favoring the development of salt and dust removal from the dried-up bottom of the Aral Sea and distribution of salt and dust over a significant part of the basin. Preliminary estimations showed the average transfer of salt and dust aerosol from the dried bottom varying between 500,000 tonnes to 20-30 m tonnes. Sedimentation of salt-dust aerosols to a certain extent depends on the orography of the landscape, wind intensity, distance from the source of the blowout, etc. Three major zones experiencing significant influence of salt-dust transfer could be defined: 0-100 km from the sea, a 100-300 km zone, and a 300-500 km zone. The total flow of dust and salt aerosols in the zone 0-100 km from the sea varies from 1.3-1.5 tonnes per hectare to

2.0-2.5 tonnes per hectare. The zone of 100-300 km receives 500-1,000 kg per hectare. The third zone (up to 500 km from the Aral Sea) receives 100 kg of deposits per hectare. Salt content in deposited aerosols in the first zone comes to 170-800 kg/hectare. In the irrigated area of the Amudarya delta this value decreases to 150-300 kg/hectare.

The intense transfer of salts by airflow is one of the most negative manifestations of the Aral disaster. It affects the living conditions of the local population, the biodiversity and biological productivity of the environment, and agricultural and pastoral productivity.

Transfer of salts from the dried bottom of the Aral Sea, estimation of its quantity and composition, the passes of transportation, areas of sedimentation and influence of these sediments on the environment, state of soil and crops – those are the most important and less studied problems of the Aral region. The significant differences in assessment of the blown out and deposited dust and salts confirm the necessity for further detailed experimental and theoretical research. Systems of monitoring sand and salt storms in the Aral Sea region could be an important input to the solution of this problem.

The problem of the Aral Sea is not unique on Earth; it is part of the general desertification process occurring in many areas of the world. Thus, the search for a solution to the Aral crisis has global importance. Success in stabilization and rehabilitation of the existing situation in the Aral Sea basin depends on the efforts and collaboration of five Central Asian States in order to coordinate the economic policy on natural resources use and support of the world community. To stem further depletion of the Aral Sea, its transformation into wasteland and a halt to the blowing out of dangerous material off the dried bottom the Aral Sea has to be guaranteed with sufficient river water inflow.

8. References

Agarkova, A. P. 1972. Distribution and duration of the dust storms in Western and Southern Kazakhstan. *Trudi KazNIGMI*, 49:111-117 (in Russian).

Babaev, A. G. and N. S. Orlovsky. 1981. Ecological types of the deserts of Central Asia and Kazakhstan, and perspectives of their development. In: *Actual problems of development and reformation of the deserts of USSR*, Ashgabat, Ylym, 8-37 (in Russian).

Breckle, Z.-V., V. Wukherer, Agakhanyantz, O. E. and B. Gel'dyev. 2001. In: Z.-V. Breckle, M. Veste and V. Wucherer (Eds). *Sustainable land use in deserts*, Springer-Verlag, Berlin, 27-37.

Breckle, Z.-V., Agakhanyantz, O. E. and V. Wukherer. 1998. Modeling experience of the Aral crisis. *Problems of Desert Development*, 6:7-14.

Chelpanova, O. M. 1963. *Climate of the USSR*. Central Asia. Leningrad, Hydrometeoizdat, 448 pp. (in Russian).

Chernenko, I. M. 1986. Problems of the Aral Sea water and salt balance regulation. *Problems of Desert Development*, 1:3-11.

Chetyrkin, V. M. 1960. *Central Asia*. Tashkent, SamGU, 240 pp. (in Russian).

Chube, V. E. 1998. Estimation of aerosol influence on climatic characteristics of the Aral Sea basin. *Problems of Desert Development*, 3-4: 50-55.

Dimeyeva L. 1998. *Floristic and phytocoenotic diversity of coastal ecosystems of the Aral Sea: present-day state and tendencies of change*. In: Sustainable use of natural resources in Central Asia, Almaty, Tethys, 107-111.

Elpiner, L.I. 1999. Public health in the Aral Sea coastal region and the dynamics of changes in the ecological situation. In: Glantz, M.H. (Ed.) *Creeping Environmental Problems and Sustainable Development in the Aral Sea Basin*. Cambridge University press, 129-156.

Fedyushina L.P. 1972. *Distribution of the dust storms in Alma-Ata and Djambul provinces of Kazakhstan as manifestation of the deflation processes*. KazNIGMI Proceedings, 49: 76-83.

Galaeva, O. S. 1998. About monitoring of carrying out of sandy salty aerosol from drained part of bottom of the Aral Sea. *Problems of Desert Development*, 3-4:17-21.

Galaeva, O. S. and O. E. Semenov. 1997. On monitoring of the blowout of the sandy salty aerosol from the dried bottom of the Aral Sea. *Hydrometeorology and ecology*, 2 (in Russian).

Galaeva, O. S., Semenov, O. E. and A. P. Shapov. 1996. On pecularities of the sand transportation in Aral region. *Hydrometeorology and ecology*, 4 (in Russian).

Grigor'ev Al. A. and K. Y. Kondrat'ev. 1985. *Space earth science*. Moscow, Nauka, 160 pp. (in Russian).

Grigor'ev Al. A. and M. L. Djogova. 1992. *Strong dust blowouts in Aral region in 1985-1990*. Proceedings of the Russian Academy of Sciences, 325(3): 672-675 (in Russian).

Grigor'ev Al. A. and V. B. Lipatov. 1974. *Dust storms by data from satellite researches*. Leningrad, Hydrometeoizdat, 11 pp. (in Russian).

Grigor'ev Al. A. and V. B. Lipatov. 1979. *Dust storms in the Aral region by satellite imagery*. In: Development and reformation of environment. Leningrad, 93-99 (in Russian).

Grigor'ev Al. A. and V. B. Lipatov. 1982. Dynamics and sources of the dust storms in the Aral region by space observations. *Proceedings of the Academy of Sciences of USSR, geography series*, 5: 93-98 (in Russian).

Grigor'ev Al. A. and V. B. Lipatov. 1983. Distribution of the dust pollution in the Aral region by space observations. *Proceedings of the Academy of Sciences of USSR, geography series*, 4: 73-77 (in Russian).

Kamalov S. K. 1998. Processes of salt migration in Karakalpakstan. *Problems of Desert Development*, 3-4:25-30.

Koksharova N. E. and G. I. Isakov. 1984. Afforestation of the dried up bottom of the Aral Sea. *Problems of Desert Environment*, 4: 27-31.

Kozhevnokiva K.Ya. 1959. The salt regime of solonchaks. In: *Ancient delta of Syrdarya River and Northern Kyzylkum*. Alma-Ata, Nauka, v. 2: 48-73.

Kravchenko I. V. 1959. *Salt dust storms*. Nature, 8: 89-92 (in Russian).

Kurochkina L. Y. 1978. Psammophylic vegetation of the deserts of Kazakhstan. Alma-Ata, Nauka, 318 pp. (in Russian).

Kurochkina L. Y. and Makulbekova G. B. 1984. Phyto-amelioration of the drying coasts of the Aral Sea. *Problems of Desert Development*, 4: 27-31.

Lobova E. V. and A. V. Khabarov. 1977. Soil resources of the world, their use and conservation. In: *Arid soils, their genesis, geochemistry and utilization*. Moscow, 7-15 (in Russian).

Motorin G. S. Peculiar dust storm. 1954. *Nature*, 11: 117-118 (in Russian).

Muminov F. A. and S. I. Inagamova (Eds). 1995. *Variability of the climate of Central Asia, Tashkent*, 215 pp. (in Russian).

Orlova M. A. 1983. *The role of aeolian factor in the salt regime*. Alma-Ata, Nauka, 230 pp.

Orlovsky N. S. 1962. Some data on dust storms in Turkmenistan. *Proceedings of the Ashgabat hydrometeorological observatory*, Ashgabat, 3: 17-42.

Pankova E. I., I. P. Aidarov, I. A. Yamnova, A. F. Novikova, and N. S. Blagovolin. 1996. *Natural and human-induced salinization of soils in the Aral Sea Basin*. Moscow, 187 pp. (in Russian).

Popov V. A. 1998. The role of salt migration in the landscape genesis of the Priaral region. *Problems of Desert Development*, 3-4: 122-126.

Radzinsky V. E. (Ed.) 1994. *Mother's and children's health in the Turkmen part of Aral Region*. Kiev, 164 pp. (in Russian).

Razakov R. M. and K. A. Kosnazarov. 1996. *Dust and salt transfer from the exposed bed of the Aral Sea and measures to decrease its environmental impact*. In: The Aral Sea Basin, NATO ASI series, Berlin, 12: 95-102.

Razakov, R. M. and K. A. Kosnazarov. 1998. Migration of salts and toxicants in the Aral Region. *Problems of Desert Development*, 3-4: 63-70.

Romanov, N. N. 1961. *Dust storms in Central Asia*. Tashkent, 198 pp. (in Russian).

Rubanov, I. V., B. I. Pinkhasov and A. K. Kurbaniyazov. 1998. Processes of salinization in the aquatory of the Aral Sea. *Problems of Desert Development*, 3-4: 31-37.

Sakharov, D. 1948. Salt transfer in Volga-Akhtuba region. *Soil Science*, 9: 576-577 (in Russian).

Sapozhnikova, C. A. 1970. Schematic map of number of days with dust storms in the arid zone of the USSR and adjacent areas. *Proceedings of NIIAK*, 65: 61-67.

Semenov, O. E. 1988. Estimation of the sand and salt transfer by wind from the exposed bottom of the Aral Sea. *Proceedings KazNIGMI*, 102: 43-57 (in Russian).

Semenov, O. E. 1990. Estimation of the amount of the sand and salt transfer from the exposed bottom of the Aral Sea. In: *Hydrometeorological problems of Aral region*, Leningrad, Hydrometeoizdat, 200-215, (in Russian).

Semenov, O. E. 1995. Estimation of the scale of the Aral aerosol transfer. *Hydrometeorology and ecology*. 1: 117-130 (in Russian).

Semenov, O. E. 1996. Radiation balance model of the flat sources of the dust and estimation of the base dry deposits. *Hydrometeorology and ecology*. 2 (in Russian).

Semenov, O. E. 1998. Deposit of the salt and dust aerosol on the surface of Aral region. *Problems of Desert Development*, 3-4: 37-44.

Semenov, O. E. and L. P. Fedyushina. 1970. Climatic pre-conditions of deflation processes in Kazakhstan, *Proceedings of KazNIGMI*, 35: 41-51 (in Russian).

Semenov, O. E. and L. P. Tulina. 1978. Spatial and temporal distribution of dangerous and especially dangerous dust storms in Kazakhstan. *Proceedings of KazNIGMI*, 71: 62-77 (in Russian).

Seredkina, A. E. 1960. Dust storms in Kazakhstan. *Proceedings of KazNIGMI*, 15: 54-59 (in Russian).

Soils of the Kazakstan SSR. 1960-1971. Alma-Ata, Nauka, v.1-16 (in Russian).

Synoptic processes in Central Asia. 1957. Uzbek Academy of Sciences, Tashkent, 477 pp. (in Russian).

Usmanov, V. O. 1998. Estimation of the influence of dusty salt transfer on the productivity of agricultural crops in the Priaral region. *Problems of Desert Development*, 3-4: 147-151.

Uteshev, A. S. and O. E. Semenov. 1967. Climate and wind erosion of the soils. Alma-Ata, Kainar, 72 pp. (in Russian).

Zamorsky A. D. 1952. Deposition of the salty dust. *Meteorology and Hydrology*, 9:25-28 (in Russian).

Chapter Nine

COMBATING DESERTIFICATION AND SANDSTORMS IN IRAQ

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Keywords: fuelwood, salinity, waterlogging, sand dune fixation, afforestation, sand storms, infrastructure, protection forestry, windbreaks, oasis development, rangelands, land tenure, socio-economics, participatory approaches, water points, livestock husbandry, Iraq

SYNOPSIS

Desertification is serious in Iraq. The main manifestations are an increase in sand and dust storms, increased soil salinity and water logging, and widespread rangeland degradation. The problems have become worse since the imposition of economic sanctions in 1990.

Projects to stem desertification in Iraq, with special emphasis on dune-fixation, are described and the lessons learned are outlined. Policy issues and socio-economic considerations receive special attention.

KEY POINTS

1. *Two main groups of people occupy the desertified regions of Iraq: sedentary farmers and pastoralists. Both have been adversely affected by desertification, both contribute to the problem through inappropriate land use practices.*
2. *The uncontrolled and indiscriminate tree cutting that has prevailed for decades, even centuries and the use of shrubs for domestic fuel have contributed greatly toward the processes of land degradation.*
3. *Poor soil/water management and severe climatological factors have changed extensive agricultural lands in Iraq's alluvial plain into the present bare, water logged soils covered with aeolian sand sheets and pseudo sand dunes.*
4. *The formation of shifting sand dunes is the worst aspect of desertification, because of the adverse impact on the environment in general, and in particular its affect on irrigation and drainage infrastructure and in the increased frequency of severe sand and dust storms.*
5. *The results of sand dune stabilization clearly indicate that efforts have made a significant contribution to the welfare of local inhabitants but the "top down" approach and the lack of participatory processes probably mean that the projects will be unsustainable. The local population was excluded from both the planning and the implementation of the sand fixing activities.*

1. INTRODUCTION

Poor soil/water management and severe climatological factors have changed extensive agricultural lands in Iraq's alluvial plain into the present bare, water logged soils covered with aeolian sand sheets and pseudo sand dunes. Iraq faces a severe desertification problem that jeopardizes its food security through the effects of soil salinity, waterlogging, loss of vegetative cover, shifting sand dunes and severe sand/dust storms. All of these problems need to be addressed to halt the threat.

To combat these problems Iraq has launched programmes to rectify soil salinity, to develop natural vegetative cover and to halt the encroachment of sand dunes, as well as reduce the frequency and severity of sand and dust storms.

2. GEOGRAPHY AND CLIMATE

Iraq is situated in the north-east of the Arab world in western Asia, between latitudes 29.5° N and 22° N and longitudes 38.45° E and 48.8° E, bordering Turkey to the north, the Islamic Republic of Iran to the east, the Syrian Arab Republic to the west and Saudi Arabia to the south, comprising an area of 438,416 km^2 (*Figure 1*).

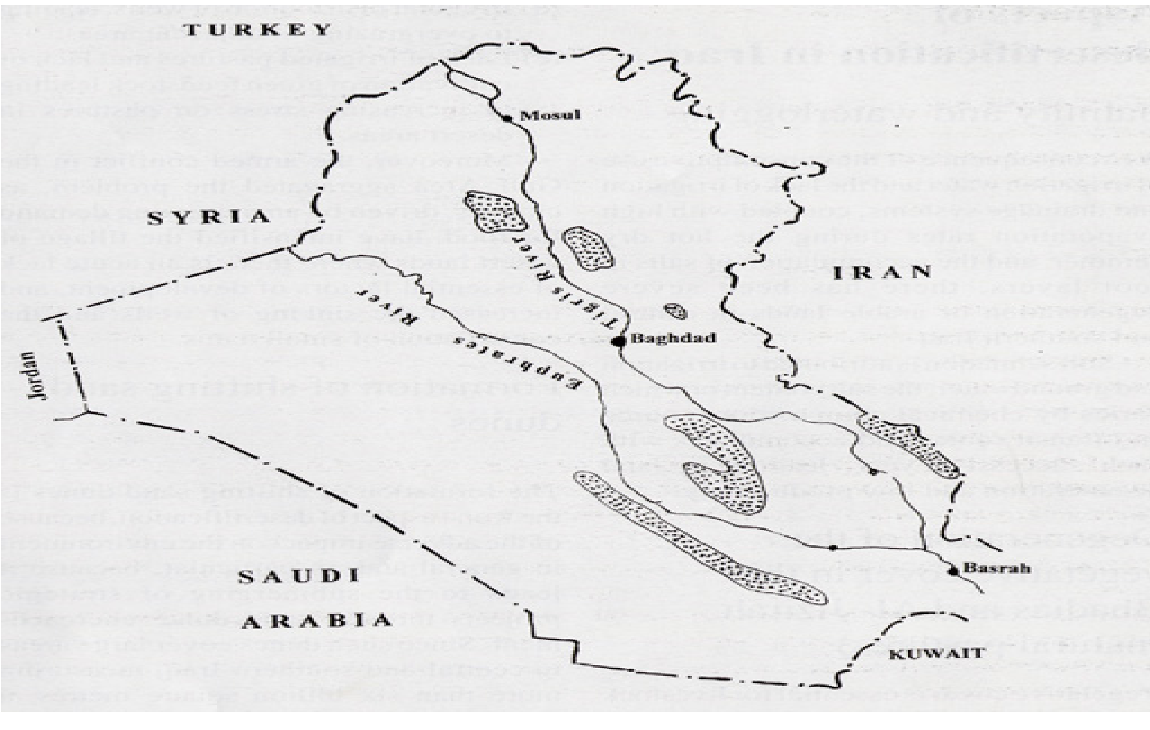

Figure 1: Map showing Iraq in relation to its neighbours and the location of the major sand dune fields in Iraq

The western desert covers a large part of its area. It is divided into:

i. The mountainous area to the north and northeast.
ii. The eastern plain area.

iii. The Al-Jizirah area lying between the Tigris and the Euphrates rivers to the northwest.
iv. The southeastern desert area.
v. The sedimentary plain between the Tigris and Euphrates south of Baghdad.

2.1. Climate

Iraq has hot dry continental weather in summer and cold, wet weather in winter. Climate characteristics are:

i. High temperatures.
ii. A significant difference between hot and cold temperatures by day and night and between summer and winter.
iii. Relative low humidity in summer.
iv. Varying degrees of precipitation, from 1,200 mm in the north to less than 100 mm in the south. Throughout the whole of Iraq the rainy season is from March-November.
v. Daily evaporation (ETP) rates vary from 1.5 mm in the winter months, reaching their peak during the summer months with a value of 9.0 mm. The total annual ETP from a free water surface is around 2,000 mm.
vi. Northerly and northwesterly winds that sweep the country during the dry months, where wind velocity may exceed 100 km/hr, raising dust storms.
vii. Wind speeds may reach their maximum by midday in July (average 3.3 m/s). The measured threshold velocity for the movement of soil and sediment particles was 3.0 m/sec (Dougrameji, 1999).
viii. Dust storms occur more frequently during spring and autumn, with an average of 20 days per year.

Rangelands cover about 75% of the entire land area of Iraq. Over recent times these have become severely degraded through faulty utilization practices including:

i. Overgrazing.
ii. Conversion to cropland.
iii. Clearing of trees and shrubs.
iv. Irregular distribution of water points and subsequent unevenness of utilization.

The armed conflict in the Gulf region has aggravated the problem, as citizens driven by economic sanctions and the need for food have intensified tillage of desert lands where there is an acute lack of essential factors for development. There was an acceleration of tree cutting, as alternative fuel sources became unavailable. This led to widespread land degradation and frequent dust storms.

3. LOCATION OF SAND DUNES IN IRAQ

Sand dunes are located mostly in the central and southern regions and are shifted by wind force. The prevailing winds are from the north and northwest. The location of the major dune fields is shown in *Figure 1*. Essentially they are in three main belts:

3.1. Eastern sand belt

This belt runs parallel to the southern mountain chains of Makhoul and Hamreen and the chain of hills, which runs parallel to the Iraqi-Iranian border. Sand dunes proliferate in Bajii, Al-Aith and Al- Miqdadiyah, as well as Al-Gharbi, Chlat and Al Teeb in the governorate of Salahu Eddin, Diala, Wasit and Missan.

3.2. Central Sand belt

The belt starts from the Greater Musyayab project down to the governorate of Muthana, Thiqar, passing through the cities of Liashimya, Shomely, Naamanya, Afak, Fajr, Al Nasar and Wakaa in the governorates of Babel, Wasit, Qadisiayah, Thikar and Muthana.

3.3. Western sand belt

The belt lies to the west of the Euphrates River. Sand dunes have emerged in locations where they have previously not been found, especially in the areas of western desert within the governorate of Al Anbar.

The texture of the materials in the dunes varied from loam to sand with fine to medium fractions being dominant (*Table 1*). The potential value of soil erodibility of the sand sheets was calculated to be about 125 T/ha/yr.

Table 1: Some properties of dune material

Dune	Sand %	Silt %	Clay %	Salinity dsm/m	Ca_2Co_3 %	O.M. %	Aggreg. > 0.8mm
1*	**17.0**	**56.0**	**27.0**	**31.0**	**25.0**	**0.6**	**77.0**
2	**28.0**	**48.0**	**24.0**	**4.0**	**27.0**	**0.5**	**48.0**

* Pseudo dune (aeolian sediments overlying coarse alluvial materials).

4. AFFORESTATION AND DESERTIFICATION COMBATING PROJECTS

Various projects were implemented to fix sand dunes and reduce their impact on strategic infrastructure such as irrigation canals, roads and railways and to reduce the frequency and severity of sand and dust storms.

Figure 2: Creeping sands cover the highways creating a serious hazard

Undoubtedly, sand and dust storms over the central and southern regions pollute the environment and affect human health and agricultural production. Dust and sandstorms disrupt the physiological functions of plants, especially during pollination and inflorescence. Sand storms blow from the dune fields in central and southern regions. Their incidence has increased during recent years.

Shifting sands affect infrastructure, often burying the canals, roads, etc. Specific problems that have been encountered include:

4.1. Highways

Creeping sands can have detrimental effects on some inter-city highway sections by hindering traffic flow, causing road accidents, and increasing maintenance costs. The sand emanates from wind erosion of the topsoil, a result of degradation of the natural plant cover caused by local overgrazing and intensive cultivation. The highway sections affected include:

i. Sections between the Diwaniyah and Nasseriyah cities, measuring more than 50 km.
ii. Sections between Al-Nasiriyah and Al-Basra, measuring more than 30 km.
iii. Sections between Ramady town and the Syrian-Iraqi border, namely the 110-160 km and the 210-450 km sections in the direction of the Jordanian and Syrian borders for a distance of more than 20 km.

4.2. Main roads and feeder roads

Some roads are particularly badly affected by sand dune encroachment:

i. Al-Nadsiriyah to Al-Basra road in the Tallahm area.
ii. Kut-Imara road in the eastern Ali region.
iii. Ramady-Rutba road (old road), between the 100m km and 140 km pegs.

iv. Fajr-Al Bdir road.
v. Tikrit-Tuz road.
vi. Shomely-Numania road.
vii. Maimona - Al-Rifaei road.

The volume of sand shifted from the affected roads reached 180,000 cubic m in one year, which gives a good indication of the cost of sustaining and maintaining the roads.

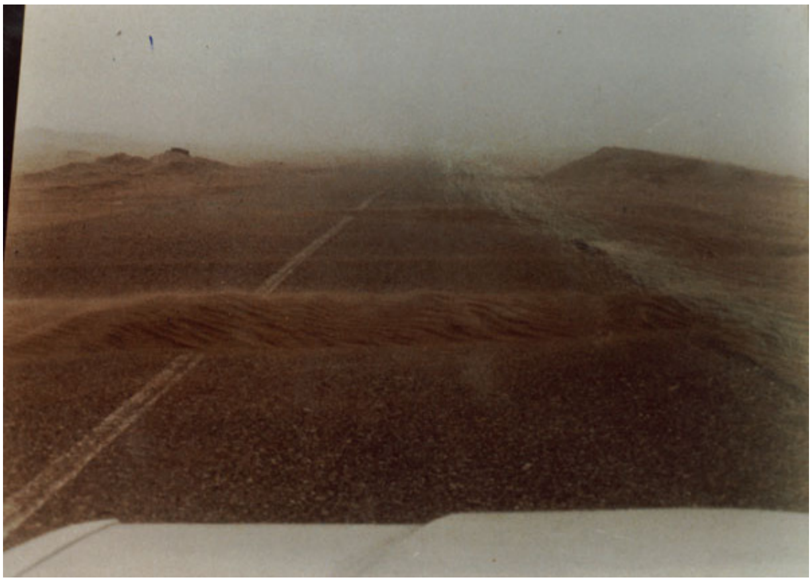

Figure 3: Creeping sands cover the feeder roads, increasing the risk of accidents and causing high maintenance costs to be incurred

4.3. Railways

The railway system is affected by shifting sand dunes between the Ghaishaya and Al-Artawi stations, where sections of the track are under sand. This hinders train movement and leads to derailments and serious accidents.

4.4. Irrigation projects

Shifting sands affect various irrigation projects as they fill in irrigation and drainage canals, reducing efficiency of water distribution and increasing maintenance costs. Among the projects that are badly affected are the Greater Musayeb project in the Vabel governorate, the Kamaliya project in Kerbala and the Saddam River.

Figure 4: Creeping sands spill into drainage and irrigation canals and threaten other important infrastructure

4.5. Other vital amenities

Creeping sands adversely affect several towns, villages and projects near sand dunes. Wind-blown sands bury dwellings and also have harmful effects on human health. This is most pronounced in the towns of Nafar, Afak, and Al-Nasiriyah, while Baiji, Sinya and Hamreen towns in the Salah Eddin governorate are also badly affected.

Figure 5: Wind blown sands bury dwellings and villages

5. DUNE FIXING PROJECTS AND TECHNIQUES

Arboretums, green belts and wind-shields have been created across the country using trees that are known for their rapid growth and environmental adaptability. Examples are *Eucalyptus, Pinus, Casuarina, Tamarisk,* and *Prosopis*.

Protection works include covering drifting dunes with mud; 25,000 ha of sand dunes have been treated this way along the riverbanks to stop encroaching sand movement. Bulldozers are used to put a layer of mud (mud blanket) over the sand to a depth of 29-35 cm.

Development of natural vegetation is encouraged and reseeding is also used. After rains, seeds that occur naturally in the soil begin to grow leading to a better fixing of the dunes. Afforestation is also used. For example, to completely protect the Saddam River it was necessary to construct a green belt, 1 km wide, along the river in which drought resistant trees and bushes with high nutritive value were planted. Approximately 6 million seedlings were planted in green belts with a success rate of 90 %. Wind-shields were cultivated in land lying between the Al-Gharraf drainage and Saddam River to reduce the damaging effects of the local winds.

Similarly, green belts were established to protect the Nasseriah-Basra railway line. Encroaching sand between Al Ghabeishya and Artawy, over a section of more than 40 km, affect this railway as they bury the line, causing disruption to the service in both directions of this vital link to the seaport at Basra. To restrict sand movement gabions were installed on both sides of the railway, and proved highly effective in halting the shifting sand. Green belts, supplied with water from 10 wells were established for the same purpose.

6. PROBLEMS AND PROSPECTS

As a direct result of the Gulf war the natural vegetation in large areas in southern Iraq were destroyed. Subsequent sanctions and difficulties for the local people led to almost complete loss of the shelterbelts and other plantings. The cutting of trees and bushes arose from the destruction of energy sources upon which people depended for their cooking and heating needs, especially during the winter months. They were forced to cut large areas of trees and shrubs, which had been sown to protect the environment. Soil erosion followed and dust storms increased. The cutting of trees and shrubs led to increased salinity and lower crop productivity and sand and dust storms became commonplace.

Efforts to combat desertification have been badly affected by the economic sanctions because of the unavailability of agricultural supplies, particularly the plastic sleeves used in the propagation of seedlings required for the planting of green belts and wind breaks.

The development of rangeland rehabilitation programmes has been retarded and the condition of the oases has deteriorated. Consequently, the output from animal husbandry has been reduced as fewer water points led to a greater concentration of livestock around existing water points and massive overgrazing within a few km radius of each one. As the equipment servicing the wells falls into disrepair the problem of overgrazing becomes worse. Essential equipment to repair the wells and pumps cannot be imported because of the economic sanctions.

The results of sand dune stabilization clearly indicates that the efforts have made a significant contribution to the welfare of local inhabitants but the *"top down"* approach and the lack of participatory processes probably mean that the projects will be unsustainable. The local population was excluded from both the planning and the implementation of the sand fixing activities. Notwithstanding this, an area of 87.500 ha of hitherto inter-dune wasteland has been converted into arable land. About 43,000 ha of these lands were leased to investors on an annual rent basis.

Regrettably, farmers and pastoralists still see their involvement in the anti-desertification project as a means of reaping immediate benefits, such as crop harvesting, grazing on crop residues and cutting of fuel wood, with minimum input from themselves. There is need for a participatory approach to the design and execution of anti-desertification measures and perhaps reform of the land tenure system to ensure greater equity. Government regulations are such that farmers cannot cut down trees growing on their plots. In addition they must plant new trees at the rate of 4 trees per ha, not allow livestock into their plots, etc. Fines may be levied for each tree destroyed but enforcement is weak.

7. ACTIONS TO MITIGATE THE PROBLEMS

For the development of the natural vegetative cover on rangelands and the fixing of dunes the following measures are essential:

i. To halt the cultivation of land in the low rainfall areas, especially in the northern and southern deserts (Badias).
ii. To raise population awareness of the root causes of the problems and to assist them to cope.
iii. Reform the present inequitable land tenure system to ensure that tenant farmers and sharecroppers retain more of the profits and to encourage a more long-term approach to land management.
iv. To expand construction of small dams and reservoirs in the western desert to utilize rainfall to the greatest extent and to spread the pressure of grazing.
v. To extend the planting and deployment of drought-resistant trees and bushes, by installing gabion walls so as to take advantage of the rainwater (water harvesting). These plants are so essential to create a natural green cover and reduce wind erosion and provide forage for livestock.
vi. To make use of the abundant groundwater resources, through the operation of existing wells; and rehabilitation of old or abandoned wells and the drilling of new wells.
vii. To form a team of specialists to address the threat posed by shifting sand and dust storms to the important infrastructure developments and strategic projects. The team should have the necessary wherewithal and be empowered to deal with problems as they arise.
viii. To plant wind breaks around agricultural lands, which should help reduce crop water requirements as well as reduce the mechanical effects of winds on the plants. Experience has shown that the productivity of all types of crops cultivated in lands planted with protection forestry increases by 25-30 %, not to mention the additional environmental improvement.

8. REFERENCES

Al-Farrajii, F.A.H. 1998. *Combating desertification in Iraq*. Desertification Control Bulletin No. 33 pp. 2-10.

Al Janabi, K.Z. Ali, A.J., Al-Taie, A. and Jack, T.J. 1988. *Origin and nature of sand dunes in the alluvial plains of southern Iraq*. J. Arid Environ. 14: 27-34.

Dougramedji, J.S. 1999. *Aeolian sediment movements in the lower alluvial plain, Iraq*, Desertification Control Bulletin No. 35 pp. 45-49.

Naqash, A.B. and Shaker, S.N. 1986. *Aeolian sedimentation processes in lower Mesopotamian Plain*; J. Water Res. 5 (1): 486-508.

Salman, H.H. and Saadallah, A.S. 1986. *Dust fallout in central and southern Iraq*. J. Water. Res. 5 (1): 599-620.

PART V

CHINA'S EXPERIENCE WITH CALAMITOUS SAND-DUST STORMS

China, as one of the countries worst affected by desertification, has real and mounting problems to overcome. Being a vast land area and faced with a large population, many of whom live in arid regions, China has a special set of problems to deal with.

The rapid, and sometimes inappropriate, economic development over the past 50 years has been, until recently, at the expense of the environment. Much repair work has to be done and precautionary measures are to be taken; China's commitment to this work is strong. In this group of articles the nature and extent of the calamities of desertification, of which the sand-dust storms are both a cause and a symptom, are revealed.

Chapter Ten

DISASTERS OF STRONG SANDSTORMS OVER LARGE AREAS AND THE SPREAD OF LAND DESERTIFICATION IN CHINA

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Keywords: drought, salinity, grassland, water resources, land management, policy, history, climate change, wind, weather patterns, economics, sociology, human influences, remote sensing, development, land-use change

SYNOPSIS

Strong and very strong sandstorms in large areas occur frequently in the arid and semi-arid areas of northwestern China. They have caused huge economic losses and ecological disasters. They are the result of the growth of desertification, so the prevention of desertification should first focus on controlling sandstorms.

Analysis of recent sand-dust storm frequency and the changes in land-use reveal that the situation is getting worse. Remote sensing reveals that the area being lost each year to desertification now exceeds 4 million ha (up from about 2.7 million ha a few years ago).

KEY POINTS

1. *Strong and very strong sand-dust storms covering large areas occur frequently and areas affected are increasing.*
2. *Under the influence of global climate change, warm winters and dry springs occur more seriously in the northwestern area where, with the disturbance brought about by irrational human activity, large areas of vegetation were destroyed.*
3. *The main causes of strong and extremely strong sandstorms are natural and artificial factors. They are the result of the integrated influences of climate, geography, society and human factors. Many factors that cause the disasters are natural but human factors always dominate over natural factors.*
4. *Sand-dust storms are the result of the growth of desertification, so the prevention of desertification should first focus controlling sandstorms.*
5. *There is an opportunity for China to tackle this serious ecological and human disaster now, as the country launches its national programme to develop the western regions.*

1. INTRODUCTION

In recent years, strong sandstorms over large areas occur frequently in the North of China. The affected area occupies about half of China, stretching from the west to the east, even to the lower reaches of the Yangtze River. Especially in the spring of recent three years (1999, 2000 and 2001), strong sand-dust storms were more frequent and more severe than in the past.

Under the influence of global climate change, warm winters and dry springs occur more seriously in the northwestern area where, with the disturbance brought about by irrational human activity, large areas of vegetation were destroyed. This caused serious desertification, water and soil loss, and secondary salinization of soil and deterioration of the physical structure of the soil.

The ongoing spread of desertification is the main reason for the frequent occurrence of strong sandstorms. A sandstorm is a process of wind erosion and wind deposition under the action of strong airflow in certain conditions. It is a kind of special wind and sand flow and weather disaster with the strength to destroy. The extent and spreading scope of desertification enlargement provide the material sources of sand and dust and unstable states of hot air near the soil surface provide the heat energy for strong sandstorms (*see Chapter 1*).

The harm caused by strong sandstorms and desertification not only brings about the loss of construction to the national economy, but also endangers the security of life and wealth of the people. This in turn seriously influences the sustainable development of resources, environment and economy and especially directly influences the development of the Western Region of China.

2. CHARACTERISTICS AND HARMS OF STRONG SANDSTORMS

The general definition of a *"dust storm"* according to the China Center Weather Bureau, is a weather phenomenon of dusty air with visibility less than 1 kilometre. It is caused by strong wind that blows a great deal of surface dust and sand. At present, the classification of sandstorms in China is not standardized. According to international classification, strong sandstorms and very strong sandstorms are defined as:

- *Strong sandstorms* occur under conditions where wind speed is over (or equal to) 20 m/s and visibility is less than 200 m.
- *Very strong sandstorms (black wind)* occur when wind speed is over (or equal to) 25 m/s and visibility is less than 50 m.
- *Strong sandstorms and very strong sandstorms* cause the most serious disasters. In recent years, strong sandstorms over large areas occur with increasing frequency, extent and scope.

These may be connected with unusual weather conditions that occur frequently and global climate change, but really the main cause of the increasing frequency of sandstorms is the increase of land degradation. There are some historical records of sandstorms in China. They reflect the process and frequency of the time, but in order to analyze the spatial-temporal distribution of sandstorms in large areas, the following issues will be discussed according to standardized weather records that only started after the foundation of our country in 1949.

3. THE SPATIAL DISTRIBUTION CHARACTERISTIC OF STRONG SANDSTORMS

The vast regions in northwest China are places where strong sandstorms occur frequently and seriously. Based on the moving path of sandstorm weather systems, the cold high pressure, which can cause strong and extremely strong sandstorms, has two main moving paths, being:

- *Down from the west*: mostly influenced by the Siberian and Inner Mongolian high pressure anticyclone, it moves quickly, is high in intensity, wide in influence, and causes serious calamity. It includes the area of Talimu basin, Tulu –Shanshan – Tuokexun basin, by way of the Hexi Corridor to the north of Shannxi. The center of the cold high-pressure after the front is in Xinjiang and the west of Inner Mongolia. Keping, Hetian, Minfeng and Geermu in line in Xinjiang. Strong sandstorm weather lasted longer in these areas. By way of Dunhuang, Minqin in line, and moving to the east.
- *Down to the South*: Cold air which moves down to the south by way of Baikal Lake, the mid parts of Mongolia invaded into the north of Shannxi directly, influencing the Inner Mongolian plateau, Erduosi plateau, Bayinmaodao of Alashan plateau by way of Yulin in line.

4. THE TEMPORAL DISTRIBUTION CHARACTERISTIC OF STRONG SANDSTORMS

According to statistics, the frequency of cases of strong sandstorms increased after the 13th century, and it increased greatly after the 18th century, in half a century after the foundation of China, the annual changes of the frequency of strong and extremely strong sandstorms every 10 years are: 5 times in the 1950s, 8 times in the 1960s, 13 times in the 1970s, 14 times in the 1980s, 20 times in the 1990s (Ci etc.1998). The increasing frequency of sandstorms is obvious.

The seasonal variety of strong and extremely strong sandstorms has certain regularity, mostly concentrating in March to May according to observation. For example, the extremely strong sandstorms of 1993 occurred on May 4th to 6th; the first strong sandstorms of 1998 occurred on April 16th to 18th; April 4th to 6th in 1999; the first of 2000 occurred on March 22nd. According to notes of the past years, the frequency of cases of strong and extremely strong sandstorms peaks in April, the most active period.

The causes of this are that the necessary conditions that promote strong and extremely strong sandstorms are present:

i. Strong wind and low visibility, the atmospheric circulation in the northwest is frequently characterized by gale force winds in spring.
ii. The existence of abundant bare and dry, sandy and dusty substances.
iii. The ground temperatures are high. This creates instability and intensifies cross-ventilation leading to updrafts that transport sediments when wind speed overruns 10m/s. If the average wind power is over force 7 strong or greater, sandstorms will occur.

In spring in the northwest, the dry surface conditions and lack of rainy weather are associated with a high rate of evaporation. The plant cover is sparse and gives little protection to the ground. All these conditions favour the occurrence of strong and extremely strong sandstorms.

4.1. Daily changes of sandstorm weather

According to notes of the key areas in the northwest and our field observations, sandstorms generally start after midday, mostly concentrated between noon and dusk; in south Xinjiang, it mostly starts in the dusk, though seldom occurs from the second-half of midnight to the next morning. This is because the temperature is increasing near the ground in the afternoon, as does the wind power. Meanwhile, the hot layers of the lower part of the atmosphere are unstable, and heat convection favours the development of sandstorm weather.

5. THE HARM OF STRONG AND EXTREMELY STRONG SANDSTORM WEATHER IN LARGE AREAS

Strong sandstorms are the main disastrous weather, so often is serious in dry and semi-dry areas. They can cause great losses to the national economy and people's lives because they can make the disaster so serious and so cover a great area, including such eastern cities as Beijing and Tianjin. There are some examples of this (*Box 1*).

People's lives are threatened; *"environmental emigration"* is happening in China today e.g Luobubo. Such a serious disaster is rare in history. If we do not do anything for the increasingly desperate environment in some northwestern areas e.g. Alashan, as soon as possible, Alashan will be a second Luobubo, and the area will need to be abandoned.

Box 1: Some examples of serious dust-sandstorms in China in recent years

On May 4th, 1993, an extremely strong sandstorm came on the line down from the west. The intruding and accelerating Siberian cold air influenced it. When down to the south, the area influenced was huge, from north Xinjiang to Gansu Hexi, the west of Inner Mongolia and most part of Ningxia, the total area is about 11 million square kilometres. The maximum wind speed of extremely strong sandstorms reached more than 37.9 m/s (over 12 degrees), the general wind speed is 21 m/s (8 degrees), visibility (<50 m). Extremely strong sandstorms can cause great losses. For instance in Xinjiang, Gansu, Inner Mongolia and Ningxia, there were 85 dead, 264 injured, 4,412 houses destroyed, 120,000 livestock dead and lost, the crops which hit by a natural calamity reached 5.6 million acres, more than 2,000 kilometres of aqueducts were covered, traffic in some areas was suffocated and telecommunications were broken off, and so on. The direct economic loss reached 550 million, and it had influenced the environment and the economic development greatly.

On Apr.16-18th, 1998, extremely strong sandstorms attacked the west of China several times, from the west to the east until reaching the lower reaches of the Yangtze River. The areas influenced were so huge that it was rare in history. It met rainfall weather when passing Beijing, so dust rain was formed. In Nanjing, the chroma of the total suspending granule was 8 times above normal conditions. Floating dust weather was present in Inner Mongolia, Beijing, Jinan, Nanjing and so on.

The social influence was great. The administration department of Alashan, Inner Mongolia, reported its calamity to the leadership: attacked by 8-10 degrees strong wind for 12 hours, environmental quality TSP average chroma was 62.4 mg/m³, exceeding the national environmental air quality standard by more than 200 times. It lasted long and covered a huge area, according to local statistics; the continuous 6 days' sandstorms caused direct economical losses of over 1 billion Yuan (land losses are not included).

6. CAUSES OF THE FORMATION OF STRONG SANDSTORMS

The main causes of strong and extremely strong sandstorms are natural and artificial factors. They are the result of the integrated influences of climate, geography, society and human factors. Many factors that cause the disasters intercross, infiltrate and relate to one another, but human factors always function through natural factors.

6.1. Natural factors causing the formation of strong sandstorms

As listed above, atmosphere, landform and vegetation have a very close connection with the forming of strong and extremely strong sandstorms.

- *The connection with the atmosphere*: the areas where strong sandstorms occur frequently and seriously are mainly located in dry and semi-dry areas of middle latitudes, and they are also the very areas which are greatly influenced by and suffer under desertification. What is more, this area is very sensitive towards the changing of global climate and can cause negative effects.

- *Very cold air is the driving force of sandstorms*: only when the air is cold enough, is it possible for strong air pressure gradients to form. Abundant dry and loose sand material is the surface condition to form sandstorms. When the airflow is driven by strong wind power and there is no vegetation cover on the earth surface, the airflow can carry a lot of surface dust, silt and sand to float in the air and form sandstorms. Its height can be 1,000-2,500 meters when it is not serious and its height can be 2,500-3,200 meters when it is serious.

- *The formation of sandstorms needs a stable heat layer on the earth surface*: there is always continuous high temperature weather several days before the occurrence of sandstorms which promotes the action of rising air flow and increases the disturbance of the air flow to the surface, so in spring with changes in temperature it is easiest to form sandstorms.

- *The formation of strong sandstorms and geographical factors*: the landform relief has important actions as direction guide and *"landform effects"* to form sandstorm weather. The feature of landforms in the Northwestern Area is that mountains alternate with basins and plateaus combine with plains. For example, the Zhunger Basin lies in the middle of the Tianshan Mountain and the Aertan Shan Mountain; the Talimu Basin lies in the middle of the Tianshan Mountain and the Kunlun Mountain. The Hexi Corridor lies to the north of the Qilian Mountain and the Aerjin Mountain and to the south of the Alashan Plateau-Baishan upheaval belt alongside the terrace. The high plain of the Corridor is in the middle. The landform plays a role of direction guide and consolidation for the run of sandstorms. It also plays a role of increasing the air pressure and temperature gradients, which bring about the occurrence of sandstorm weather. The weather of sandstorms often occurs in inland desert areas. There are the Taklamakan Great Desert, the Badanjilin Desert and the Tenggeli Desert in northwestern China, so it is known as a frequent area of sandstorms.

- *The relationship between the formation of strong sandstorms and vegetation:* In dry and bare arid areas, large areas of sandy land and sand provide abundant sand and dust sources for the formation of sandstorms. Where the surface has a cover of shrubs, the vegetation changes the coarseness of the surface; this increases the resistance of surface to airflow and changes the airflow structure of the surface layer near the surface. According to surveys and research, when the air flow enters the grassland belts from the bare areas the roughness of the surface can increase from $8x10^4$ to $3x10^5$ times and the resistance to air flow could increase 17-26 times, while the drag coefficient can increase 4-5 times. In an area with shrubs and grasslands whose width is at least 244 meters, the energy supply of airflow at the upper layer to air flow near the surface can decrease, which decreases the wind speed near the earth surface by 40%. At a height of 10cm, the wind speed can decrease by 90%.

In the belts with the protection of defense forest nets, the protection scope of forest belts with sparse structures can be 24-38 times higher and the wind speed can decrease 34-41% on average, so the effect of forests in preventing sandstorms is very apparent. For example, in 1961, a very strong sandstorm occurred in Tulufan County. It continued for 13 hours and the wind power was class 12. The disaster area of crops in the whole county was 85%. Among them, the average output per mu of over 6,700 ha wheat with harvest about to occur was only 4.5 kg. Cotton of over 2,667 ha and grain sorghum of over 4,000 ha were blown out totally. Agricultural production encountered serious losses. In April 1975, strong sandstorms and very strong arid winds attacked this area several times. The harm done was the same as in 1961. However since 1961, Tulufan County began to construct forests of defense, close the sand and plant grasses, prevent wind and sand and start construction of irrigation works. By 1975, over 3,100 forest belts of farmland protection were built and preserved. Over 5,333 ha sandy areas were closed for planting grass. The forest nets were built for 70% of cultivated lands in the whole county and the ability to defend against sandstorms increased. In this year, the total disaster area was only 8% of the total sown area. Another example, in 1998, saw an extremely strong sandstorm bring about economic losses of over 900 million Yuan in Xinjiang. However, in the Shihezi area, due to the planting of forests, the green coverage was over 40%. There was no loss in this region while this sandstorm attacked Xinjiang, which was a rare result in the past 40 years.

6.2. Human factors in the formation of strong sandstorm weather

Human activity plays an important role in the formation of sandstorms and mainly includes two aspects: the first one is irrational land-use. The office of environmental planning of UNEP analyzed the human factors of global desertification and pointed out that overgrazing caused 34.5% of the degraded land area, forest damage caused 29.5% and irrational local agricultural use comprised 28.1%. The others such as irrational use of water resources, mining and transportation comprised 7.95%. The situations are similar in China. The second aspect is population growth and the rapid development of urbanization, which increase the pressures on the current productive land. The peasants pursue short-term action to improve their life through intensified economic activities. The human factors are mainly as follows:

6.2.1. Excessive cultivation

In the North half of the cultivated land was opened up during the ten years of cultivation. The national office of agricultural regionalization carried out the survey of Landsat remote sensing for 10 years in 53 county units in Helongjiang, Inner Mongolia and Xinjiang in 1986 and 1996. They discovered that in these four northern provinces the situation of damage to grassland and forests are very serious over the last 10 years. Nearly half of the cultivated land was opened up. During the last 10 years the cultivated area totals 1.74 million ha but the preserved cultivated land area is only 884,000 ha, which comprises 50.8% of the total cultivated area. The local people said sadly: *"to cultivate grassland in the first year, to get a little grain in the second year and to turn them into sand in the third or fifth year."* The abandonment of cultivated land formed a large area of sandy land, enlarged desertification and provided abundant sandy material for the formation of sandstorms. From history, it can be seen that some large areas of sandy land are related to farming cultivation and wars on a large scale. The three great episodes of cultivation since the foundation of New China destroyed a large area of natural vegetation. In many places where conditions of cultivation are not enough and there are no protection measures, cultivation without plans and limitations brought about land desertification.

6.2.2. Excessive deforestation

The natural desert forests distributed around the deserts and sands are outcomes of a natural balance formed over a long time. Combined with all kinds of artificial forests with large planting areas (including shrubs), they formed the protection system, which is an important part of a stable ecological system in desertified areas. In western regions, for reasons of excessive deforestation, there is no single vital force in the fragile eco-system and sands occur everywhere. For example, in the areas along the lower reaches of the Talimu River, the area of *Populus diversifolia (euphratica)* forest has decreased from 53,000 ha in the 1960s to 1,333 ha. It decreased 75%. In the transition area of grassland and forest in the Bashang area, due to excessive deforestation, the ecological environment was seriously destroyed. According to interpretation analysis of Landsat images, from 1987-96, in these 9 years, the forest area decreased from 363,500 ha to 222,400 ha, by 38.82%. The area of flow sands increased from 68,000 ha to 129,100 ha, by 81%.

6.2.3. Excessive grazing

Excessive grazing can lead to the degradation of grasslands. At present, in northwestern areas nearly 70% of grasslands are degraded because of excessive grazing. The overloading rate of animals in grasslands is 50-120%. It can be 300% high in some places. In the Hunshandake Sands excessive grazing brought about desertification. In 7 years, from 1989-96, the area of flow sands increased by 93.3%. The area of grassland decreased from 602,500 ha in 1989 to 430,100 ha in 1996, by 28.6 %. Moreover, for the irrational distribution of grazing spots and watering points, the vegetation of grasslands was destroyed seriously and wind erosion increased.

6.2.4. The abuse of water resources

In the northwestern arid and semi-arid areas, the sources of total water resource are precipitation, surface runoff and underground water. The use of water resources falls short of scientific management. The situation of waste is very serious. In the upper reaches, for lack of a strict system of irrigation, the amount of irrigation is too large. The serious shortage of water resources and uneven distribution brought about difficulties for ecological water in northwestern areas, which caused a large area of natural desert forest to die and vegetation to wither (*see Chapter 11*). Under a situation of continuous development of economic construction and increasing development extension of water resources, they led to the lower reaches of river drying up, the excessive exploitation of underground water, the imbalance of water and soil and the growth of desertification.

7. The growth trend of desertification and sandstorms

According to research on global climate change, analysis of surface remote sensing and the features of sandstorms, the future changing trend of desertification is studied.

7.1. The influence of global climate change

The arid and semi-arid area in the northwestern China mainly lies in the mid-latitude region, which is greatly influenced by global climate change. According to various researchers, if the industrial development and the structure of fuel application do not change, by 2050 the content of CO_2 and greenhouse gasses in the air will double the content of CO_2 before industrialization. Then it will increase the average atmospheric temperature by 1.5-2.5^0 (estimated by IPCC). If this situation is not controlled global change will bring huge human disasters, especially in the arid and semi-arid areas, which lack water in the mid-latitude areas and the frequent occurrence of drought will increase in summer.

We collected continuous weather data of ten years in over 1,000 meteorological stations in China and applied the calculation method of Thornthwaite's potential transpiration, which is universally applied in both China and overseas. According to the climatic regionalization indices of UNEP, the boundaries and scope of arid areas, semi-arid areas and sub-humid areas in China are defined. In China, the area of extreme arid regions is 697,000 km^2. The total area of arid regions (including arid, semi-arid and sub-humid regions) is 2,976,000 km^{2,} which occupied 38.3% of the total area. It is forecast that by 2030 the content of CO_2 will double, the average global temperature will increase by 1.5^0 and the area of arid regions will increase. Its total area could reach 3,777,000 km2, which will occupy 39.23% of the total land area of China. Global climate change has the greatest influence on the semi-arid regions and sub-humid drylands.

7.2. Land-use pattern changes

Landsat remote sensing and aerial images were used to analyze land-use patterns on case studies in the northwestern region. It can be seen clearly that irrational land-use is the main human reason for the enlargement of desertification. The growth trend is alarming. The following summary shows the extent of the problem.

7.2.1. The degradation rate of grassland increased by 2.6% every year

According to the national survey of remote sensing of grasslands, the national degraded grassland increased from 86.67 million ha to 113 million ha in the last 10 years. The increased area is 43.33 million ha and it also degraded at an accelerating rate at a speed of 4.333 million ha every year. The results of grassland degradation are desertification and salinization.

7.2.2. Maowusu desert

This is a typical mixed belt of agriculture and husbandry and lies in the boundary area of Inner Mongolia, Shaanxi and Ningxia. The total area is over 40,000 km^2 and involves 10 counties. Through long-term over reclamation, overgrazing and deforestation, desertification is growing rapidly in this area. According to analysis of Landsat and aerial images, the mobile sand area increased from 76,300 ha in 1958 to 112,400 ha in 1993 in 35 years. It increased by 47.3%. The area of forest decreased from 18,000 ha in 1958 to 4,246 ha in 1993. It decreased by 76.4%. Since the 1950s, this area has been managed. However, management destroys it and the damage is still increasing. The situation is very serious.

7.2.3. The area governed by Kerqin Zuoyihouqi and Kulunqi in Inner Mongolia

According to the interpretation and analysis of Landsat images in this area in 1975 and 1994, due to the planting of artificial forests in this area, the forest area increased by 109.4% while 29% of degraded grassland was recovered.

7.2.4. Interpretation of land set images in the 17 case studies in Alagan, Minqin and Ejina downstream of the Talimu River

Showed that in the last 10 years, the land patterns changed greatly, which brought about the shocking situation of increased desertification and sand growth. In Alagan, Minqin and Juyanhai, desertification is very serious.

7.2.5. Strong and very strong sandstorms in large areas occur frequently and their scope is increasing

With Western development, natural disasters caused by desertification and sandstorms may develop in a new style. In the 1930s, at the beginning of the development of America and the Soviet Union, the vegetation was seriously destroyed and strong sandstorm weather occurred frequently, which almost smashed the production of agriculture and industry that they were developing. We have to use their painful lessons for reference. At present, strong and very strong sandstorms in large areas occur frequently and they are more and more serious year by year, which becomes the obstacle to western development. With the great western development, new desertification could be promoted.

8. COUNTERMEASURES AND ADVICE

Strong and very strong sandstorms in a large area occur frequently in the arid and semi-arid area of northwestern China, which caused huge economic loss and ecological disasters. They are the result of the growth of desertification so the prevention of desertification should in the first place be controlling sandstorms. Advice includes:

a) To increase the sense of responsibility among the country's leaders at all levels, and to stress the urgency to prevent desertification and sand-dust storms. Strong and very strong sandstorms are very savage and can destroy just as flood disasters do. In order to guarantee the western development, leaders at different levels and people generally should increase their responsibility and sense of urgency to prevent desertification. The prevention of desertification is different from other ecological constructions. It is a long-term task but we cannot solve this once and forever. When humans destroy it, the land is ruined in a very short time. It is advised that taking the task of preventing desertification into account to evaluate political performance during the prefecture of leaders through certain administrative methods is vital.
b) To bring the prevention of desertification into the development plan of the national economy and society in the 21st century. It should be the project of national infrastructure construction.
c) To make the plan to prevent desertification strict and careful and finish it in different stages. To plan scientifically, carry out according to plans and manage strictly. The task to prevent desertification is a major programme of lasting importance to the 21st century. This important opportunity presented by the national programme of the Western Region Development should be seized to stop the growth of desertification and decrease the occurrence of sandstorms. It is a systemic engineering process to prevent desertification. While the extent of management should be increased in the areas with serious desertification, ecological construction should be done properly and must set up defenses in the common areas. Areas with serious desertification are also heavy disaster areas and the sources of sandstorms. To prevent the growth of sandstorms is the same principle as preventing desertification, that is to say, to set up defenses layer upon layer, to close the sand and plant forests, grass, quit the cultivated land to return to forests and make the barren hills green, adjust measures to local conditions and set up defenses according to disasters. The sandy material floating on the air is mainly provided by rising sand on the spot so strict measures should be taken to quicken the speed of reforestation on the bare surface without the cover of grass and trees.
d) To strengthen scientific technology, value the participation of experts, set up new engineering structures combining the production, scientific research and extension under new situations. Public bidding should be invited to increase the competitive mechanism when the task is to be carried out. At the same time, conditions should be created to let experts with genuine ability and learning participate in the engineering construction in order to increase the content of science and technology.
e) Advice is given: scientific research should be launched combined with engineering practices and pick up 3-5% of the basic funds from the engineering outlay to support scientific research and increase engineering quality. At the same time, new technology, new experiences and theories should be applied to meet out needs.
f) To do the work of monitoring and forecasting of desertification well and take the defense of desertification as the first priority. A national information net system to prevent desertification and sandstorms should be built to launch the forecasting and control of desertification at the early stages.
g) To strengthen international cooperation, communication and interchange. The prevention of Desertification and sandstorms are both involved with the international environmental problem. It is very important to strengthen international cooperation and intercommunion. It will enlarge the influence of China; meanwhile it could strive for international funds and technological support applying any possible opportunities to promote the successful progress of the whole engine of desertification prevention.

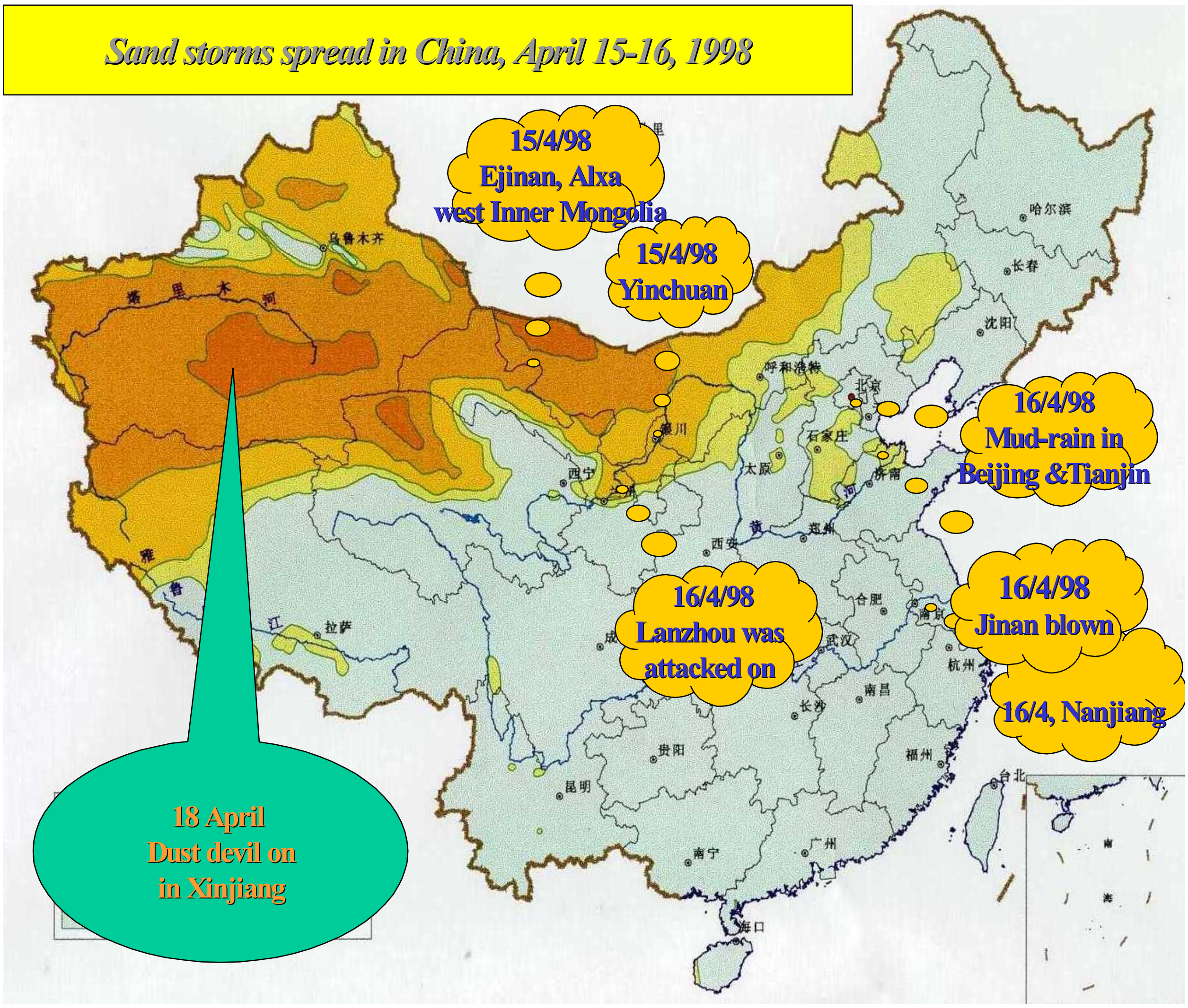

Figure 1: Sandstorms spread in China in 1998

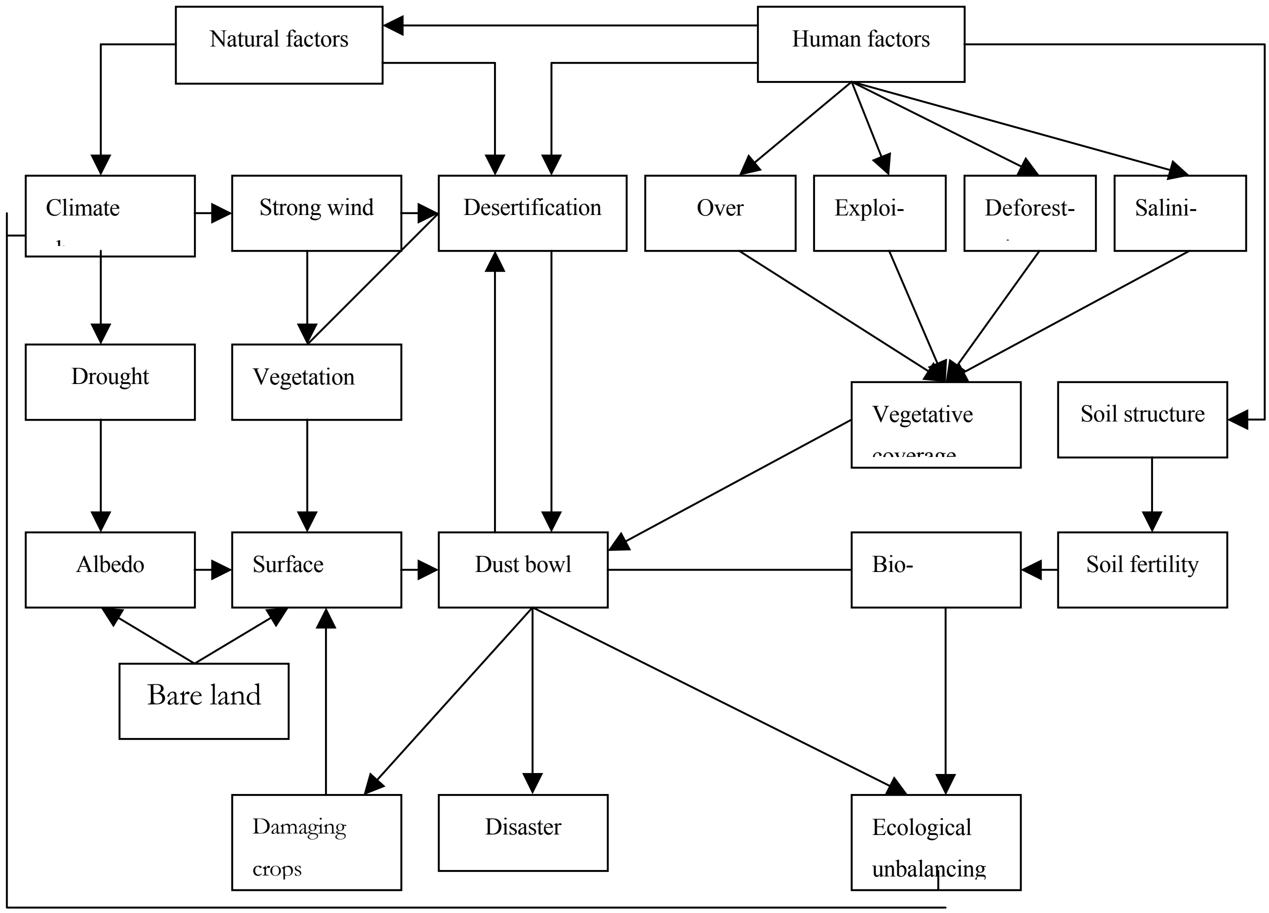

Figure 2: Dust storm weather and tendency of desertification

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10. REFERENCES

Aridity Droughts and Human Development, 1998, Springer.

Ci Longjun, Mechanism of Desertification and sustainable Strategies to Combat Desertification in China. *Quaternary Sciences* 1998, 5 (2).

Hare, F. Kenneth, 1993, Variaciones Climaticas, Sequia Y Desertification, *Organizacion Meteorologica Mundial (WMO)*.

Wang Shigong, Yang Debao, Zhou Yusu el al. 1995, *Analysis on the formative causes of sand-dust Desert Research*, 15 (4): 332-338 (in Chinese).

Williams, Martin A.J., Robert C. Balling, 1974, *Interations of Desertification and Climate*. WMO/UNEP.

Xu Guochang, Cheng Minlian, Wu Guoxiong. 1979, On an extraordinary heavy sandstorm on April 22nd in Gansu Province. *Acta Meteorologica Sinica*, 37 (4): 26-35 (in Chinese).

Xu Jianfeng, Niu Zhiming, Chen Weiming et al. 1996, Study of sand and dust storm weather in northwest China on April 5, 1994, *J. Desert Research*, 16 (3): 281-286 (in Chinese).

Chapter Eleven

DUST-SANDSTORMS: INEVITABLE CONSEQUENCES OF DESERTIFICATION – A CASE STUDY OF DESERTIFICATION DISASTERS IN THE HEXI CORRIDOR, NW CHINA

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SYNOPSIS

This case study outlines the problems faced by the peoples of the Hexi Corridor. These problems are serious and urgent, and are representative of those faced by other communities right across western China. The root causes are outlined and some remedies are suggested. The practical measures proposed under China's National Action Plan to Combat Desertification are described and discussed.

KEY POINTS

1. *During the last four decades, great efforts have been made to combat desertification and control sand disasters in the Hexi Corridor, a vast arid area in China's western region.*
2. *The direct economic losses of desertification, including frequent and damaging dust storms are considerable and the effects are not restricted to the local region.*
3. *Despite these efforts desertification is on the increase as a result of conflicting policies, irrational use of resources (such as water), inappropriate land-use, lack of finance, and the effects of poverty.*
4. *An urgent rescue mission needs to be mounted. The blueprint for this has been developed as part of China's National Action Plan to Combat Desertification.*

1. GEOGRAPHICAL SETTING

The Sand Desert Region in the Hexi Corridor, including the Alxa Plateau, contains geographically vast areas in the west of the Wushaoling Mountain Range, totaling 21 cities and counties of Wuwei, Zhangye, Jiuquan Prefectures and Jinchang and Jiayuguan Cities, and the three counties, Alxa Zuoqi County, Alxa Youqi County and Ejinna County, in Western Inner Mongolia. The total land area of this sand desert region is approximately 485,000 km² with a total population of 3.7 million. It is roughly estimated there is 3.58 million ha of affected land that can be rehabilitated, of which 1.011 million ha are mobile sands, 1.006 million ha are semi-fixed sands, 1.191 million ha are fixed sands and 376,000 ha are latent desertification-prone land. Under the impacts of uncontrolled fuel wood and medicinal herbs collection, desert reclamation and irrational use of water resources at the lower reaches of some inland rivers in the mentioned region, the issue of desertification is becoming crucial and annual average encroachment of sand dunes is 5-10 metres.

During the last four decades, great efforts have been made to combat desertification and control sand disasters. In the Hexi Corridor, both the local governments at different levels, and people have made significant contributions and achievements have obviously been gained in this field. However, troublesome issues and difficulties still prevail in the Corridor region.

2. SERIOUSNESS OF WIND DISASTERS AND FREQUENCY OF DUST-SANDSTORMS

The area of land affected by desertification is being enlarged and disasters caused by wind-dust-sandstorms are being intensified. At 12:00 on May 5th 1993, a strong wind-dust-sandstorm took place from northwest to southeast with a blowing speed of 50-60 km/hour. The coverage scale of the wind-dust-sandstorm spread all over the east central Hexi Corridor, Alxa Prefecture in western Inner Mongolia and parts of Ningxia Hui Autonomous Region. The maximum movement speed of the front peak of the dust was 76 km/hour, the average wind velocity was 11-17 m/s and wind force was 6-7 on the Beaufort scale with gusts of wind velocity at 20 m/s. Maximum wind velocity at 34 m/s was observed in Jinchang City and wind force was 12 at Beaufort scale. Black wind formed around Jinchang City. Sand and dust were deposited on all exposed surfaces and the atmosphere was filled with yellow sand. All villages, farmlands, grazing fields, minefields, and people on the road, on farms and even in their yards were suddenly attacked by the dust-sandstorm. The sky was as dark as a winter night and the horizontal visibility was zero. In the sky, a 300-400-metre high wall of yellow sand was formed and three layers of ball-shaped sand clouds rolled over with the hurricane. As a shadow, dust-sandstorms were observed in Wuwei Prefecture and Baiying City one after another. This strong wind-dust-sandstorm lasted for 2-6 hours and was sustained up till early dawn of the next day in Gansu province. It then invaded Ningxia Hui Autonomous Region and Inner Mongolia Region. This strong wind-dust-sandstorm wrought serious damage and caused a huge casualty list.

According to estimated statistics, only in the Hexi Corridor, 256 million RMB Yuan of direct economic loss was caused, 170,000 ha of crop fields were destroyed, more than 40,000 individual trees were damaged, 66,685 heads of cattle and sheep were killed, 27,000 ha of plastic greenhouse-cash crops were blown away, 278 people were wounded, 49 people were killed and 4 people were missing, presumed dead. Jinchang City, Wuwei City, Gulang County, Minqing County and Jingtai County were the most seriously impacted ones and direct economic loose was as high as 214 million RMB Yuan; 786 telephone-line and electricity poles were pushed down or broken, 78 km of high-voltage electricity wires were pulled and broken. The high-voltage electricity supply wire of the Jinchuan Non-ferrous Metal Corp was discontinued and lack of electricity supply caused more than 100 factories, mills, minefields and enterprises to stop production for 24 hours. This dust storm also caused some fires: 145 houses in Changcheng Township of Wuwei City were burned and 240 heads of draft animals were killed in fires. This strong wind-dust-sandstorm led to sand transportation and accumulation along railway lines. Some 42 passenger- and freight trains were postponed, delayed and parked and more than 10 million RMB Yuan was lost. The main causes of this dust event are: prevailing weather patterns, scarcity of vegetative coverage, exposed loose sandy land surface, abundant sand and dust sources and impacts on the fragile ecosystem from short-sighted human economic development activities.

During the last 10 years or so, the average annual increase of desertification affected land in Alxa Prefecture is more than 1,000 km²; the net increase is 11,800 km², occupying 90% of the available land area or more. Hazards of wind-dust-sandstorms are accelerated and sudden disasters are more frequent than before. Four strong and devastating tornado outbreaks took place in 1993, 1994, 1995 and 1996 respectively and the dried denuded areas in Alxa were the dust sources. All of the Alxa Prefecture, the Hexi Corridor of Gansu Province, Yinchuang Plain of Ningxia Hui Autonomous Region, Hetao (Great Bay of the Yellow River) Plain of Inner Mongolia were heavily threatened. Personal and property damages were caused and more than 1,500 million RMB Yuan of direct and indirect economic casualty was brought about.

On April 5th 1998, the fifth in the series of most serious wind-dust-sandstorms was again observed in Alxa prefecture. Around 09:00 AM a dust storm developed in Ejinna County and moved eastward, gradually crossing Alxa Youqi County and Alxa Zuoqi County. Up to 21:30 early evening of the same day, the main body of the tornado became weakened and migrated out of Inner Mongolia from Bayanhot, capital of Alxa prefecture. This sandstorm and dust event lasted for 12 hours and 30 minutes inside the range of Alxa Prefecture. The wind force was 8-10 on the Beaufort scale and surface visibility was 500 metres. In some parts, visibility was only 20 metres, wind velocity was 23-27 m/s and the dust storm prevailed in a height of 4-5 km. This dust storm persisted for such a long time and over so wide an area that it was one of the rare dust events in the history of Alxa. Despite the impacts of the rapid eastward movement of the Mongolian frontal surface cyclone and the evolution of atmospheric circulation, the key factors causing these sandstorms in Alxa are the gradual degradation of the eco-environment and the further acceleration of desertification in the region.

On the basis of initial survey data, 10,600 ha of crop fields in the whole Alxa Prefecture were destroyed, of which 330 ha of wheat crops were covered up by shifting sands, and 20,000 kg of seeds of autumn crops were lost because of sand movement and transportation. About 630 ha of plastic mulching crops were blown away or broken and 134 plastic greenhouses were damaged. More than 400 drinking wells were filled up with sand and 150 km of irrigation canals were flattened by sand accumulation, and one floodgate was damaged. About 130 ha of fruit gardens at blossom season were completely destroyed. Nearly 66 million ha of available grazing land was seriously swept and strong wind-sand drifts withered newly emerged green grasses and shrubs. Approximately 800,000 kg of hay and dried forage in open fields were carried away. 600 sheep-sheds and sties and 80 warm booths for baby sheep were damaged. 1000 yurts were knocked down or blown away. 210,000 heads of animals were lost, of which 7,000 were killed by the sand disaster. Direct economic losses of crop farming and animal husbandry were as high as 60 million RMB Yuan. Only in Alxa Prefecture, 270,000 km² of dryland was attacked by this dust storm and heavy losses were experienced, particularly damages to crop and animal production, mining, water supplies, electricity, traffic and communications. Jilantai Salt Lake, Yablay Salt Lake, Dunchi Salt Lake, Chahanchi Salt Lake, Zhongquanzi Nitrate Lake were almost covered up or buried with sand sediments. Direct economic loss to industries in Alxa Prefecture was 2.34 million RMB Yuan.

Highways and railways were threatened, electricity and communication facilities were harmed over a wide area and total economic losses were 1.5 million RMB Yuan.

3. ROOT CAUSES OF WIND-DUST-SANDSTORMS

3.1. Development in disorder and *"grasp all and lose all"*

Alxa Prefecture, situated at the lower reach of the Heihe River, was magnificent in historical times. Forest, shrubs and grasses densely covered the Juyan District in ancient times. It was vast fertile territory to grow cereals and to graze animals. The practical system for stationing troops and for cultivating crop-farming had turned this district into the *"Huge Juyan Granary"* after the Han Dynasty (220 AD). The ancient Town of Juyan was an important barricade linking the *"Ancient Silk Road."* In the early 13th century, Marco Polo, famous Italian traveler, had been here. In the early 20th century, many Bamboo Slips of the Han Dynasty were unearthed in the Ancient Juyan Town. Relics during the archaeological discoveries show sufficiently that the Ancient Juyan Oasis was a rich region with a glorious history that could be endlessly depicted by written language.

The State has determined the Hexi Corridor the commercial cereal base and the Hexi Corridor has definitely contributed abundant food supplies in past decades. The achievement is indeed significant and has helped the State overcome the issue of lack of cereal supply and solve the issue of food security. However, the achievement and cereal contribution are gained through the expensive cost of sacrificing the eco-environment of the entire region of the lower reaches of the Heihe River. The negative consequences caused by land reclamation and cereal production in the region can be easily understood from the existing status of desertification processes and their impacts on land/environment at the lower reaches of rivers and streams. For instance, since the 1950s, newly opened arable lands and crop fields at the upper reaches of the Shiyang River and the Heihe River have doubled in acreage. Consequently, the Minqin Oasis has contracted one third and about 20,000 ha of irrigated lands at the lower reaches of the Shiyang River have also been decreased. The total annual consumption of water supply was 8 billion cubic metres, which exceeded 7.3 billion cubic metres, the total volume of water storage in the entire region of the Hexi Corridor.

3.2. Prolonged drought and downstream cut-off of water flow

Annual atmospheric precipitation in the Hexi Corridor varies from 37-100 mm and annual evapotranspiration is as high as 3,700 mm. During the last decade, water flow entering the Ejinna County from the Heihe River was reduced to 300 million cubic metres from the former 800 million cubic metres and only 183 million cubic metres was charged into Ejinna in 1992. From the 1950s to the 1960s, the cut-off duration of water flow downstream was less than 100 days and was extended to 200 days in the 1990s. It is estimated that 49% of water volume flowing into Ejinna from the main course of the Heihe River has been reduced and one third of the area of the Ejinna Oasis has been invaded under the threats of desertification and land degradation. The Sogo Nor and Gashun Nor that occupied more than 300 km^2 at the end of the 1950s has been completely dried up. The exposed bottom of the lakes, other deflation sites and even spot-shaped Yardong landforms are a source of sediment for dust storms.

3.3. Degradation of plant community and shrinking of oases

The Hexi Corridor region is characterized by its harsh natural conditions. Local governments and local people deal with the task of combating desertification year by year. However, sand movement, dune reactivation and land desertification take place every year. Great efforts have been made for alleviating the poverty on the one hand, while blind economic development arrangements have been made to destroy the living environment on the other hand. By analyzing the existing facts, the following root causes emerge:

- The Hexi Corridor region is a typical less-developed region where farmers are less educated ethnic group people in rural areas.
- Local financial sources are limited due to lack of tax income; government financial administration cannot afford the high cost efforts to combat desertification, at least in the near future.
- The local cost-sharing budget is designed in all plans and programmes, but allocation of budget is always impossible.
- The ability to introduce, to adopt and to extend new techniques, new research results and advanced know-how is weak and the capacity building system is insufficient.

There are 3.34 million ha of degraded grazing land, occupying 34% of the total available grazing land in the whole region of Alxa Prefecture, of which 60% is seriously degraded and where edible forages are reduced down to 20 species from a former 120 species. The fodder production and carrying capacity of grazing land has decreased 43% and 46% respectively. The average body weight of an individual draft animal has been reduced by 50%. There were 1.133 million ha of *Hedysarium* spp. forests and woodland crossing the Alxa plateau in the 1950s, but it has been deforested and only 530,000 ha is left in unhealthy survival. There are 72,600 ha of desert bushes and woodlands at the downstream bank of the Heihe River, which is decreasing at an annual rate of 2,600 ha. In comparison with the situation in the 1950s, woodlands of *Populus euphratica* and *Eleagunus* spp. have been reduced by 54.6%, *Tamarix* shrubs have declined by 33%. Pests (insects and diseases) are rampant in the residual bushes and 40,000 ha of them are under the impact of pest hazards every year.

Several decades' efforts have been spent on dune stabilization, sand disaster control and desertification combating, however, most of the traditional approaches are still the key measures to deal with the issues at the moment. For instance, flood irrigation is the main irrigation method in most arid, semi-arid and dry sub-humid regions, although there is an abundant of new irrigation technology and advanced facilities. Technological significance of advanced irrigation technology is well recognized, but *the "budget pockets of local governments"* are empty. Some small-scale experiments or demonstrations have been conducted and nationwide extension of advanced irrigation techniques needs a long-term time frame and much effort. The time when water-saving techniques are introduced and popularized in the Hexi Corridor region is the era when desertification will be turned back.

3.4. Deforestation, uncontrolled collection of herbs and exposure of the fragile land surface

Uncontrolled collection of medicinal herbs in Dunhuang, Anxi and Jiuquan caused severe vegetation degradation in fragile dryland ecosystems and dense spot-shaped blowouts and denuded sites, sand mounds and sand sheets have appeared. Scarcity of vegetative coverage was as complete *"as a shaved person's head."*

3.5. Overgrazing and the vicious cycle

Overgrazing in Jingtai County, Gulang County and Ejinna County caused serious rangeland degradation and the situation will be more critical in the near future if no more practical approaches are adopted to rehabilitate and restore it.

A Vicious cycle of poverty is characterized by an enlargement of animal population – degradation – double increase of animal population – further degeneration unceasingly practiced. Poverty has forced people to enlarge animal grazing and dense grazing or overgrazing resulted, causing further consequences in poverty in both economic and ecological aspects. Such disastrous circulation caused by unwise development of animal industries will go round and begin again.

3.6. Mismanagement and irrational utilization of water resources

Wasteful water use in the upper reaches of rivers in the Hexi Corridor Region brought about relentless degradation of eco-environments at the lower reaches of the rivers and water systems in the mentioned region. The policy for protecting water resources in the Qilian Mountain ranges is unfair and needs to be perfected. The existing situation of water resources in the Hexi Corridor is that *"large scale development of water resources for wide irrigation profit benefits those at the middle reaches and water allocation results in poverty and sad suffering for those in the upper reaches or at headwater."* Water resource protection is not compensated with subsidies and the operation of the overall plan of water resource management was critically affected; negative influence was brought to integrated rehabilitation. Due to the blind exploitation of underground water, large areas of natural vegetation were withered in Minqin. Pressures of human population and insufficient arable land are always a couple of outstanding contradictions.

Minqin County is located at the lower reaches of the Shiyang River in the eastern Hexi Corridor that is characterized by typical desert zonality. The county is an oasis farming area in an arid desert zone and oases are situated just along the two banks of the Shiyang River. The Minqin Oasis is squeezed in the transition belt between the Tengger Sand Desert and the Baidan Jilin Sand Desert. Since historic times, under the impacts of prolonged drought, harsh climatic conditions and human factors of economic development and mis-management of resources, have caused most of the land area of the county to constantly experience unceasing spread and cases of desertification. The landscape of *"abundant waters benefit fertile soil and fresh water flows across green pasture"* at the ancient terminal lake basin has been completely turned into desert, the same as the prevailing surface features of sand dunes, the Gobi desert, and denudation sites. In total, various types of desertification affected lands occupy 94% of the county territory and only 6% is the oasis where farming is widely developed and water is blindly utilized.

Since the 1950s, due to the rapid growth of the human population and the development of agriculture and industries along the Shiyang River Valley, the contradiction between supply and requirement of water resources is becoming crucial day after day, especially the contradiction of the distribution of water resources between the upper reaches and downstream is worsening. The annual surface water flow volume in Minqin County, which is located at the lower reaches of the Shiyang River, decreased by 1.3×10^8~$1.5\times10^8 m^3$ in the mid-1990s from the former $5.8\times10^8 m^3$ at the end of the 1950s. To meet the need of irrigation, large-scale exploitation of underground water was initiated in the early 1970s and the annual pumping volume of underground water is as high as $5\times10^8 m^3$ and it is estimated that the annual volume of pumping underground water is about 2.0×10^8 to $2.5\times10^8 m^3$. Consequently, such unwise irrational utilization of underground water resources resulted in directly further accelerating the modern desertification process in Minqin County, particularly at the fringe of oasis areas.

The irrational utilization of water resource in Minqin County has created desertification affected land and is mainly manifested in the following two aspects:

1) Soil salinization is further spreading in the northern part of the Minqin Oasis, which is located at the end site of the lowest reaches of the Shiyang River which was termed the lacustrine depression, and the oasis is declining. Soil salinization in this lacustrine area prevailed in historic times and most farming lands here were fundamentally reclaimed from old salinized soil. Over the last decades, strong evaporation has increased the salt concentration on the land surface due to the lack of fresh irrigation water on the one hand, and the wide use of blackish water for irrigating (mineralization is >3g/l) has accelerated the increase of the salt content in top soil and the area of salinization has been enlarged on the other hand. As a consequence of soil salinization, land productivity decreased rapidly and large amounts of arable land were turned into unproductive soil as wasteland. According to local government statistics, abandoned cropping land is currently 20,000 ha.

2) Oases areas in south-central Minqin, which refer to the middle and lower reaches of the Shiyang River and used to be named dyke areas, were widened. However, wind erosion at the fringe areas of oases further accelerated. The dyke areas are situated at the middle and lower reaches of the Shiyang River and the ground water level is at moderate depths with supplies of fresh quality water. Due to the existence of the Hongyashan Reservoir, the water supply in this area is relatively sufficient. After the 1970s, surface water supply was rapidly reduced and large volumes of underground water were pumped to meet irrigation needs. Underground water table was sharply deepened and a 22 km^2 sized funnel descending basin was formed around oases and their adjacent areas. The underground water table dropped to 11-20 metres today from 1.5-2 metres in the 1950s. The annual descending depth is 0.5-1.0 meter and further potential deepening exists. As a result of the deepening of the underground water table, natural vegetation and artificial plantations around oases and their fringe areas withered or disappeared, fixed sand dunes were reactivated and the desertification process was accelerated. Since the early 1980s, high priority has been given to high economic returns, and a large-scale reclamation of desert land around oases has been launched for planting cash crops. Underground water was drastically over-exploited. Up to the mid-1990s, more than 15,000 ha of cropping field were opened from desert areas to cultivate cash crops. The reclamation of desert land has led to the direct destruction of desert plants outside oases on one hand, and has brought about disappearance of desert vegetation due to the rapid descending underground water table on the other hand. In addition, without the establishment of windbreaks, sandbreaks and farmland protective shelterbelts, dry hot winds and dust-sandstorms threatened the newly opened fields. Disastrous climatic phenomena are the main factors reducing crop yields or even complete crop failures. Most of these newly opened fields were abandoned after two or three years cultivation and thus desertified by shifting sand land or salinized soil. At the same time, undeveloped modes of production and near-sighted beneficiary behavior have resulted in rapid spreading of desertification processes in Minqin. From the point of view of land-users, land-use rights were unsettled, benefits were divorced from input, responsibilities and rights were undefined, morale was unstable, and farmers were interested only in the immediate harvest of crops of the very year. Such shortcomings pressed people to take care only of immediate interests and neglect long-term interests. The direct consequences of all development activities include large-scale destruction of vegetation. Without effective protection of vegetation, the land surface is exposed under blowing wind and deflation and is at risk from degradation and desertification.

Food is the first necessity the people and farmers have to open new fields for growing more grains. *"Poverty makes further plowing and extensive land cultivation produces further poverty"* is an actual portrayal of Minqin County in the Hexi Corridor.

3.7. Weak legal framework and lack of awareness

Desertification combating is a long-term hard task and continuous and sustainable arrangement is a necessary policy. The existing policies of rewards (to encourage) and punishment are not enough. With regard to most local governors and decision-makers, it is their core responsibility and task to solve the lack of food and shortages of warm clothes for local people while they are on duty as local administrators. It is hard for them to have strategic thinking about the environment and sustainability when faced with numerous problems of immediate urgency forced on them by hard natural and economic conditions. Local officials in desertification-affected areas, are in less developed areas due to poor economic potential. They do their best within their limited capability and this is why there are so many further occurrences of *"new sands"* around their lands every year when *"old sands"* were stabilized. The process of *"retreating sands by human resettlement"* is confined to some regions and *"human moving-out by sand invasion"* is under initial control, however, the fact that *"desertification is partially controlled and the total spreading trend is continuously developing"* remains at present time.

4. STRATEGIES AGAINST DESERTIFICATION

Over the last five decades, impacted by prolong drought and irrational human economic development activities, the eco-environment of Alxa prefecture, western end of Inner Mongolia, sharply degraded from the former gradual deterioration.

Other countries in the world have had experiences in serious land degradation during last decades (*see Chapters 4-9*).

1) On May 15th 1933, a serious black dust-sandstorm was observed on the Great Plain of the United States. This dust storm swept two thirds of the areas of the North American Continent with coverage of 2,400 km long and 1,440 km wide. The dust transported reached a height of 3 km and soil particles landed several hundred km away in the Atlantic Ocean. This was the world famous *"Dust Bowl"* that took place in the 1930s in the United States (*see Chapter 5*).

2) From 1954-64, the government of the former Soviet Union opened 250,000 sq. km of steppes and rangeland in the northern Kazakhstan Republic for agricultural use. This new cultivation covers 42.1% of the total steppes of Kazakhstan. The former scene of *"fresh breeze moves grasses on green rangeland"* was completely polluted. Annual frequency of dust-sandstorm was 20-30 days. It was tested that 550 tons of yellow sand was deposited in a profile of 100 metres long and 1 metre above ground under wind force 6-7 on the Beaufort scale in a span of 12 hours. Wind erosion and deflation have brought about serious land desertification in this Republic.

3) From 1968-72, the Sudan-Sahelian Region experienced the most serious drought disasters in human history and approximately 200,000 humans and millions of animals were killed during this time (*see Chapter 6*).

These lessons are very painful. It is our top priority to avoid the occurrence of such disasters mentioned above. In China, the situation of desertification is getting worse and worse and hazards caused by desertification are becoming common. The consequences of desertification cannot be ignored and similar attention should equally be paid to other natural disasters, like forest fires, earthquakes, floods and others. The same as other hazards, desertification directly weakens the foundation of social and economic development. The final impact and far-reaching threats of desertification are the destruction of the environment and the loss of land resources that humans depend on.

In 1997, the National Bureau to Combat Desertification (NBCD) and the State Forestry Administration (SFA) (the former Ministry of Forestry) of People's Republic of China revised the National Action Programme for Combating Desertification (NAP) on the basis of a previous NAP prepared at the end 1995. A new plan for natural preservation, rehabilitation and development for the Hexi Corridor has been designed and contains:

4.1. Regional objectives

Particular emphasis was laid on regional development and reconstruction of entities. Under the principle of the general concept of *"stopping sand movement in the north part, preserving headwater in the south part, practicing crop farming in the central part, and helping people to get rich across the board,"* windbreaks and sandbreaks should be established in the northern part of the Hexi Corridor and in the western part of Alxa Plateau to contain the sand invasion from the Baidan Jilin Sand Desert; sunshine agricultural projects for developing high-yield of high quality cereals should be launched in the central part of the Hexi Corridor and commercial grain bases should be limited to a reasonable portion; the headwater preservation forest in Qilian Mountain ranges should be prioritized for preservation, safeguarding and maintenance in the southern part of the corridor. These purposes are aimed to guarantee the total volume of water requirements, to spur economic development and to raise income in the whole Hexi Corridor Region.

4.2. Rehabilitative Approaches

1) Centred on the oasis, a protective system will be established, including protective tree networks inside the oasis, complex biological approaches to control sand encroachment at the fringes of the oasis, establishment of sandbreaks and wood stands in the inter-dune low-lying areas, installation of sand barriers on dune surfaces, and establishment of straw grids and plantation of sand-fixing varieties inside the straw grids. At the same time, attention must be paid to the preservation of existing desert vegetation and rational utilization of water resources.

2) In the Hexi Corridor, particularly in Alxa Prefecture of western Inner Mongolia, both local government and people are in a very difficult financial situation. Combating desertification is a long-term difficult benevolent administrative project and task needing a huge budget and stubborn efforts from generation to generation. More financial input is demanded to combat desertification. The annual budget for combating desertification from the central government is lower in percentage and the negative interest loans from the central bank often reach local banks out of the planting season. It is reported that the percentages of negative interest loans used for ecological purposes are lower. It is recommended that higher percentages of financial inputs should be allocated from the central government. At the same time, the budget inputs to

desertification affected regions from the central government for other projects, like poverty alleviation, integrated local area development, agricultural promotion, food security, relief arrangement, water conservancy maintenance, basic farmland construction and steppe improvement, should take out a certain for combating desertification with close inter-agency coordination.

3) The objective of central government inputs to affected areas is to increase their ability and capability to strengthen local development. Local governments are also requested to increase financial input to combat desertification. It is unrealistic to merely request the central government to bear all the financial contributions for dealing with the issue. The increase of input ability to combat desertification needs positive forces from both the central governmental agencies/ministries and local governments.

4) Capacity building should be promoted through science advancement and wide extension and full adaptation of existing experiences and traditional know-how in the fields of desertification combating, water-saving techniques, control of salinization, and dryland management. Effective ways of optimum resource utilization should be explored through formulation of optimum models of land development and resource utilization. Farmers and herdsmen, particularly women, should be trained with special skills and approaches through more patterns, various levels and channels. Some model villagers, demonstration households and extension service should be supported through assistance of pilot projects. The popularization system of research results and technical achievements should be promoted through introduction, experimentation and adaptation of existing traditional knowledge, know-how, practices and skills from other affected regions.

5) All the stakeholders, such as organizations, enterprises, citizens, farmers and herdsmen, who benefit from the achievements of desertification-rehabilitation, should assume the corresponding responsibility and obligation in the drive to combat desertification. The systems of obligation labour and accumulation labour should be defined according to the local actuality and the duty requirement for combating desertification. In the affected areas, the priority rights for rational development and utilization of resources should be given to those who contributed efforts and input. All governmental agencies, collective enterprises, civil societies, business groups, private sectors (particularly women), should contract with local governments and rehabilitate the desertified lands, while developing rational resource use in the affected areas. The correlated policies will be kept in practice without change for five decades. The inherited and legal pay-back transfer should be assented and protected in State laws. Trans-boundary development and inter-county level contracts should be permitted to encourage all stakeholders to further contribute to the heavy task of combating desertification.

6) It is suggested that governmental agencies at the central level should include all the affected counties along the Heihe River, the Shiyang River, Alxa Zuoqi County, Alxa Youqi County and Ejinna County of Alxa Prefecture, of western Inner Mongolia into the key projects, such as the National Project of Water Conservancy at the Middle and Upper Reaches of the Yellow River, and the National Project of Ecological Improvement in Wind-eroded Areas. An Ecology Restoration Project in Hexi Corridor and Alxa prefecture should be launched as early as possible. Air seeding is recommended on a large-scale at the lower reaches of the Heihe River and the Shiyang River; wire-fencing systems and artificial plantations should be carried out at the same time. Gulang County, Jingtai County, Minqin County, Alxa Zuoqi County, Alxa Youqi County and Ejinna County are strongly suggested to be included into the National Natural Forest Protection Project.

7) Hexi Corridor Region is rich in scenic spots, human cultural scenery, and amazing natural landscapes for developing tourism. Pyramid megadunes in the Baidan Jilin Sand Desert, colourful painted Gobi in Liuyuan Oasis, Qilian Mountain glaciers, alpine meadows, mountain forests, desert salt lakes and streams, and Yardang landforms noticed for their special features in the desert region. Popular customs and folk customs of Mongolia, Tibet, Hui, Sala and other ethnic minorities are attractive. Ancient and mystical Islamic mosques, Buddhist temples, soul altars and other religious sites are fascinating to visitors. The rational development of these tourism resources does not only promote the tourism occupation, but also plays an effective role in promoting social advancement and economic growth in the affected counties in the Hexi Corridor Region, under the premise of close coordination and joint efforts between various sectors and different branches.[14]

8) In Dunhuang County and Ejinna County, as the key project sites of NAP, it is suggested that 500 sets of demonstration facility of *"solar energy kitchen"* should be installed respectively in the two counties. It is aimed to stop desertification processes caused by undue collection of firewood and unwise destruction of desert vegetation. Dunhuang is an important town on the ancient Silk Road. Under the impacts of frequent warfare, overgrazing, firewood collection, mismanagement and over-exploitation of water resources in history, the county is completely reduced to wild desert land. At present, the well-known world treasure of Mogao Grottoes is under serious threat of shifting sands and wind deflation.

How can the process of desertification in the Hexi Corridor be controlled? What approaches are effective in minimize the intensity of desertification disasters? The development of solar energy and protection of natural desert plants and artificial plantations are sustainable measures to answer these questions. Most land areas of Ejinna County have been buried by shifting sands and dune movements due to cut-off of water flow at the lower reaches and the irreversible cutting of firewood and unwise medicinal herb collection. Soguo Nor and Gashun Nor (Juyan Lakes) have been dried up and the bottom of the lakes were completely exposed without any biological mulching or vegetative coverage, and as a consequence, the Yardang Landform occurred in the previous lacustrine depression. The old desert scenery of *"Tamarix grow ten metres high and Populus euphratica line two banks of river"* has become a remote memory of local herdsmen. The development of solar energy will reduce the opportunities of undue collection of firewood and guarantee the practice of vegetation protection in desert regions. It is initially intended that some budgets of the NAP should be allocated to create *"solar energy kitchen"* demonstration sites in both Dunhuang County and Ejinna County. The successful result of this solar kitchen demonstration will produce effective promotions of alternative energy resource development, rehabilitation of desertification affected lands, ecological restoration, improvement of the living environment and increase the people's quality of life in western China in the 21st Century.

[14] Some cities in the deserts of western America have experienced similar procedures in previous decades and their successful stories and fruitful achievements show us that under the protection of preferential state policies, the proper, reasonable and appropriate development of tourism resources bring about not only rich economic return, but also spur the progress of society and improve the degraded natural landscape.

Figure 1: Reactivation of vegetated dunes along the Hexi Corridor, West Gansu

Figure 2: New sand dunes along the dried up river course, Hexi Corridor, West Gansu

Figure 3: Nomadic settlement under sandstorm on desert steppe

Figure 4: Dust devil: final consequences of desertification. Sandstorm on May 5th, 1993 in northern China

5. REFERENCES & FURTHER READING

China National Bureau to Combat Desertification, MOF, Jan 1995, *"China National Action Programme to Combat Desertification,"* Beijing.

"Desertification: An Urgent Challenge China Faces," Oct. 2000, Page 200, China Science and Technology Series Book, Kaiming Press, Beijing,.

Lu Qi, Y. Yang & B. Wu. 2000. *Strategy for Scientific Research and Integrated Rehabilitation of Desertification in 21 Century*. Review of China Agricultural Science and Technology, 2 (1): 47-53.

Lu Qi & Yang Youlin. 1999, *Desertification and Its Combating Strategy in the Qinghai-Tibet Plateau – A Case Study of Qinghai Province*. Chinese Journal of Arid Land Research (Allerton Press, Inc. New York), 12 (1): 55-64.

Project Proposals of Roundtable Meeting for Searching Technical Consultation and Mobilizing Funds to Implement the National Strategy of Development of Western China and the United Nations Convention to Combat Desertification, 2000, p. 97-107, CCICCD/NBCD/SFA, Beijing.

Sen Wang, Rui Zheng, Youlin Yang, 2000, International Forestry Review 2 (2), p. 112-117, *Combating Desertification: the Asian Experience*.

United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, 1997, Text with Annexes in Chinese Version, Beijing.

Yang Youlin, Lu Qi, et al. Oct. 1995, Chapter Eight Natural Resources in Deserts: Vol. 1: *Natural Resources in China*, China Forestry Press, ISBN7-5038-1728-3/S.0989, p. 177-205.

Yang Youlin, 1997, Chinese Farmers, Vol. 7., p. 48-50, *Desertification Rehabilitation in Kuwait*.

Yang, Y-L. & Q. Lu. 1996. *Desert Rehabilitation and Forestry Development in Israel*. WFR, 9 (4): 41-46.

Yang Youlin, 1999, Executive Editor, *Traditional Knowledge and Practical Techniques for Combating Desertification in China*, the Secretariat of China National Committee for the Implementation of the United nations Convention to Combat Desertification (CCICCD), China Environmental Science Press, ISBN 7-80135-925-9/X. 1499, p. 200.

Yang Youlin, Lu Qi, 1997, Forestry Science and Technological Management, Vol. 2, p. 13-15, *"Review of Global Dynamics for Combating Desertification."*

Yang Youlin, 1990, *Range Management in Arid Zone*, in Kegan Paul International, London and New York, KISR. I*Human Population Growth and Its Impacts on Rangeland Desertification in Eastern Inner Mongolia* p. 71-76.

Yang Youlin 1999. *Review on Desertification Research in China. Chinese Journal of Arid Land Research* (Allerton Press, Inc. New York). 12 (2): 99-113.

Zhu Z, Liu S, Yang Youlin, etc., Geographical Science, Vol. 4. *"The reality and Possibility to Rehabilitate the Desertification-prone Lands in Northern China."*

Zhu Z, Liu S, Yang Youlin, 1983, Vol. 3., Journal of Desert Research, IDRAS, CAS, *"Study on the Environmental Change in Ancient Sogol Nor."*

Chapter Twelve

ROOT CAUSES, PROCESSES AND CONSEQUENCE ANALYSIS OF SANDSTORMS IN NORTHERN CHINA IN 2000

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Key words: sandstorms, climatic factors, greenhouse, nationwide trend, regional trend, Northern China, underground water, oasis

SYNOPSIS

Land degradation in the marginal areas of north China, on the important ecological transition between semi-arid and the sub-humid climate zones, is very serious and is getting worse. It is a relatively narrow belt of 100-250 km width and about 2,000 km long. The annual rainfall varies from 300-400 mm. In the past (before the 20th century) it was mainly used for grazing and some dryland cropping.

As land-use intensified, and particularly from the 1970-80s and onwards desertification accelerated. Several case studies are presented to demonstrate the spread of this land degradation and an analysis is presented as to why it occurred.

KEY POINTS

1. *Sand-dust storms are the result of a combination of weather factors, including strong winds, but their frequency and intensity are mostly related to precipitation. The El Nina/ El Nino effect is strongly implicated.*

2. *Human economic activities supply sufficient sand-dust sources to create a hazard if the wind and other weather factors are conducive. Large-scale land conversion for cropping, deforestation, irrational use of water resources and over-exploitation of groundwater have all contributed to the problem.*

3. *Evidence exists that the frequent occurrence of dust storms is not about to end soon. Severe disasters occurred five times in the 1950s but there has been a five-fold increase since then.*

4. *At the regional level there are two main types of severely affected landscapes where desertification is spreading quickly and the hazards are serious. The first of these is the great area of sandy land and the second are the oases areas developed along the major rivers in the desert margins.*

1. CLIMATIC FACTORS CAUSING SANDSTORMS

1.1. Climatic background causing cases of sandstorms

Sand-dust storms are the resultant affect of strong winds, but their frequency and intensity are mostly related to precipitation. Analysis of fundamental data of millennium climatic variation indicates that the curves of frequent occurrences of sand-dust storms are well matched with climatic background curves of drought periods (inclined line in *Figure 3*). The periods of frequent sandstorms that occurred from 1060-1270 and 1470-1920 coincide with prolonged droughts that happened during the same periods of time.

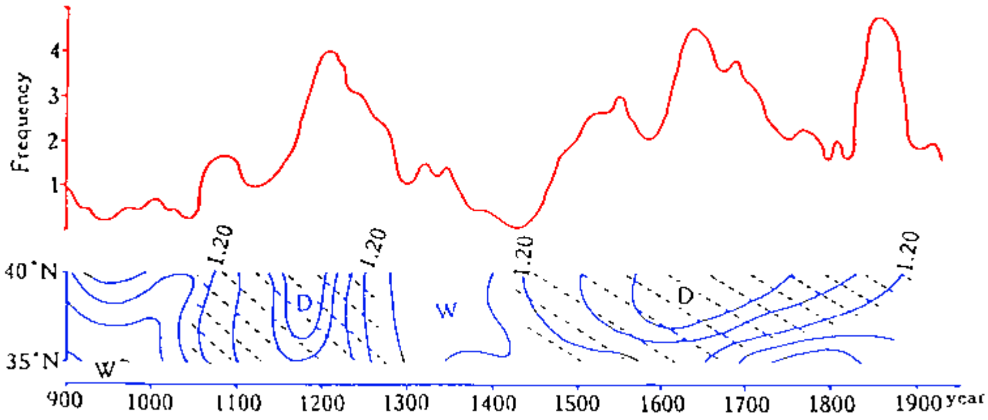

Fig.3 Comparison of frequency of dust fall with curve of humidity index for the last 1000 years.

In addition, the frequency of strong sand-dust storms goes up quickly in recent years and this is possibly related to the frequent occurrence of El Nino events, strong La Nina events that occurred in the Eastern Pacific Ocean since June 1998, and global warming caused by the increase of man-induced greenhouse gasses.

1.2. Analysis of the climatic factors causing sandstorms in the spring of 2000

During a period of 45-days from March 2nd 2000, in total eight blown sands, suspension dusts and sand-dust storm weather took place on a large scale in Northern China. These sand-dust storms occurred very early with a high frequency, wide scale and powerful strength and are closely related to the climatic variations from 1999.

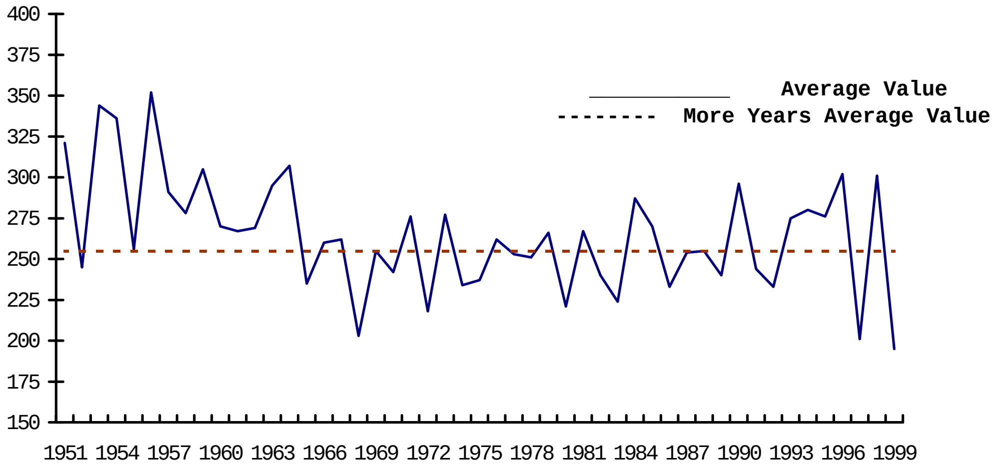

Figure 1: Curve of precipitation (mm) distribution from June-Aug. in Northern China

1.2.1. Prolonged scarcity of rainfall, high temperature and frequent drought in 1999.

There was significant sparse rainfall in most regions in Northern China in 1999. Particularly, the summer rainfall that covers 60-80% of the total annual precipitation was the lowest in the last 50 years (*Figure 1*). Mean annual temperature was 1-2 times higher than normal years and prolonged high-temperature weather, seldom seen since the early 1950s, occurred in the summer season in many regions of Northern China. Scarce rainfall and evaporation loss has caused severe drought on a large scale in Northern China in 2000.

1.2.2. Coldest winter since 1997

After thirteen continuous warm winters, the air temperature in the winter of 1999 was fairly common, particularly in the eastern part of Norwest China, most regions of Central Northern China and the west part of Northeast China, the regional mean air temperature in January in 2000 was as low as the minimum since 1977 (*Figure 2*), which was 2 times lower than that in the same period of time in normal years, or even 4 times lower in some regions. Frigid frozen weather critically exposed land surfaces and frozen soil layers were thick, which easily caused the formation of loose soil layers when the land surface defrosted.

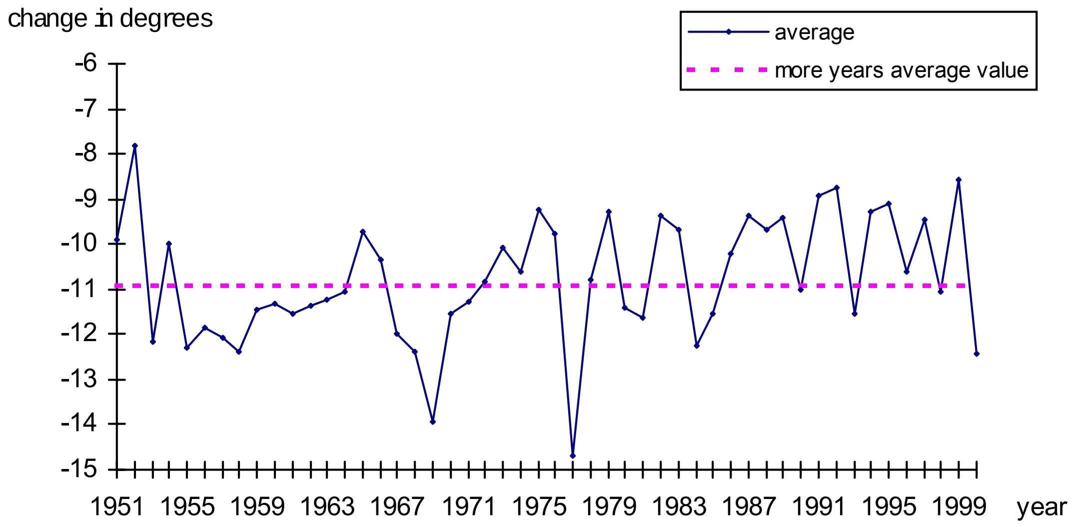

Figure 2: Curve of change of mean air temperature in January in the western part of Northwest China, Central Northern China and the eastern part of Northeast China from 1951-2000

1.2.3. Sparse rainfall and high temperatures at the end of winter and early spring

There were several snowfalls in January 2000, but the precipitation from February to early April in most regions of Northern China was partially sparse in comparison with early years (*Figure 3*) and even precipitation in some regions were at minimum values ever since the 1950s (*Figure 4*). Simultaneously, air temperature was 1-2 degrees higher than that in the same period of perennial years (*Figure 5*). These climate conditions have caused low water-holding capacity, dry and loose topsoil. There was no obvious rainfall that could control the blow up of fine sand and silt participles before the sweep of prevailing winds.

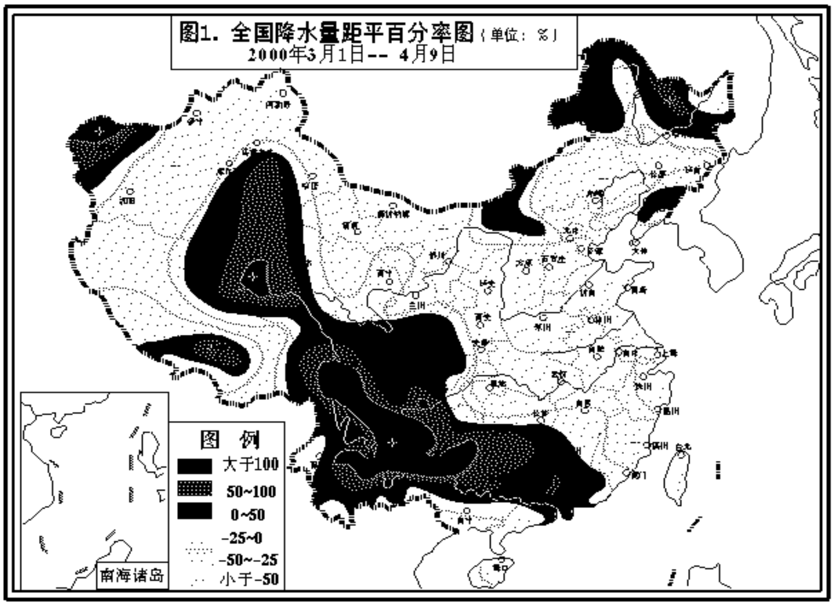

Figure 3: Anomaly percentage of precipitation from March to early April 2000

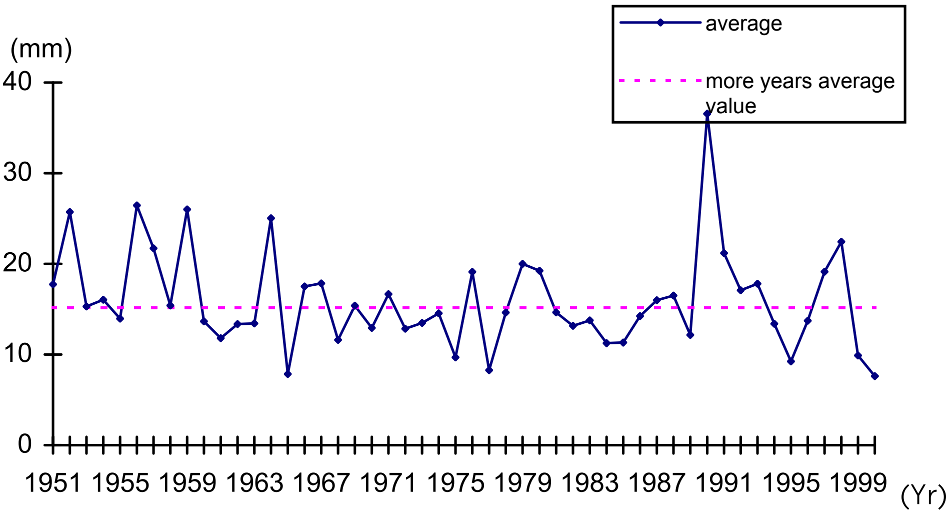

Figure 4: Precipitation from February to Early April, 1951-2000 in Northern China

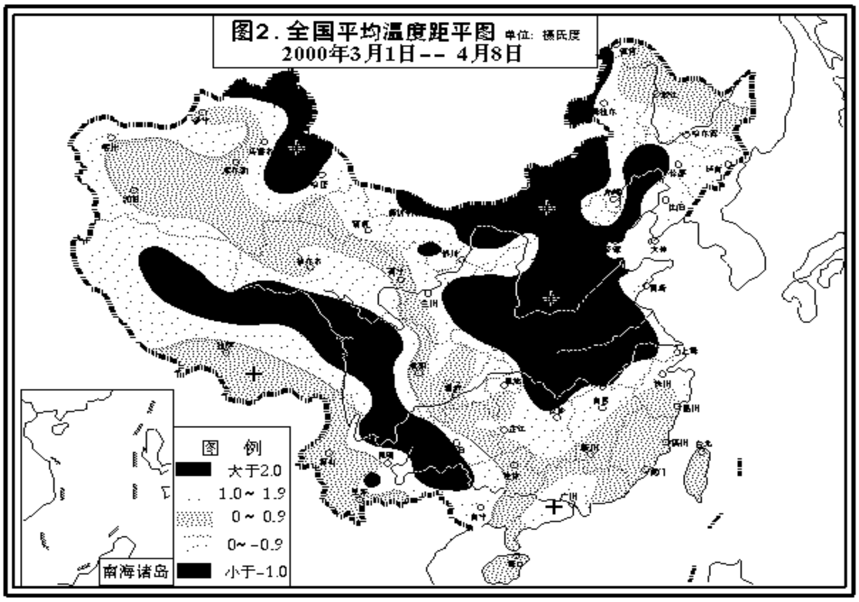

Figure 5: Anomaly of Mean Air Temperature from March to Early April 2000

1.2.4. High Frequency of cold atmospheric air and vortex winds in early spring

Due to the strong strength of longitudinal circulation, cold air threatening China was frequent since the early spring. Along with the cold air, strong wind weather obviously increased. In addition, vortexes of Temperate Zone were strongly developed in Inner Mongolia and Northeast China while cold air arrived. These vortexes did not reduce the temperature severely, but significantly increased the wind force.

1.2.5. Human economic activities supply sufficient sand-dust sources to prevailing winds

In recent years, over-grazing, large amounts of deforestation, large-scale opening-up of rangeland and irrational irrigation in many regions have distinctly destroyed natural vegetation, while land surfaces were exposed to denudation and the water-holding capacity of soil was lost; land degradation and desertification processes became more serious year after year. Urbanization has also caused reduction of vegetation and topsoil exposure that provide material sources suffer under wind-sand weather.

2. NATIONWIDE TREND OF DESERTIFICATION

2.1. Increase of sandstorm frequency

The frequent occurrence of sand-dust storms has promoted disasters of severe sand-dust storms. According to historical records, severe disasters caused by strong sand-dust storms have occurred five times in the 1950s and have doubled since then, and sand-dust storm disasters have reached 23 in the 1990s (*Figure 6*). In 2000, Beijing and adjacent regions experienced the most severe sand-dust storms in 10 decades and *Table 1* below shows the intensity of disasters of sand-dust storms (Technical Programme for Combating Desertification and Controlling Sandstorm developed by the Ministry of Science and Technology, PRC in 2000).

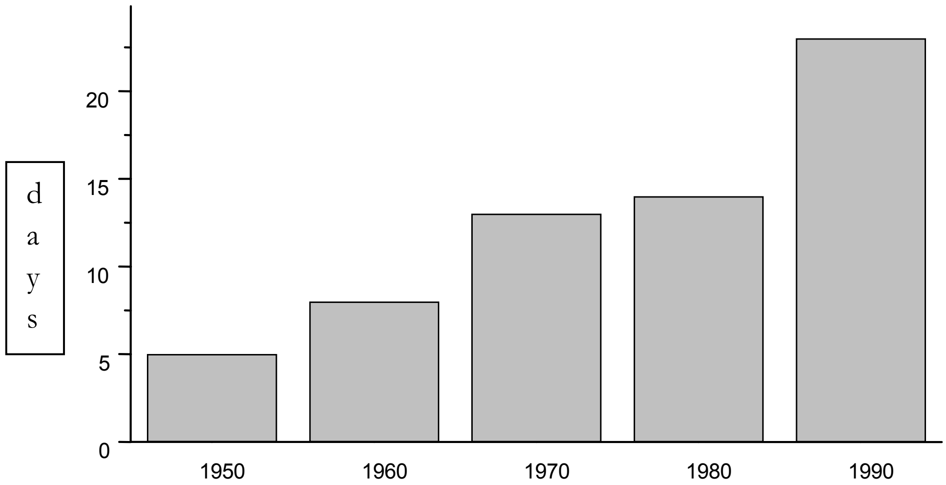

Figure 6: Frequency of sand-dust storms during the last five decades

Table 1: Record of Sand-dust Storm Weather in Beijing and Adjacent Regions in 2000

No	Date	Impacted regions	Sandstorm types
1	Mar.3rd	Inner Mongolia, Beijing and Nearby regions	Suspension dust, sand drifts
2	Mar.17-18th	Beijing and Adjacent regions	Strong wind, suspension dust, and sand drifts
3	Mar.22-23rd	Inner Mongolia, Beijing and Nearby regions	Blowing sands
4	Mar. 27th	Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Beijing, Hebei, Henan, Shandong	Blowing sands and strong winds
5	April 3rd	Beijing and nearby regions	Blowing sands and strong winds
6	April 6th	Inner Mongolia, Shanxi, Hebei, Beijing and Tianjin	Blowing sands, suspension dusts, sand-dust storm and strong winds
7	April 9th	Beijing and nearby regions	Strong wind
8	April 25th	Beijing and adjacent regions	Suspension dusts

2.2. Acceleration of expanding eroded and desertified lands

How do we evaluate the developmental trend of desertification in China? It is a very difficult issue with challenges. There is much evidence to show that, since the 1950s, desertification in some regions in China spread more recently more quickly (E Youhao, et al 1997; dong Guangrong, et al, 1998; Liu Xinmin, et al, 1996; Dong Guangrong, et al, 1993, 1999; Desertification/Land Degradation Research Group, 1998; Wang Gengxu, et al, 1999; Wang Tao, et al, 1998; Wu Bo, et al, 1997, 1998, 1999; Wu Wei, et al, 1997; Zhu Zhenda, 1985; Zhu Zhenda, et al, 1990). However, there is not enough and reliable time sequence data that can be used to clearly describe the nationwide trend of the spread of desertification in China.

There are two data regarding the nationwide developmental trends of desertization (some use the term sandification) from the 1950s to the mid-1980s. Zhu Zhenda, et al has described that the annual spread of desertization from the 1950s to the mid-1970s was 1,560 km² (Zhu Zhenda, 1985) and 2,100 km² from the mid-1970s to the mid-1980s, Zhu Zhenda, et al 1990). These two data were gained on the basis of study of some specific areas through interpretation of black-white aerial photos in the 1950s, 1970s (1975-76) and 1980s (1985-87). It should be pointed out that Zhu and his group concluded in their study that the total area of desertization in China was 137,000 km² in the 1950s, 176,000 km² in the 1970s and 197,000 km² in the 1980s. These data are very discrepant to data (1.607 million km²) published officially by the China National Committee for the Implementation of the United Nations Convention to Combat Desertification (CCICCD). Such differences were caused by the definition of desertification. According to Zhu's viewpoint, land desertization (sandification) refers only to desert-like land characterized by aeolian sand movement and is mainly caused by human activities during man's historical period. All those sand deserts and Gobi formed naturally in pre-historical eras and geological periods are excluded from land desertification. Referring to Zhu's viewpoint, land desertification is mainly distributed on alluvial sand plains, alluvial and lacustrine plains and alluvial-deluvial plains in arid and semi-arid zones, including oasis peripheries and inland rivers downstream in arid zones, steppe areas in semi-arid zones and dryland farming areas and adjacent areas in semi-arid and dry sub-humid areas (Zhu Zhenda, 1985; Zhu Zhenda, et al, 1989; Zhu Zhenda, et al, 1990; Desertification/Land degradation Research Group, 1998). As a result, Zhu and his groups' studies show that the annual growth rate of desertization in China from the 1950s to the mid-1970s was 1% and increased up to 1.1% since the mid-1970s to the mid-1980s. The growth rate in some specific regions is higher than that of the entire country. Details will be discussed in part three below (*regional trends of desertification*).

On the basis of a nationwide survey of deserts, Gobi and wind-sand impacted lands in China, conducted by the Ministry of Forestry, PRC from 1994-96 (CCICCD, 1996), the annual rate spread of land desertization (sandification) from the mid-1980s to the mid-1990s was 2,460 km². However, the survey report has not described the spread of land desertification at the regional level with detailed information or data; namely, about 60-70% of desertization (sandification) of 1.607 million km² are sand deserts and Gobi areas and those areas of newly desertified lands in the affected regions occupy a small percentage of total land desertization (sandification). Yet there is no further detailed evidence at the moment. In the above-mentioned nationwide survey, the definition of land desertification and the criteria system for distinguishing land desertification adopted in the above-mentioned nationwide survey were completely different from that Zhu Zhenda used. Therefore, the data of 2,460 km² (CCICCD's figure) and the two above-mentioned data of 1,560 km² and 2,100 km²) (Zhu Zhenda's figures) cannot be used to compare each other for the time sequence from the 1950s to the mid-1990s. At present, the developmental trend of desertification since the 1980s can be discussed only at the regional level.

3. REGIONAL TRENDS OF DESERTIFICATION

There are two types of most severely impacted regions where desertification spreads quickly and hazards are serious. One type are the four Sandy Lands, namely Horqin Sandy Land, Mu Us Sandy Land, Hulun Bir Sandy Land and Otindag Sandy Land. These four sandy lands are mainly distributed in Inner Mongolia. Another type is the oases located along inland rivers or downstream of inland rivers in arid zones in Northern China. They are mainly distributed in Xinjiang and Gansu, NW China.

3.1. Marginal area in Northern China

It should be pointed out that land desertification in the marginal area in Northern China is serious. The marginal area in Northern China is located in an important ecological transitional zone, from semi-arid to sub-humid zones. This transitional belt stretches from Daxingan Ling in Eastern China to the northeastern part of Qinghai Province in Western China via the east and southeast parts of Inner Mongolia, the north part of Hebei Province, Shanxi Province, Shaanxi province and the eastern part of Gansu Province. Administratively, this belt is mostly situated in Inner Mongolia and its adjacent provinces. It is a narrow belt with a width of 100-250 km and a length of 2,000 km and annual rainfall varies from 300-400 mm. Spatially, it is an inlay of rainfed (dryland) farming and steppe (rangeland). The belt was alternatively used for dryland farming and animal grazing before the 20th century, but rainfed farming and animal grazing coexist.

There are three major issues concerning this marginal area: 1) rangeland or steppe degradation caused by over-grazing, deforestation and undue collection of firewood and blind gathering of medicine herbs, such as the re-activation of fixed dunes, decline of rangeland productivity and loss of biodiversity; 2) arable land degradation caused by rough and extensive cultivation systems; 3) without careful protection of tree-networks surrounding settlements or villages, sand invasions and dune movement become disastrous. The first issue is the key issue that relates to social and economic development in the marginal area

Research indicates that, from the 1970s to the 1980s, desertization (sandification) in marginal areas quickly accelerated. In some parts of Inner Mongolia, the annual growth rate of desertization (sandification) is as high as 8-9% (*Table 2*; Zhu Zhenda, et al, 1990; Wang Tao, et al, 1998). In Horqin Sandy Land, the total area of desertified land has rapidly increased and intensity of land desertification has worsened (*Table 3*; Liu Xinmin, et al, 1996).

From the 1980s to the 1990s, due to lack of sufficient data and case studies, it is difficult to analyze in detail the developmental situation of desertification. Some evidence shows that desertification in China is still developing (spreading) at a high rate. For instance, in the northern part of Duolun County of Inner Mongolia and Fengning County in the north of Hebei Province, the rate of desertified land of the total land area increased to 74% in the mid-1990s from 42.9% in the mid-1980s. In Haolaiku, the eastern part of the Otindag Sandy Land in Inner Mongolia, desertified land increased to 28.3% in the mid-1990s from 19.8% in the mid-1980s (Desertification/land degradation research group, 1998).

Table 2: Developmental trends of desertification in some typical districts in marginal area from the 1970s to the 1980s

Districts	Land desertification in the 70s		Land desertification in the 80s		Annual growth		Year
	Area (km^2)	% of desertified land in study area	Area (km^2)	% of desertified land in study area	Area (km^2)	Rate (%)	
Cereal cultivated area, Qahar Steppe, Inner Mongolia	2,848.3	31.5	5,992.9	66.1	262.1	9.20	1975-87
Ulan Qab Prefecture, Inner Mongolia	2,031.4	4.4	4,055.2	8.7	168.7	8.30	1975-87
Western part of cereal cultivated steppe in North Hebei	1,761.7	13.4	3,272	24.9	125.9	7.14	1975-87

Eastern part of cereal cultivated steppe in North Hebei	762.3	22.3	1,336.6	39.1	47.6	6.28	1975-87
Steppe of Yanchi, Southeast Ningxia	1,368.9	29	1,845.5	31.8	47.6	3.48	1977-86
Northwest of Horqin Sandy Land and Xiliao River upstream	28,971	68.4	32,851	77.6	323.3	1.12	1976-88
Ordos Steppe, Ih Ju of Inner Mongolia	43,407	88.3	45,973	93.6	256.6	0.59	1977-86
Yulin Prefecture, North Shaanxi	7,808	43.3	8,166.9	45.3	35.9	0.46	1977-86

Source: Wang Tao (1998). Remote sensing monitoring and assessment of sand desertification. Journal of Quaternary Research of China, No. 2: 108-118 and Zhu Zhenda, et al, (1990), based on interpretation analysis of aerial photos in two different time periods.

Table 3: Developmental trends of desertification in Horqin Sandy land from the 1970s to the 1980s

Intensity of desertification	Severe land desertification	Medium land desertification	Slight land desertification	Micro-degree land desertification	Total
1970s (km^2)	2,908.25	7,969.22	24,986.84	22,114.05	57,978.37
1980s (km^2)	5,384.17	5,637.15	24,480.47	36,181.90	71,683.69
Growth rate (%)	85.13	-29.2	-2.03	63.61	23.64

Source: Liu Xinmin, et al (1996), *Wind-sandy Environment and Vegetation in the Horqin Sandyland*. Beijing, Science Press. Based on interpretation of aerial photos at two different stages.

Other research (Wu Bo, 1997, 2000; Wu Bo, et al, 1998, 1999) done in the Mu Us Sandy land indicate that the spreading rate of desertification has slowed down from the end of the 1970s to the early 1990s. Furthermore, negative increases of land desertification have occurred in some parts of the affected areas.

Table 4: Growth Rate (%/yr) of Land Desertification in different periods of time in Mu Us Sandy land

Code of study area	Area of study area (km^2)	Growth rate (1958-77)	Growth rate (1977-93)	Growth rate (1958-93)
YC	92.2	8.2	1.3	5.9
TL	105.8	1.3	0.3	0.9
CC-1	98.9	3.4	-0.8	1.2
CC-2	63.0	0.7	-0.9	-0.1
KKG-1	58.3	0.6	0.3	0.5
KKG-2	28.6	-0.1	-0.8	-0.4

Source: Wu Bo, et al (1999). Developing stages and causes of desertification in the Mu Us Sandy land. Chinese Science Bulletin, 44 (9): 845-848.

Box 1: Case study: Mu Us Sandy Land

Mu Us Sandy Land is located at the boundary areas of Inner Mongolia, Shaanxi and Ningxia and covers an area of approximately 40,000 km². in which, 65% is situated in Inner Mongolia. It is the marginal area (transitional area of dryland farming and animal grazing) in Northern China. The steppe in the northwest part is grazing land belonging to Inner Mongolia. In the east and south part, some steppe was opened up for dryland farming and animal and cereal farming coexist.

On the basis of aerial photo interpretation, a land-use map with a scale of 1:500,000 of Mu Us Sandy Land was compiled in the 1950s (1958). By utilizing satellite imagery, a land-use map with a scale of 1:500,000 of Mu Us Sandy Land was compiled in the 1990s (1993). Research results show that desertification in Mu Us Sandy Land from the 1950s to the 1990s developed at a high rate, and net increase of land desertification was 940,200 ha: the growth rate was 60.37% and the annual growth rate was 1.7%.

According to interpretation analysis of black-white aerial photos in three stages (1958, 1977 and 1993), the spreading rate of land desertification from the end of the 1950s to the early 1990s is notably lower than that from the end of the 1950s to the end of the 1970s and an obvious negative increase of land desertification has occurred in some parts of the affected area.

3.2. Arid oasis

In Northwest China, oases in the arid zones are located along inland rivers or distributed downstream of inland rivers. Administratively, these oases are mainly situated in Xinjiang and Gansu. Desertification in these oases were jointly caused by the following processes:

a) Drying up of oases under the impact of mismanagement and irrational use of inland river water or over-exploration of underground water, including the decline and decrease of natural vegetation, descending of ground water tables and drying-up of lakes and catchments.
b) Salinization caused by irrational irrigation methods.
c) Over-grazing caused by unwise opening-up of steppes or rangeland for cultivation purposes, undue collection of firewood and blind gathering of medicinal herbs and over-grazing.
d) Sand encroachment and dune movement because of the less protection of tree-networks and shelterbelts around settlements and villages. The former two are the core problems caused by mismanagement of water resources. The issues in oases are comparatively easier to solve, because they are closely related to water resources. In searching a better resolution to this issue, a set of sound policies and optimum mechanisms for managing water resources have to be developed. Of course, advanced technology for optimum irrigation is needed and investments for installation of water saving facilities are essential.

It is reported that desertization (sandification) in some sections of rivers in arid deserts is continuously accelerating (*Table 5*; Zhu Zhenda, et al, 1990).

Table 5: Degradation of natural forests downstream of the Tarim River in Xinjiang from the 1970s to the 1980s

District	Area in 1973 (km^2)	Area in 1983 (km^2)	Reduced rate (%)
Tieganlike to Karguyi	317.5	224.7	29.2
Karguyi to Alagan	224.4	135.9	39.4
Alagan to Yiganbujima	92.6	34.2	63.1

Source: Zhu Zhenda, et al (1990). Analysis on evolution trend of land desertification in recent ten years in several typical regions of China. *Acta Geographic Sinica*, 45 (4): 430-440.

Box 2: Case study: Yingbaza District

Taking Yingbaza District at the middle reach of the Tarim River as an example, in comparison of the situation in the early 1980s and the early 1990s, the severely desertified land increased to 14.6% from 13.1%, medium severely desertified land accelerated to 15.1% from the former 14.7%, and the slightly desertified land has decreased to 33.6% from 40.7% (Desertification/land degradation Research Group, 1998).

Source: Research Group of *"Study on Combating Desertification/Land Degradation in China,"* 1998. Study on Combating Desertification/Land Degradation in China. Beijing: China Environmental Science Press.

Box 3: Case study: Ejina Oasis

Ejina Oasis downstream of the Heihe River is situated at the Alxa plateau in western Inner Mongolia. This is one of the driest regions in China. Annual precipitation is less than 50 mm and total human population is 15,000. Since the 1950s, the climate became drier and drier. But in comparison with the impact of climatic fluctuation, human economic activities brought about more serious impacts in the change of water flow from the Heihe River. Due to over-exploitation and irrational utilization of water resources at the middle reaches of the river, land degradation and environmental crises were assured downstream: (i) on the basis of analysis of remote sensing data, desertified land increased to 6,000 km^2 in 1986 from 3,400 km^2 in 1975 and the annual growth rate was 6.5%. About 71% of the existing arable land along the river course was abandoned; (ii) since the period from the 1950s to the 1990s, 54% of the area of *Populus euphratica* forest and *Eleagunus spp*. Was reduced, about 33% of *Tamarix spp*. was reduced, the area of *Hedysarium spp.* declined to 5,300 km^2 from the original 11,300 km^2. At the same time, coverage of the plant community slowed down to 10-30% from 30-50% in the 1950s; (iii) the productivity of desert steppes descended to 150 kg/ha in the 1990s from 225-300 kg/ha in the 1950s. Meanwhile, the carrying capacity of desert steppes was reduced to 0.27 sheep unit/ha from the former 0.5 sheep unit/ha. The average weight of sheep/goat and camel was reduced 10 kg and 150 kg from 25kg and 300 kg in the same period of time; (iv) two natural lakes, namely Gashun Nor, 267 km^2 in size in 1958 and dried up in 1961 and Sogol Nor, 35.5 km^2 in size in 1958 was periodically dried up in 1973, 1980 and 1986. It was completely dried up in 1992. In addition, another 11 small lakes and four swamps were dried up during the same period of time.

Box 4: Case study: Minqin Oasis

Minqin Oasis is a natural oasis located at the Shiyang River downstream in West Gansu Province. Annual rainfall varies from 80-160 mm and approximately 300,000 inhabitants dwell in the oasis. Due to the quick development of irrigated agriculture and increased consumption of water in the middle reaches of the Shiyang River, serious ecological crisis have taken place in Minqin Oasis. (i) Natural plants declined and withered in large amounts due to descending of underground water tables. About 70% of natural desert plants were degraded and deceased and vegetative cover was reduced to 15% or less in the 1990s from 44.8% in the 1950s; (ii) since the 1960s, 25,200 ha of farming land were abandoned that covers 36% of the total arable land in the oasis; (iii) over-exploration of underground water was caused by excessive pumping (*Table 6*; E Youhao, et al, 1997). Mineralization of underground water is as high as 4-6g/L. More than 70,000 villagers and 120,000 animals are suffering from a lack of drinking water; (iv) Minqin County receives 1.5 million kg of cereals and 180,000 RMB Yuan from the central government as relieve substances. Minqin is one of the county where people live under the poverty line.

Table 6: Underground Water Table Changes in Minqin Oasis, Gansu

Years	Underground water table (m)	Rate of decline (m/yr)
1961-67	2.24-2.93	0.12
1967-78	2.93-5.20	0.21
1978-88	5.20-9.00	0.38
1988-94	9.00-12.99	0.67
1961-94	2.24-12.99	0.33

Source: E. Youhao, et al (1997). Study on the underground water variation of Shajingzi region Minqin County. *Journal of Desert Research*, 17 (1): 70-76.

4. REFERENCES

Qian Ning et al.; 1983; *The dynamics of the sands*. Beijing: Science Press.

Ye Duzheng, et al, 2000, *Causes of sand-dust weather in Northern China and controlling strategy*, Journal of Geography, 55 (5): p513-521.

Wang Shigong, et al, 2000, *Progress of research on Sand-dust Storm*, Journal of Desert Research, Vol.20, No. 4, p349-356.

Zhao Guangping, et al, 2000, *Preliminary Study on the Ecological Rehabilitation of Sand-dust Storm in Ningxia*, Journal of Desert Research, Vol.20, No. 4, p447-450.

Zheng Xinjiang, et al, 2000, *Study on Monitoring of Sand-dust Storm in South Xinjiang by Utilizing Fengyun-1C Meteorological Satellite*, Journal of Desert Research, Vol. 20, No. 3, p286-288.

Niu shengjie, et al, 2000, *Aerosol Analysis of sand-dust in Spring in Helan Mountain Area*, Journal of Desert Research, Vol. 20, No. 3, p264-268.

Zhao Guangping, et al, 2000, *Preliminary Study on the Ecological Rehabilitation of Sand-dust Storm in Ningxia*, Journal of Desert Research, Vol.20, No. 4, p447-450.

Zhu Zhenda et al. (1990). Analysis on evolution trend of land desertification in recent ten years in several typical regions of China. *Acta Geographic Sinica*, 45 (4): 430-440.

PART VI

FORECASTING, MITIGATING AND PREVENTING SAND-DUST STORMS

Many countries face mounting pressure to arrest the spread of desertification and to ameliorate the impact of wind erosion. This is especially so in respect to the long range transport of dust and sand into urban areas located quite a distance from the desert margins, that supply the sediment and generate the weather patterns fostering the entrainment and transport of particulate matter and that can be a threat to human life and ecological support systems.

One of the challenges is to try to separate out the natural factors from the human-induced ones. It is important to see how the behavior of people living in the desertified areas can be changed.

Forecasting, mitigating and preventing sand-dust storms is a challenge high on the agenda of many governments and UN agencies.

Chapter Thirteen

DISTINGUISHING NATURAL CAUSES AND HUMAN INTERVENTION AS FACTORS IN ACCELERATED WIND EROSION: THE DEVELOPMENT OF ENVIRONMENTAL INDICATORS

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Keywords: precautionary principle, economics, society, traditional knowledge, information technology, biodiversity, networking, non-equilibrial systems, remote sensing, meteorology, sustainable development

SYNOPSIS

Indicators of environmental change have been developed to reflect the anthropogenic pressure, current condition and the human response to such threatening processes as accelerated erosion and disturbance of nutrient cycling through loss of surface soil. Terrestrial processes may be altered by human actions in which case anthropogenic cause and effect may be distinguishable from the natural "signature" of the process. Indicators should be able to distinguish anthropogenic interventions from natural causes as unambiguously as possible.

This chapter reviews progress in finding suitable indicators and monitoring systems that will help to mitigate the effects of dust storms and other wind-related erosional processes.

KEY POINTS

1. *Dust and sandstorms are a consequence of soil erosion by wind. Therefore a better understanding of the factors contributing to wind erosion in drylands is a prerequisite to putting measures in place to combat this aspect of desertification.*
2. *Erosion is a natural process that shapes all terrain. It proceeds inevitably in all environments. Accelerated erosion, on the other hand, is the product of human interventions that remove vegetational protection from the earth's surface. It is the largest, best known, and probably least quantified form of land degradation in the world's drylands.*
3. *Environmental indicators are physical, chemical biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue.*
4. *One difficulty that is faced in trying to monitor change in dryland ecosystems is that they are inherently non-equilibrial, and do not progress in a gradual and orderly manner from pioneer to climax vegetation assemblages, rather, they fluctuate between states of punctuated equilibria.*
5. *The development of robust and widely applicable indicators and systems of monitoring is the challenge for scientists and land managers.*

1. INTRODUCTION

There are many environmental problems that weigh on the future of our planet. Beyond the phenomena of population growth and increasing urbanization, industrial and agricultural and transport activities are bringing about a major transformation of the global environment with serious consequences for human health and the productivity of ecosystems. The world's drylands are particularly susceptible to environmental degradation.

Human action has even started to affect the functioning of global life support systems such as the climate system. The need to adopt the precautionary principle, take preventative action, and indeed make sustainability an essential ingredient in any model of development has become more evident at a time when societies, cultures, economies and environments are becoming increasingly inter-dependent.

One of the greatest challenges facing the world community in the 21st century will be the attainment of sustainable development, calling for balanced interrelated policies aimed at economic growth, poverty alleviation, human well-being, social equity and the protection of the Earth's resources, commons and life support systems. Nowhere is this more important than in the world's drylands where the disparities between the *"haves"* and the *"have-nots"* are wide indeed.

2. MODERN SCIENCE AND OTHER SYSTEMS OF KNOWLEDGE

Countries should promote better understanding and use of traditional knowledge systems (CCICCD, 2000). Knowledge should flow simultaneously to and from rural communities. A new relationship has to be built between those who create and use scientific knowledge, those who support and finance it, and those concerned with its application and impacts. Efforts should be made to sustain traditional knowledge systems through active support to the societies that are keepers and developers of this knowledge, their ways of life, their languages, their social organization and the environments in which they live, and fully recognize the contribution of women as repositories of a large part of traditional knowledge.

Government should support cooperation between holders of traditional knowledge and scientists to explore the relationships between different knowledge systems and to foster inter-linkages of mutual benefit. Of course it is necessary to recognize that many traditional methods of land-use and husbandry have proven to be inadequate to cope with the pace of change and the increasing population pressures that have often been the root cause of imposing unsuitable land management on marginal drylands.

3. DISTINGUISHING NATURAL CAUSES AND HUMAN INTERVENTIONS

Dust and sandstorms are a consequence of soil erosion by wind. Therefore a better understanding of the factors contributing to wind erosion in drylands is a prerequisite to putting measures in place to combat this aspect of desertification (*see Chapter 1*).

There are two interrelated tasks: *inventory* (or base line studies) and *monitoring*. Base line studies are required to set the current status and provide a benchmark against which monitoring can take place. Direct measurement of soil loss is often costly and difficult and so the search for surrogates has proceeded as a way to develop useful indicators.

Indicators of land resource conditions in drylands need to be able to distinguish, in an unambiguous and cost-effective manner, between natural and anthropogenic causes of environmental change. However, when natural processes operate in a chaotic, non-systematic fashion or on very long scales, differentiation may not be possible unless a characteristic anthropogenic signature is detectable.

Erosion, for example, is a natural process that shapes all terrain. It proceeds inevitably in all environments. Accelerated erosion, on the other hand, is the product of human interventions that remove vegetational protection from the Earth's surface. It is the largest, best known and probably least quantified form of land degradation in the world's drylands. The reasons for the lack of quantification are that it is difficult to distinguish from natural erosion, deposition also occurs at the same time from both natural and induced erosion, and detailed case studies that measure both the scale and amount of erosion are costly. They frequently require specialist tracer methodologies and are therefore rarely undertaken.

4. THE SEARCH FOR ENVIRONMENTAL INDICATORS

The Organization for Economic Cooperation and Development (OECD; 1993) developed an approach, the Pressure-State-Response (P-S-R) model. The OECD P-S-R model describes, respectively the anthropogenic pressures on the environment, conditions or states of valued elements of the environment (e.g. water, soil, vegetative cover), and human responses to changes in environmental pressures and conditions.

Environmental indicators are physical, chemical biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue. An indicator is embedded in a well-developed interpretative framework and has meaning well beyond the measure it represents. A set of indicators must be the minimum set, which if properly monitored, will provide rigorous data describing the major trends in, and impacts on the dryland ecosystem. It should include:

- Indicators that describe the ***condition*** of all the important elements in each biological level in the main ecosystems.
- Indicators of the extent of the major ***pressures*** exerted on the elements.
- Indicators of ***responses*** to either ***condition*** or changes in the ***condition*** of the ecosystems and their elements.

Each indicator should:

- Serve as a robust indicator of environmental change.
- Reflect a fundamental or highly valued aspect of the environment.
- Be either national in scope or applicable to regional environmental issues of national significance.
- Provide an early warning of potential problems; be capable of being monitored to provide statistically verifiable and reproducible data that show trends over time and, preferably, apply to a broad range of environmental regions.
- Be scientifically credible.
- Be easy to understand.
- Be monitored regularly with relative ease.
- Be cost effective.
- Have high relevance to policy and management needs.
- Contribute to monitoring of progress towards implementing commitments in nationally significant environmental policies, where possible and appropriate.
- Facilitate community involvement.
- Contribute to the fulfillment of reporting obligations under international agreements, such as the UNCCD.
- Where possible and appropriate use existing commercial and managerial indicators.
- Where possible and appropriate, be consistent and comparable with other countries' and provinces' indicators.

One difficulty that is faced in trying to monitor change in dryland ecosystems is that they are inherently non-equilibrial, and do not progress in a gradual and orderly manner from pioneer to climax vegetation assemblages, rather, they fluctuate between states of punctuated equilibria (Lykke, 2000). This view accounts for the sudden and catastrophic effects that periodically disrupt gradual ecosystem processes, *"resetting"* ecosystem sequences and interactions between component functions. Resilience, or the ability of the system to recover, is thus the most significant attribute of ecosystem sustainability (Holling, 1986).

If sudden collapses and unpredictable fluctuations are part of the normal pattern of non-equilibrating systems, then attempts to forecast future ecosystem behavior from indicators that provide monotonic trends will be doomed to failure. A distinction may be needed between those processes that are dominated by physico-chemical reactions and those that are mediated principally by biological components.

Table 1 summarizes some key indicators proposed for use in Australian drylands. These are arranged according to the OECD P-S-R model.

4.1. Accelerated erosion and loss of surface soil

A key issue. Processes that operate on bare soil surfaces dominate erosion by wind and water. Remote sensing data sources (NOAA-AVHRR data and Landsat data) provide the regular operational framework for identification of the major areas of green cover (NVDI for broad area studies and Landsat for closer scale reference sites). Due to the difficulty of distinguishing woody perennial (non-chlorophyll biomass) from bare surfaces, remote-sensed data must be supplemented by ground-truthing. Wind erosion models (McTainsh, et al, 1990; Shao et al, 1996) can be used to calculate the potential erosivity of soil by land-use type.

4.2. Monitoring design

A proposed design could include transects at right angles to rainfall isohyets, and directions of dominant wind, over a distance of 200-250 km, taken from Landsat imagery – with ground-truthed spot checks along the same transect lines. Occurrence and situation to be obtained from Landsat TM at a resolution of 30 m^2 reported at 1 km^2, and computed as a proportion of the total area.

4.3. The area of unsealed roads and earthworks as a proportion of total land area

A useful indicator that gives the proportion of exposed surface contributing eroded materials coming from unstable earthworks, principally unsealed road sand adjacent verges – as a percentage of the total areas. Due to the highly dispersible and erodable nature of many dryland subsoils, where over one-third are sodic, water borne and wind transported materials derived from this source are expected to be of significant quantity. The contribution to sediments and dust from these sources is nearly always ignored in estimates of anthropogenic erosion. However, as the majority of road length in rural areas is unsealed it is probable that this source of materials is far greater than that coming from such isolated activities as mining and forest logging operations.

4.4. Total grazing pressure

A highly significant cause of accelerated erosion as well as deterioration of remnant vegetation. As total grazing pressure has little meaning unless related to the biomass production capacity in each environment, the net primary productivity – calculated from the potential biomass production capable of being produced under the prevailing radiation, temperature and rainfall conditions – is proposed as a minimum reference point against which to evaluate total grazing pressure. Ground truthing and remote sensed estimates of the actual standing biomass in any one reporting period are considered.

Regions where total grazing pressure exceeded estimated safe levels should be compared with the total area of bare ground (*see above*). It is possible to derive a *"surface soil loss index"* across all land cover regions. Relationships between these might be capable of further refinement for future predictive estimates of safe and harmful levels of grazing pressure to minimize accelerated erosion.

4.5. Surface soil loss index

A key indicator. Loss of organically rich A horizon from soil profiles is serious. The most important ecosystem functions affected by erosion are plant nutrient supply, nutrient (especially carbon and nitrogen) cycling and sequestration, and waste material decomposition. Reduction in nutrient supply directly reduces primary productivity and thus vegetation cover, which in turn affects habitats, climatic conditions (through changes in albedo) and erosion control. Direct surface loss is difficult to assess at the continental and regional scales. Yet localized studies may not be representative of large areas, and therefore a combination of sub-indicators of comprehensive and site-specific studies is required. Modern soil classification systems recognize a separate and distinctive anthropogenic form of soil surface in agricultural regions that have been disturbed, inverted and reformed from cultivation. However, a total lack of soil surface – distinguished by the absence of organically stained dark materials, with low levels of soil biota and microbial activity – is the most telling evidence of gross ecosystem deterioration. Remote sensed data (principally Landsat TM) can be used to compare dominant soil colour values at fixed locations over time to detect possible changes in surface conditions.

4.6. Changes in the frequency of dust storms relative to the number of high wind events

Useful indicators. A dust storm index that combines the records of three types of dust events is useful: severe dust storms (SD), moderate dust storms (MD) and local dust events (LDE), compared with the level of dust storms predicted from values derived from the *"effective moisture"* (E_m) model of Burgess et al., (1989). The model describes the climatic parameters controlling wind erosion. The index values are related to each other for each type of event. The Dust Storm index (DSI) then is:

$$DSI=(5xSD)+MD=LDE/20$$

Where dust storm severity is defined according to the weather codes. SD= days when visibility is reduced to <200 m; MD= visibility is <1,000 m and LDE when total suspended particulate matter >150 $\mu g/m^3/hr$.

The wind erosivity (E_w) index of McTainsh et al., (1990) is predicted for an area, and where the DSI exceeds this value enhanced erosion has occurred, this may be attributed to anthropogenic activities in the region where comparisons between land-uses are possible. This indicator has been developed in Australia to monitor the off-site environmental impacts of dryland cropping. In that form the down-wind populations and atmospheric air quality will be measured, using historical records of visibility as a surrogate for dust flux and a climate terrain model to partition components due to natural and anthropogenic dust.

The procedure is to use meteorological stations with at least 40 years that record wind runs and/or wind velocity as well as other basic meteorological data, together with modeled wind energy, evaporation and vegetation cover to predict erosivity and record the dust storm indices for locations downwind of different land-uses that exceed the predicted E_w index.

Changes in DSI over time will be computed for individual stations and interpolated isolines by regression analysis. Interpolation algorithms and confidence limits provide cutoffs to regional analysis. Wind erosion factor analysis is able to assist in locating the source of dust, with information from vegetation cover, land-use and land tenure information used to assist interpretations for the reasons for deviations of E_w from those predicted. The extent to which anthropogenic enhanced wind erosion can be detected is only partly assured at present and the current Australian research project will assist in establishing the validity of this method. If successful it will allow maps of dust storm totals, wind erosion factors and resultant dust storm activity and erosivity, with text and graphic information on regions of high dust sources and depositions.

5. CONCLUSIONS

It is clear from the case studies reported in this volume from regions as diverse as the Sahelian, Central Asia, China, Australia and North America that there is much that can be learned from the experiences of others. In spite of the wide differences in the level of economic development and industrialization, the different political climate in each region and the level of technical capacity there are elements in common. A key factor that underlies the problems of dealing with desertification, dust storms and land degradation generally is that unless there is recognition that it is more effective to deal with the *"people who use the land"* rather than with *"the land they use,"* there will be no progress. This implies a shift from technical approaches to the problem of abatement to a combination of approaches (policy, socio-political and economic measures) that reinforce each other.

5.1. Sharing scientific information and knowledge

Each country needs to have the capacity to design and implement its own science policy with responsibility within the global context, and to confront the dilemmas of priorities and competition for resources from the particular phase of economic development and industrialization in which it finds itself. Measures to combat desertification and the related issue of maintaining biodiversity are examples.

There is today an accumulation of discoveries, applications and know-how that constitute an unprecedented source of knowledge, information and power. Never have discoveries and innovations promised a greater increase in material progress than today, but neither has the productive – or destructive – capacity of mankind left unresolved so many uncertainties. The major challenge for the 21st century lies in the ground between the power that mankind has at its disposal and the wisdom that it is capable of showing in how to use it. Guided by the conviction that it is both urgent and possible to take up this challenge the contributors to this volume are determined to concentrate efforts on the production and sharing of knowledge, know-how and techniques to address the major problems in desertification control – whether local, regional or global. It is evident to everyone that it is not science alone that will solve these problems. More attention must be given to the human dimension of desertification.

Regional and international networking and cooperation can facilitate the exchange of national experiences and design of more coherent policies. Scientists, research institutions and learned scientific societies and other relevant non-governmental organizations should commit themselves to increased international collaboration, including the exchange of knowledge and expertise.

The new communication and information technologies have become an important factor of change, giving rise to new directions, methodologies and scenarios for scientific work and new ways of producing, assessing and using information.

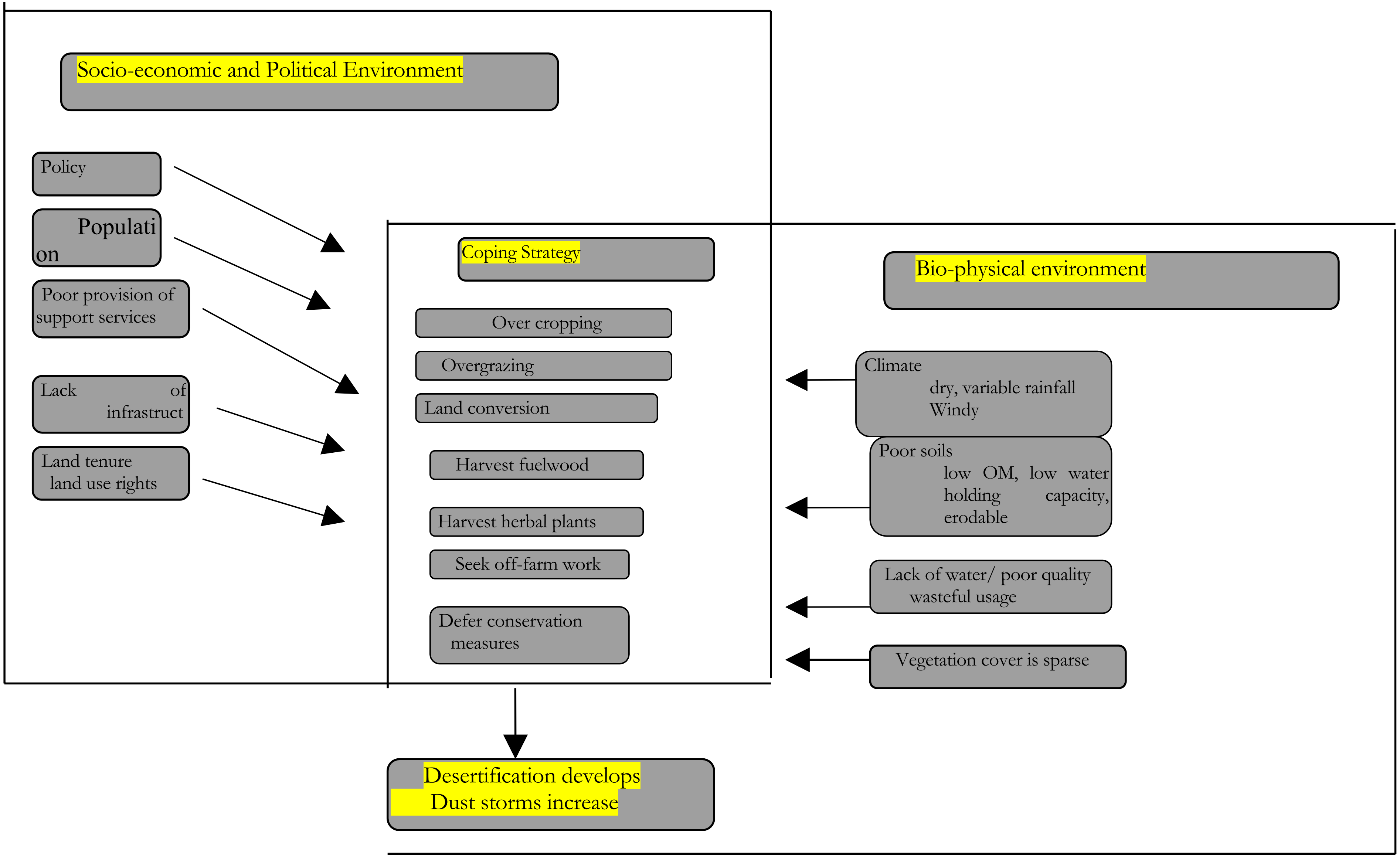
The publication and wider dissemination of the results of scientific research carried out in developing countries should be facilitated, with support of developed countries, through training, the exchange of information and the development of bibliographic services and information systems better serving the needs of scientific communities around the world.

Table 1: Examples of indicators using the Pressure-State-Response model

Number	Name	P,S.R*
Pressure		
Issue 1	Accelerated erosion and loss of surface soil	P
1.1	Change in total exposed soil surface contributing to erosion, as a percentage of land area, per land cover region, stratified by major land-use	P
1.1A	Percentage of cultivated land with exposed soils by catchment and agro-ecological region (AER)	P
1.1.B	Area of unsealed roads and earthworks as a proportion of total land area, per catchment	P
1.2	Total grazing pressure relative to net primary productivity (biomass) by landcover regions and AERs	P
State		
1.4	Surface soil loss index	S
1.5	Change in dust storm index relative to number of high wind events by AERs and landcover regions	S
Response		
1.6	Percentage, number and area affected with stocking rates at or below *"safe"* limits, by AER and landcover regions	R
1.7	Areas of rangelands reducing grazing damage by alternative land-use, by county and landcover region	R
1.8	Percentage of counties destocking when forage reaches advised threshold, by AERs and landcover region	R
1.9	Implementation of new drought policies to mitigate drought	R
1.10	Percentage of cropland using reduced tillage and other soil conservation methods	R

*State in this context refers to the current condition of the landscape.

Figure 1: Desertification occurs when the pressures exerted by forces within the socio-economic and/or the biophysical environment exceed the capacity of coping mechanisms adopted by the local inhabitants. In the past traditional land use systems were able to adapt to the spatial and temporal variability through strategies like migration and transhumance. As population pressures increased and with it the demand for food, more risky and exploitative measures were taken. Once the threshold of resilience was crossed the system crashed and desertification set in. Accelerated soil erosion led to an increase in the severity and frequency of dust storms.



6. REFERENCES

Burgess, R. C., McTainsh, G. H. and Pitblado, J.R. 1989. *An index of wind erosion in Australia*. Australian J. Geographical Studies 27 (1) 98-110.

CCICCD, 1999. *Traditional knowledge and practical techniques for combating desertification in China*. The Secretariat of China National Committee for the Implementation of the United Nations Convention to Combat Desertification (CCICCD), China Environmental Science Press, Beijing, 181p.

Holling, C.S. 1986. *The resilience of terrestrial ecosystems: local surprise and global change*. In: W.C. Clark and R.E. Munn, Eds., *Sustainable Development of the Biosphere*, Cambridge Univ. Press. Pp 292-230.

Lykke, A.M. 2000. *Refining the ecological aspects of disequilibrium theories for Africa's pastoral drylands*. Desertification Control Bulletin No.36: 23-33.

OECD 1993 *Core set of indicators for Environmental Performance Reviews*. Environment Monographs No.83 Organization for Economic Cooperation and Development, OECD, Paris.

McTainsh, G.H., Lynch, A.W. and R.C. Burgess, 1990. *Wind erosion in eastern Australia*. Australian J. Soil Research 28: 3234-339.

Shao,Y.P. Raipach, M.R. and Leys, J. E. 1996. *A model for predicting aeolian sand- drift and dust entrainment on scales from paddock to region*. Australian J. Soil Research 34: 302-342.

Chapter Fourteen

MITIGATING AND PREVENTING SAND-DUST STORMS: PROBLEMS AND PROSPECTS

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Key words: mitigating, global, extinction, pollution, environmental management, ecosystem, monitoring, long-term, short-term, information systems, environmental modeling, drought

SYNOPSIS

Monitoring complex phenomena like desertification and sand-dust storm events requires aggregating a number of indicators, but there is still disagreement about which set of indicators to use. The purpose of having an adequate monitoring system in place is to be able to distinguish between natural causes and human-induced changes.

At present the establishment and application of the benchmarks and indicators for desertification is still in the early of development in most places in the world's drylands and it will take several more years to prepare the necessary information to precisely assess the situation. It is recognized that it is an iterative process and that it will be refined as information, experience, enhancement of capacity, advancement of technologies, social demand and changes in priorities (national, regional and local) dictate.

This chapter reviews some developments in the establishment of information systems, and modeling and gives examples of the application of predictive models from work carried in Australia.

KEY POINTS

1. *Land has a variety of users, both urban and rural. Any decisions to implement measures to combat desertification and mitigate the effects of dust storms that lead to changes in land use must involve all the relevant land users.*

2. *Environmental management relies heavily on our understanding of the environmental processes and on our capacity to assess and predict the environment. The major tasks for environmental modeling and prediction lie in the simulation of the system by modeling both the individual components and their interactions. Clearly, environmental modeling must be multi-disciplinary, as it requires understanding from a range of traditional disciplines.*

3. *The development of integrated environmental modeling has significantly improved our capacity to assess and to predict the environment. Such a system bridges the vital gap between dynamic modeling and spatially distributed data and enables policy and scenario development to be tested.*

4. *Monitoring, prediction and mitigation are three key elements in any national action plan to combat desertification and drought and to mitigate the effects of dust storms. The success of monitoring will depend*

on establishing good baseline data and in ensuring that the way the data is to be used is determined before the data is collected.

1. INTRODUCTION

On a global basis humans are facing the challenge of major human induced environmental change from the effects of deforestation, desertification, extinction of native flora and fauna, destruction of the ozone layer, global climate change and pollution of air, water and soil. It is now increasingly understood that better environmental management is of fundamental importance to the sustainable social and economic development. Economic development at the expense of the environment is no longer acceptable (Squires, 1998).

Environmental management includes a wide range of issues, which can be classified as:

- Better management of natural resource. For instance, water and wind erosion, dry land salinity and other forms of land degradation pose a serious threat to a sustainable agriculture.
- Strategic response to long-term global environment changes, such as the greenhouse effect and the destruction of the ozone layer.
- Adequate response to natural disasters, such as flood, drought, and dust storms.
- Protection of air, water, soil and ecosystems from pollution.

2. THE ENVIRONMENT AS A COMPLEX SYSTEM

The environment is a complex interactive system of five major components and many sub-components. The major components are the atmosphere, the hydrosphere, the lithosphere and the biosphere. These components of the environmental system interact (feedback) with each other either non-linearly or complicatedly (such as air-sea interactions). The system as a whole is also strongly influenced by human activities, such as the releasing of greenhouse gasses, deforestation, air and water pollution. The environmental processes include physical processes and biochemical processes.

2.1. Monitoring is vital

One key point is to have an adequate monitoring system in place. This is essential to distinguish between natural causes and human-induced changes (*see Chapter 13*). However, the challenge is to develop a monitoring system that provides useful information in a form that is readily usable.

Monitoring systems are designed to gather more information on changes in the condition of land and the welfare of the people, but this raises the question of what should be monitored, how and by whom? Consideration should be given to the purposes of monitoring and issues such as intensity of monitoring, the balance between collection of data of sufficient detail to be meaningful, and the cost of monitoring. Monitoring should be sufficiently holistic to give a basic perspective, rather than focussing too closely on one element, be it related to socio-economics or environment. The process of constructing monitoring systems that meet the key needs is a continual struggle to make the system realistic while keeping it manageable.

To meet the managerial needs for those concerned with predicting and mitigating dust storms, the monitoring system should be:

- Accurate.
- Flexible.
- Synthetic/holistic.
- Problem oriented.
- Accessible.
- Need driven (answers questions that people are asking).

- Economical.

Monitoring and assessment should be scientifically and economically based, and allow adequate scrutiny of the techniques used and the conclusions made, particularly where the information is used when making decisions on future land-use. Data should be compatible in terms of methodology and objectives, so that valid comparisons can be made between information collected by different agencies, and findings can be extrapolated.

The process is likely to highlight deficiencies in existing knowledge, providing direction to researchers to fill these information gaps. Availability and access to data is an issue. Community groups (including NGOs) and researchers should have improved access to data from Central and Provincial or County government sources and vice versa.

The International Negotiating Committee for the Desertification Convention (INCD) has placed strong emphasis on the development of indicators as tools to meet the monitoring and evaluation requirements of the CCD and to measure the progress towards its implementation. No monitoring system will be effective if it lacks the precision appropriate to the phenomenon being observed.

Monitoring complex phenomena like desertification and sand-dust storm events requires aggregating a number of indicators, but there is still no agreement on which set of indicators to use. Some experts argue that physical indicators measuring the main components of soil and vegetation degradation would be sufficient, while others claim that only when the meteorological and soil moisture conditions are included that a useful monitoring system can be put in place.

A methodological tool for analyzing anti-desertification measures has been developed to deal with the multi-dimensionality of environmental stress assessment by using different indicators of ecological stress referring to events occurring on different space-time scales. The graphic representation of the system is simply based on a division of the plane into four quadrants, each describing a different view of the system (*Figure 1*).

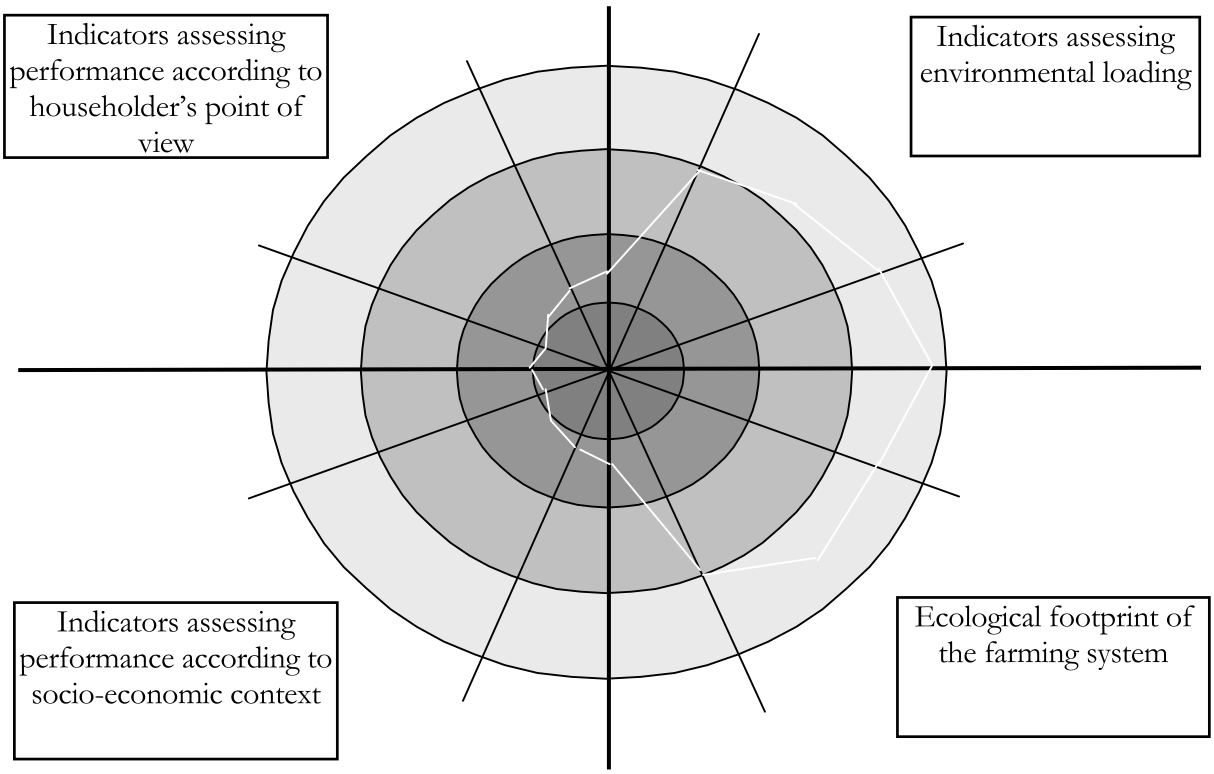

Figure 1: A typical amoeba reading representing a subsistence farming system. Dark (near center) is "bad" and light (near perimeter) is "good." So, this sample system (in white line) has "soft" ecological footprint but does not do so well for the regional economy nor does it provide a high level of welfare to the household. Of course not all subsistence farming has such a soft ecological footprint. This type of approach helps to detect the onset of desertification because the ecological footprints of any given land use system can be monitored

Within each quadrant, a number of axes referring to different indicators of performance are then drawn. The choice of both quadrant and axis is arbitrary and is made according to the system's characteristics and which are considered relevant for the analysis. Generally, it takes into account four main points of view: (i) farmer's, (ii) regional or national economy, (iii) extent of environmental loading (stress) and (iv) ecological footprint of the farming system. The latter is a measure of the extent to which a system is dependent on external inputs (oil, outside labor, etc) and on accumulation of pollutants (salinity, agricultural chemicals).

Indicators are proposed to cover different scales and related to different perspectives. For example, at the level of the farm household indicators might consider such objectives as minimization of risk, food security, maximization of income and net disposable cash, and maximization of the potentiality of household members (better education). Several indicators might relate to agricultural performance at the national or regional level. At this level, several goals are considered such as self-sufficiency in food production, minimization of the indirect costs of food production, minimization of the gradients in economic development between rural and urban areas.

Indicators to monitor ecological impacts should cover various distinct scales (e.g. region, watershed, village, farm, field, and soil level). They might refer to (i) direct measurements of environmental loading (e.g. fertilizer and pesticides applied per ha per year and per unit crop output; (ii) pollutants discharged into the environment (saline drainage water, pesticide residue); (iii) alterations to the natural configurations of matter and energy flows (inputs of nutrients, nutrient flows, fuel energy expended per ha); and (iv) use of bio-indicators (e.g. biodiversity). Finally indicators can be derived to measure the *"extent of freedom"* of any agricultural system from local biophysical constraints (e.g. whether the system requires irrigation, fertilizer, plastic, fuel energy, pesticides).

Basically, this last set compares the ecological footprint with the amount of natural capital available (water, soil fertility, solar energy, etc) in the natural ecosystem without generating irreversible degradation of the dryland system. Ironically, the more human choices are *"free"* from local natural constraints (technological inputs shortcut the ecological system of feedback controls), the more human activity is at risk of generating negative consequences for the dryland ecosystem.

At present the establishment and application of the benchmarks and indicators for desertification is still in the early stage in most places in the world's drylands and it will take several years to provide the necessary information to precisely assess the situation. It is recognized that it is an iterative process and that it will be refined as information, experience, enhancement of capacity, advancement of technologies, social demand and changes in priorities (national, regional and local) dictates. A proposal to develop and test a *"desertification index"* should be followed up.

This proposed index would be derived from a mathematical/numerical combination or aggregation of all or some of the chosen biophysical and socio-economic indicators. The objective would be to yield an index figure that would provide a single comparative measure of the severity of desertification and its impacts across the affected regions. It would be derived from indicators that are proven to be sufficiently accurate and responsive in illustrating impacts. For this reason, the Desertification Index will probably be best considered after impact indicators have been selected, tested, and refined over a period of years.

If a useful and realistic index can be derived, it would provide a valuable management tool to track progress and to assist planning, priority setting and continuing review of the actions required to mitigate the impacts of sand-dust storms. Because such an index could be mapped, it would be a valuable illustrative tool to track progress. Because it seems likely that much of the relevant information is collected at the county level, a likely approach is to derive a desertification index for each county. This would seem to have potential administrative advantages, and would facilitate the setting of priorities for action at the county level.

2.1.1. Long-term vs. short-term trends

The difficulty of dealing with short-term variations that often obscure long-term trends is quite confusing. Much emphasis has been placed on the results of remote sensing. The synoptic overview and the temporal dimension made this the monitoring method of choice. But remote sensing studies are easily confused by short-term variations. Remote sensing studies need good support from ground-truth data, and can be misleading if such data are obtained using a poor sampling design, particularly on landscapes where complex spatial processes operate.

Because a lot of desertification is characterized by a more dispersed, patch-like process of degradation it is not amenable to remote sensing. It has long been recognized that operational monitoring of patchy soil and vegetation degradation in dry areas is inherently difficult, even with medium resolution satellite technology like Landsat MSS and that improved techniques are needed to make reliable monitoring and trend detection viable.

Available data may be sufficiently reliable to contribute to an understanding of the baseline condition of a particular area, and to monitoring of trends. Region-specific information is appropriately the starting point in determining the general condition of the land.

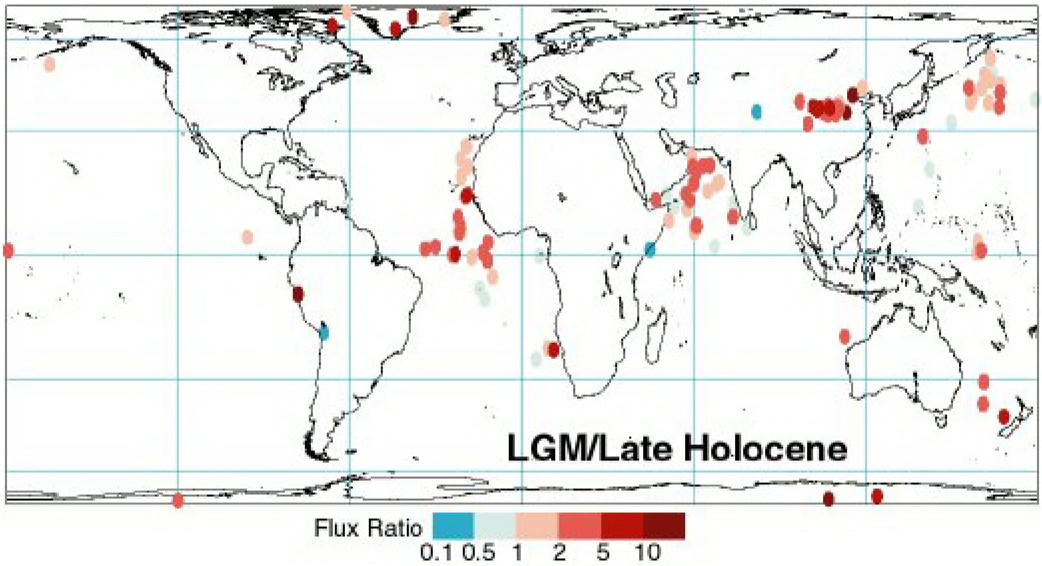

Figure 2: A map showing the flux in dust accumulation over the past 150,000 years. Note the heavy concentration in the Loess areas of the world, especially China

The International monitoring network DIRTMAP (Dust Indicators and Records of Terrestrial and Marine Paleo-environments) is based in Germany, but with collaborators worldwide, seeks to develop a better understanding of dust movement. The DIRTMAP Database contains records of dust accumulation rates, grain size, and mineralogical properties, and mineralogical and isotopic provenance tracer data from ice cores, marine sediment cores and sediment traps, and terrestrial sites (loess, lakes). Different elements of these data can be used to document changes in the dust cycle, to provide important additional information (e.g. regional mineralogy, grain size distributions) for modeling the dust cycle, and to evaluate simulations of the Paleo-dust cycle. The DIRTMAP database targets data from 0-150,000 years B.P., and also contains sediment age models and accumulation rates, bulk densities, chronological data (e.g. radiocarbon dates, luminescence dates, stratigraphic correlations, etc) and additional documentation that is required for interpretation. *Figure 2* shows the areas of maximum dust flux over the past 150,000 years.

2.1.2. Information systems and monitoring issues

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

The National Action Plans should develop guidelines to meet the different monitoring and information requirements of the various users groups, remembering that there is more than one user for each parcel of land and that urban as well as rural populations are affected (*Figure 3*). The data provided to each of these groups should be of the right quality for decision-making. For example, *"land capability"* information may be inadequate for environment impact assessment of new business ventures or industry. Some policy decisions will need to be made well before the appropriate information is available. This is a particular dilemma for fast developing countries where the urgency of the task, the lack of coordination of effort between various ministries and agencies, and the lack of agreement on just what to monitor and how to do it complicates the issue.

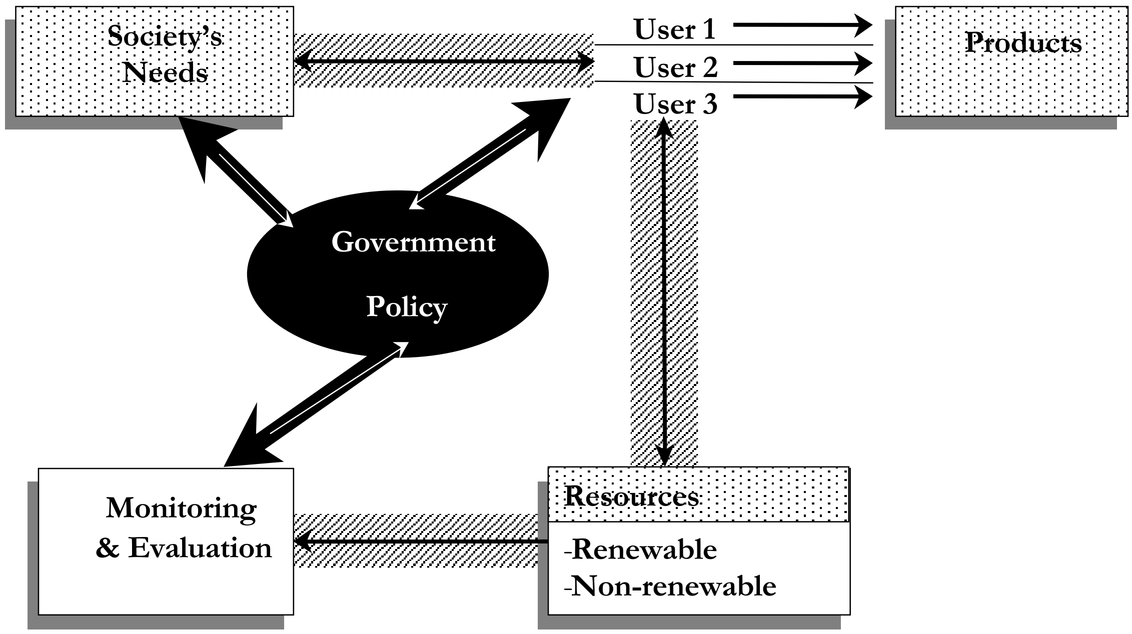

Figure 3: Land has a variety of users, both urban and rural. Any decisions to implement measures to combat desertification that must lead to changes in land use must involve all land users

2.1.3. Impact Monitoring

Impact indicators are intended to monitor the actual impacts of sand-dust storms and the effectiveness of actions taken to counteract and ameliorate the situation.

Generally, there is need to monitor two strongly interrelated dimensions of impact indicators. The bio-physical indicators provide the necessary information with respect to changes in the geo-ecological environment, whereas the socio-economic indicators assess the impact of external and human factors on desertification and desertification control.

Local, county and provincial governments routinely collect a considerable amount of data on biophysical aspects and statistical data on production levels, fertilizer use, crop yields, etc. It is of the greatest importance that socio-economic indicators are also devised and data collected. These need to be available at all levels from central government to local administration. Monitoring also implies looking at the bigger picture, often well beyond the boundaries of the country or region where dust storms are being experienced.

Meteorologists need up-to-date information on global climate patterns for early warning and monitoring of weather conditions conducive to sand-dust storms and drought (often a precursor to dust events). Under the umbrella of the World Meteorological Organization (WMO), there is an international weather and climate watch program. The Meteorological Office's (WMO's) new Climate Information and Prediction Services (CLIPS) project is designed to enable member nations to make the most of new abilities to monitor and predict seasonal climate variations.

3. UNDERSTANDING THE PROCESSES IN ENVIRONMENTAL MANAGEMENT – THE ROLE OF MODELING

Environmental management relies heavily on our understanding of the environmental processes and on our capacity to assess and predict the environment. The major tasks for environmental modeling and prediction lie in the simulation of the system by modeling both the individual components and their interactions. Environmental modeling and prediction is one of the major challenges of the 21st century, especially, high-resolution weather forecasting and global atmosphere-ocean-biosphere modeling.

3.1. Integrated Modeling System

In environmental modeling and prediction, the following problems must be addressed:

- The physical, chemical and biological processes.
- The interactions between components of the environmental system.
- The variability, predictability, stability, and sensitivity of the environmental system on all scales, from local to global.

Clearly, environmental modeling and prediction must be multi-disciplinary, as it requires understanding from a range of traditional disciplines.

The recent development of integrated environmental modeling has significantly improved our capacity to assess and to predict the environment. An integrated environmental modeling system includes:

- Dynamic models for, for instance, the atmosphere and the ocean.
- Geographic information database, remote sensing and other sources of data.
- High performance computation.
- Decision making tools.

Shao and Leslie at the University of New South Wales, Australia (*see Box 1*), have developed an integrated environmental modeling system. This has provided a powerful tool for the quantitative prediction of environmental problems on a wide range of temporal scales and broad scales with high spatial resolution. Such a system bridges the vital gap between dynamic modeling and spatially distributed data and enables policy and scenario development. The modeling approach is also complementary to field measurements and allows the establishment of guidelines for environmental management practice. Shao, Raupach and Leys (1996) have developed a model for predicting aeolian sand drift and dust entrainment on scales from individual fields to whole regions. Their model WEAM (Wind Erosion Assessment Model) is a physically based model utilizing a combination of established and recent theoretical and experimental results. Key components of the model include the Owen equation for the saltation flux; the observed and theoretically predicted proportionality between saltation flux and dust entrainment by saltation bombardment; theoretical and experimental theories on the amelioration of wind erosion by non erodible roughness; and new experimental results on the suppression of erosion by surface moisture. The size distribution of the particles on the soil surface (in their natural state) is used as a primary parameter. By offering a synthesis of available physical knowledge of sand drift and dust entrainment, the model also indicates key areas of uncertainty where there is scope for further research. Currently there is an international project to test the major wind erosion models in use around the world. Each model is being tested on a standard data set with known wind erosion rates. Raupach, McTainsh and Leys (1994) have developed an approach to estimating dust mass in dust storms (*see Box 2*). This could be useful in other field situations.

Box 1: Environmental Modeling at the University of New South Wales, Australia

The UNSW (University of New South Wales) integrated environmental modeling system consists of dynamic models for the atmosphere and the ocean and a range of schemes for environmental physical, chemical and biological processes.

The model components are outlined below:

- The atmospheric prediction model is the high-resolution limited area model (HIRES) that provides high resolution (2 km x 2 km) atmospheric data, including wind speed, air temperature, humidity and pressure, precipitation and radiation. The model uses high-order differencing in time and space with a horizontal resolution down to 2 km and 40 layers in the vertical. Currently, the vertical turbulent exchange of momentum, heat and moisture is represented using the Monin-Obukhov similarity theory and a Mellor-Yamada level 2.5 and 2.25 scheme in the atmospheric boundary layer. Large-scale condensation and sub-grid scale convection are parameterized using the most recent schemes. The model is self-nested and has the capability of predicting climate patterns with increased resolution for regions of particular interest. HIRES can be nested in global circulation models and is self-nesting. Apart from atmospheric predictions, the atmospheric data are required for investigation of a number of environmental issues ranging from air quality to land use sustainability.
- The atmosphere and land surface interaction scheme (ALSIS) simulates the complex interactions between the atmosphere, soil and vegetation and predicts surface energy fluxes, but most importantly, the model predicts evapotranspiration, surface and subsurface runoff and deep soil drainage that determine the evolution of soil water in the vegetation root zone. The model also predicts solute movement in the unsaturated flow.
- The ground water model simulates saturated water flows in deep soil layers. This system component is of great importance, as it is linked to the surface soil hydrological model, so that the ground water table, pollutant dispersion and salinity problems can be better studied.

A comprehensive GIS database for surface topography, soil and vegetation provide parameters, such as soil hydraulic properties and vegetation leaf area index, required by the dynamic models described above. For air and water pollution studies, the GIS includes data for urban population and traffic as well as data for industrial emission sources.

Other important system components include an ocean model, an air-sea interaction scheme, a soil erosion scheme, and an atmospheric chemistry model, a transport scheme for pollutants in saturated and unsaturated flows, a plant growth scheme; and models for data manipulation.

To build such a comprehensive numerical system is a challenging task that must involve extensive knowledge of numerical modeling of atmospheric, land surface and soil hydrological processes, as well as bridge the vital gap between dynamic models and spatially distributed GIS data.

Box 2: Estimating dust mass in dust storms

Raupach, McTainsh and Leys (1994)* have developed an approach to estimating dust mass in dust storms:
The total mass of dust in the dust cloud can be estimated by two quite different methods:

Estimate 1: From visibility – Chepil and Woodruff (1957) related visibility to dust concentration *C* with the empirical formula:

$$\text{Visibility (km)} = 7{,}080\, C^{0.8} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where C is μg/m^3. This formula is valid for visibilities from a few metres to several kilometres. Taking a visibility of 100 m, the value assigned by Lorenz and Abe (1993) is $C = 1.15$ g/m^3, about 1/1,000 of the density of air.

The mass M of dust in the cloud is:

$$M = XYhC \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where X and Y are the mean dimensions of the cloud in the along-wind and cross-wind directions respectively, and h is the mean cloud height.

Although h varies with distance along the wind and C varies throughout the cloud, this equation provides a means of estimation (and can be justified formally) if h and C are taken as suitable averages through the dust cloud. At the coarse level of approximation to which we are constrained by the available data this is an appropriate course.

They use the somewhat conservative value of $X = 20$ km, to account for fact that quoted visibility of 100 m pertains to the peak of the storm and that dust concentrations would diminish with time thereafter. The duration of the storm X/U_c would be about 15 minutes if $X = 20$ km (and $U_c = 20$ m/sec); this is approximately consistent with observations of dust storm events in Australia.

With $X = 20$ km, $Y = 500$ km and $h = 320$ m, *Equation (2)* gives $M = XYhC = 3.7 \times 10^9$ = 3.7 million tonnes.

Estimate 2: From deposition – The deposition velocity W_d for a trace constituent of the atmosphere is defined as $W_d = F/C$ where F is the deposition flux density to the surface (with units mass/area/time) and C is the concentration. For suspended particulates, W_d depends on the particle diameter *d*., the friction velocity u_* and the roughness of the underlying surface. Chamberlain (1975) gives experimental values of W_d as a function of d for various u_* values over grass-covered surfaces; the data indicate that when $u^* = 1$ m/sec, $W_d = 0.01$ and 0,03 respectively. These W_d values are in reasonable accord with theoretical predictions by Raupach (1993). A mean diameter between 5-10 µm for the suspended dust is roughly consistent with unpublished measurements on airborne dust samples collected in Australia in 1987 where dust was transported by 11 m/sec winds. These measurements yielded a mean diameter of 9.3 µm at height 1.5 m, implying smaller mean diameters at greater heights.

If the concentration of C (averaged over cloud depth) is allowed to vary with streamwise distance x or time t at a fixed location then we may write:

$$M = Yh\int C dx = \frac{Yh\int F dx}{W_d} = \frac{YhU_c \int F dt}{W_d} = \frac{YhU_c}{W_d} G \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where $G = \int F\, dt$ is the total mass deposited per unit are during the storm. Lourenz and Abe (1983) gave a figure of G = 106 kg/ha. Putting this into *Equation (3)*, with $Y = 500$ km, $h = 320$ km and $U_c = 20$ m/sec as before, and taking $W_d = 0{,}01$ m/s, we obtain $M = 3.4$ million tonnes. If the estimate $W_d = 0.03$ m/sec is used for the deposition velocity, the lower value of 1.1 million tonnes is obtained.

The two estimates use quite different ways to obtain C. That their agreement to better than an order of magnitude is encouraging, given the gross assumptions embedded in each. *Estimate 1* may well be an over-estimate because of the assumption that the peak concentration (minimum visibility) represented the average cloud concentration for a period as long as 15 min. In *Estimate 2*, the value of W_d is likely to be closer to 0.03 than 0.01 m/sec., assuming the particle size was closer to 10 than 5 µm. Taking all these uncertainties into account, a conservative estimate for $M \cong 2$ million tonnes.

The development and implementation of integrated environmental models has been made possible by the maturing of advanced dynamic models, increasing amount and accuracy of real data and the rapid expansion of computational power and information technology.

3.1.1. Example of some applications of the model

The integrated modeling system has a wide range of applications. A shortened list is as follows:

- Atmospheric predictions with improved accuracy; the system is especially powerful in the prediction of severe weather events, such as floods, strong winds, hurricanes and bush fires.
- Broad scale modeling and prediction of land surface processes with high spatial resolution of soil water, dust storms, dry land salinity, ground water table, pollutant transport.
- Air quality: urban air quality and long range transport of air pollutants.
- Assessment of wind and solar energy resources.

3.1.2. Example 1 - Dust Storms

Wind erosion is a serious problem in Australia and many other arid or semi-arid regions in the world. During an erosion event, small soil particles rich in nutrient and organic matter become suspended and are dispersed away from the surface by atmospheric turbulence and then transported over distances up to thousands of kilometers, leading to soil degradation (*see Chapter 1*). From the perspective of land care it is important to quantify the risks of wind erosion on scales from individual cultivated fields to whole regions and to identify the responsible environmental mechanisms. From the perspective of atmospheric studies, particles suspended in the atmosphere may significantly influence the radiative processes as they absorb and scatter various radiative components (*see Chapter 2*).

Wind erosion is a complex interacting set of physical processes governed by many factors (*Box 3*), which can be broadly grouped into three categories:

- Weather and climate (especially high winds and low precipitation).
- Soil state (mineral composition, particle size characteristics, crusting and aggregation, and soil moisture).
- Surface roughness (non-erodible soil aggregates, micro-topography, and vegetation cover).

Land management practice also plays an important role (*see Chapter 15*). As a consequence, wind erosion events are spatially variable and highly intermittent and often are associated with meso-scale frontal systems under dry climatological conditions. Therefore, to predict wind erosion, it is necessary not only to predict atmospheric conditions but also to model and/or describe the conditions of the surface, including soil state, surface vegetation cover, and soil moisture (*see Chapter 3*).

In summer 1996, large areas in Australia received rainfall below or much below average and were therefore under high wind erosion risks. Shao and Leslie applied the integrated system to the February 1996 wind erosion event over the Australian continent. Model results of the erosion events, including wind erosion origin and intensity, are compared with available data. *Figure 4* shows the dust concentration in the atmosphere according to the model prediction. *Figure 5* is a computer simulation of the passage of that storm.

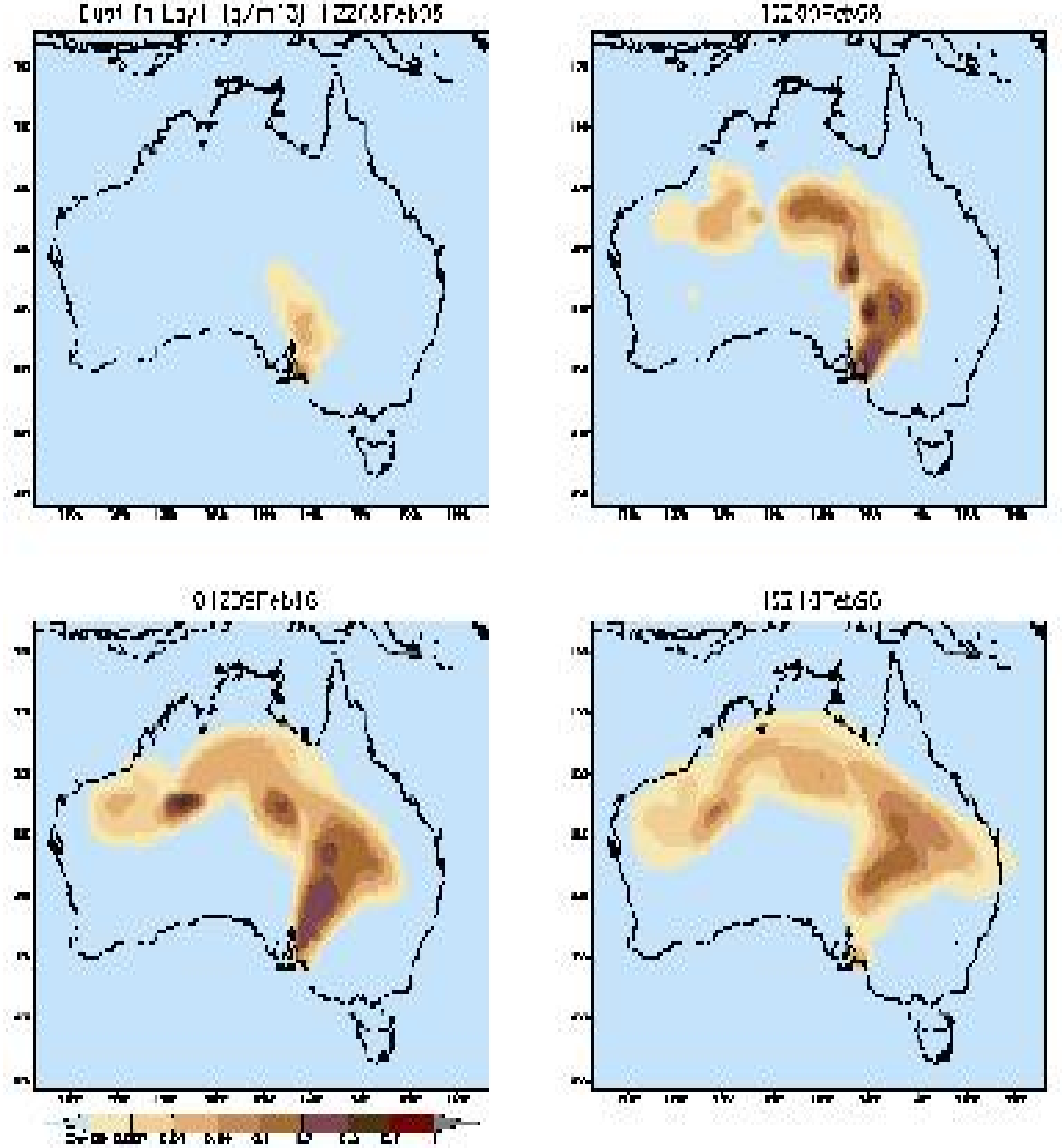

Figure 4: Concentration of dust particles in the atmospheric boundary layer for four different times during the February 1996 dust storm over the Australian continent (data from Shao and Leslie, University of NSW)

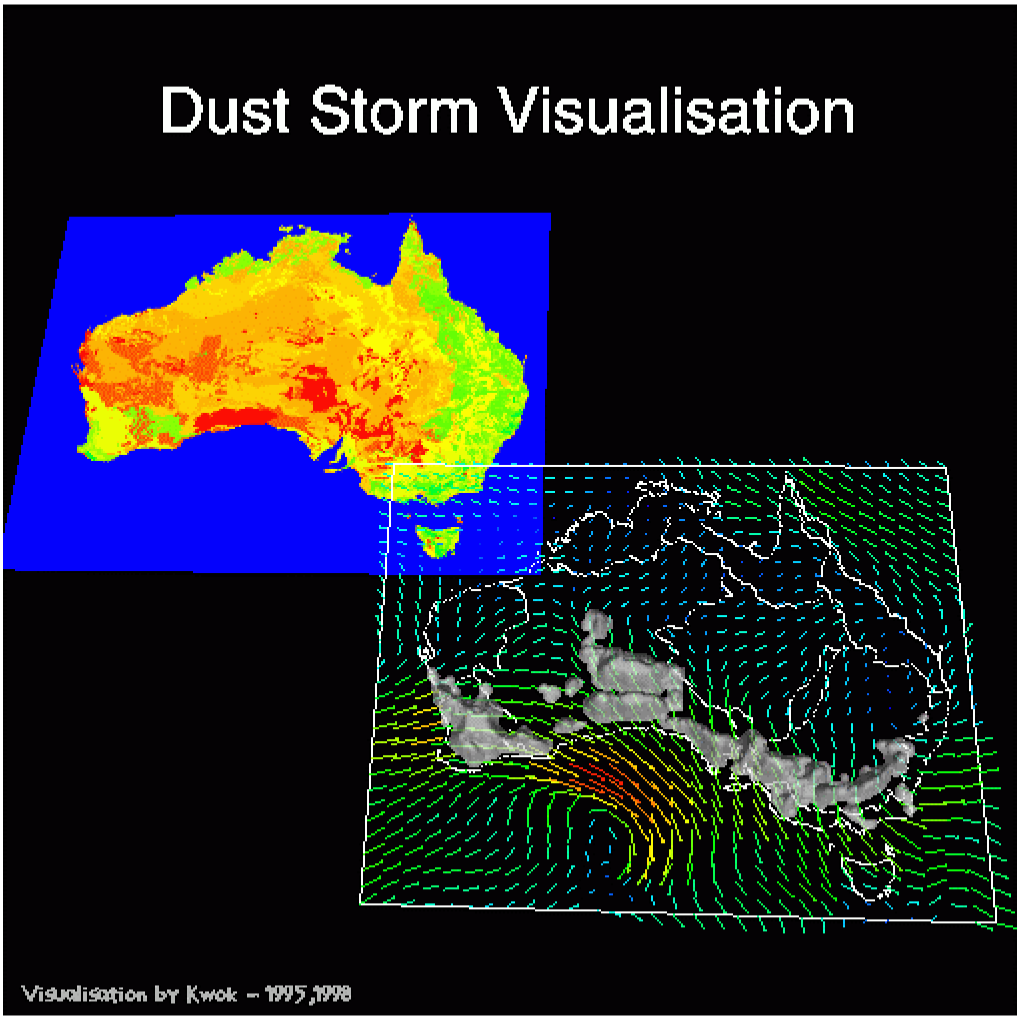

Figure 5: Computer generated visualization of dust storms (courtesy of Professor Shao, University of NSW)

4. DROUGHT AND DUST STORMS

A drought is defined as a prolonged, abnormally dry period when there is not enough water for users' normal needs (*see Chapter 1*). Drought is not simply low rainfall; if it were, much of the world's drylands would be in almost perpetual drought. Because people use water in so many different ways, there is no universal definition of drought.

Meteorologists monitor the extent and severity of drought in terms of rainfall deficiencies. Agriculturists rate the impact on primary industries, hydrologists compare ground water levels, and sociologists define it on social expectations and perceptions (Squires, 1995). The risk of serious environmental damage, particularly through vegetation loss and soil erosion, has long-term implications for the sustainability of our agricultural industries. Dust storms often increase during dry times.

4.1. Causes of drought

Drylands are characterized by variable rainfall. Over the long-term there are about three good years and three bad years out of every ten, although the sequence can be very unpredictable. Drought frequency is crucial. Long-term historical rainfall records give a clearer picture of what is *"normal"* for an area, and how much variation might be expected The mean annual rainfall for a any place is only a statistical construct. Some droughts are long-lived; some are short and intense, causing significant damage. Some can be localized while other parts of the country enjoy bountiful rain (*Figure 6*).

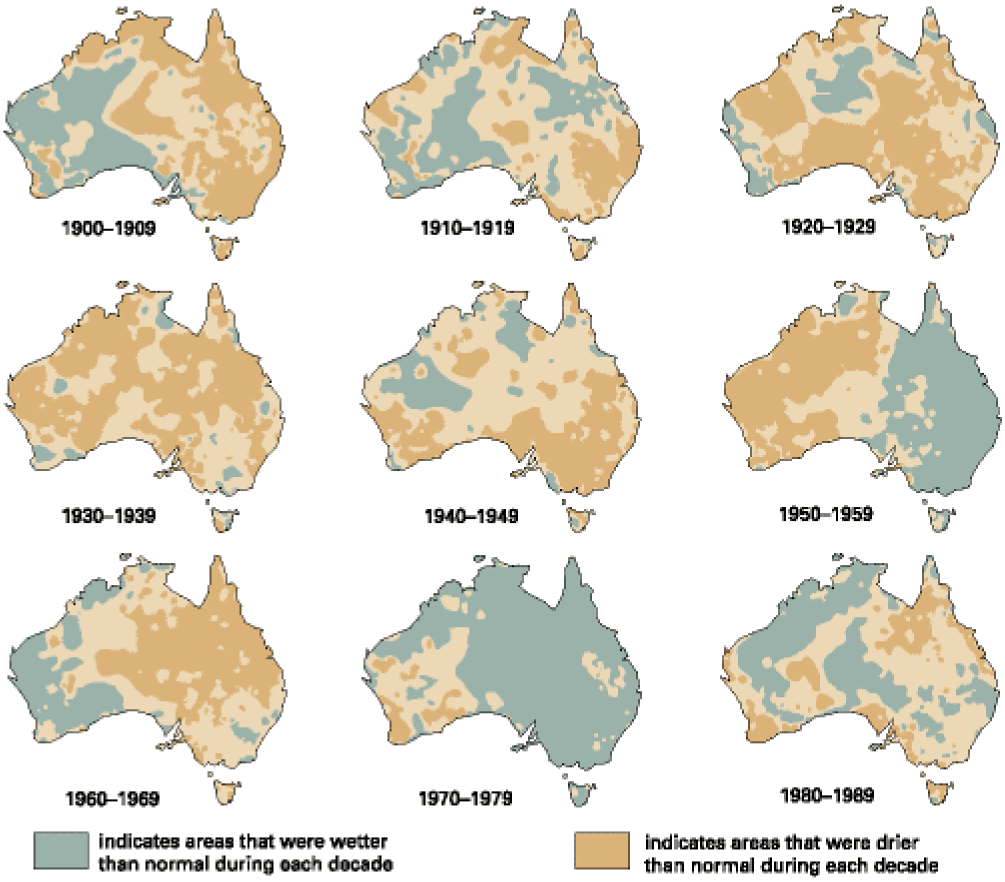

Figure 6: Incidence and distribution of severe drought over the Australian continent during the past 100 years

These fluctuations have many causes, but the strongest in many regions is the climate phenomenon called the Southern Oscillation. This is a major air pressure shift between the Asian and east Pacific regions - its best-known extreme is El Niño (Nichols, 1991).

The change in weather patterns during an ENSO event alters regions of high and low pressures around the globe. Descending air of atmospheric circulation cells creates high-pressure centers at the surface. The high surface pressures prevent areas of precipitation from moving into its region. When these abnormal high-pressure patterns persist they lead to drought conditions, depriving the area and its ecosystem of rainfall. Droughts generally occur in the western Pacific during ENSO events, an area normally rich in rainfall. However, droughts in many other regions of the world, including southeastern Africa, India, China and the northeastern region of the South American continent, have been linked to El Niño.

In recent years, the greater understanding of El Niño has improved the ability to predict seasonal rainfall and help authorities and individuals with early drought warnings and has helped in the management of drought. Some regional droughts are not related to El Niño events, and are therefore harder to forecast (*Figure 7*).

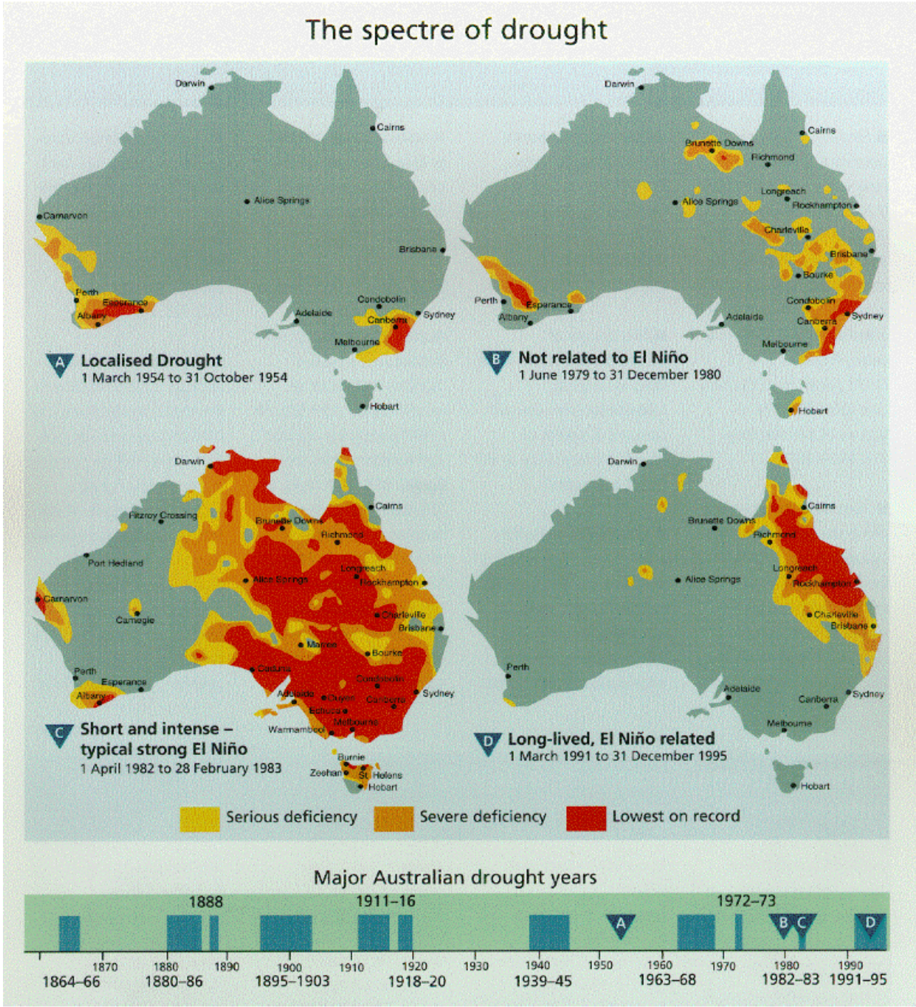

Figure 7: Not all droughts are associated with El Nino events. This makes drought prediction and forecasting more difficult

In Australia, the Bureau of Meteorology's Drought Watch Service has been a key component of national drought management since 1965. It is based on a nationwide daily rainfall measuring network and established relationships between rainfall deficiency and the severity of recorded drought. Its rainfall information assists government, business and the rural community. It also helps to assess the current situation, providing early indication of the need for contingency action or drought relief.

Using monthly rainfall analysis, areas suffering from rainfall deficiencies appear in the Drought Statement as well as the publication *Monthly Drought Review.* If the accumulated rainfall over three successive months was within the lowest 10% on record, a Drought Watch is commenced and the region is highlighted. This initial dry period stretches to six months for arid regions. Consideration is also given to whether an area is usually dry at that time of the year. There are two rainfall deficiency categories:

i. A **severe** rainfall deficiency exists in a district when rainfall for three months or more is in the lowest 5% of records.
ii. A **serious** deficiency lies in the next lowest 5% i.e. lowest 5-10% of historical records for a three-month or longer period.

Allowing for seasonal conditions, the Drought Watch may continue for many months and ceases when plentiful rainfall returns. "Plentiful" *is defined as well-above-average rainfall for one month or above-average rainfall over a three-month period.*

The Drought Watch Service provides a consistent starting point for national drought alerts. Drought declarations take account of other factors in addition to rainfall and are the responsibility of the State Governments.

5. CONCLUSIONS

Monitoring, prediction and mitigation are three key elements in any national action plan to combat desertification and drought. The success of the monitoring will depend on establishing good baseline data and in ensuring that the way in which the data is to be used is assessed before the data are collected. Modeling has the potential to predict the occurrence and likely severity of dust-related events. Local and regional climatic data and hour by hour meteorological data can be helpful but global scale monitoring of such phenomena as the El Niño effect are also important. Multi-disciplinary approaches are called for.

Success will depend on several criteria:

1. An integrated environmental modeling system that couples dynamic models, real data and policy development tools.
2. Integrated environmental modeling system that provides a powerful tool for the assessment and prediction of the environment and provides the necessary knowledge for environmental management.
3. More research should be focussed on the way to model and predict the onset of conditions favoring sand-dust storms and the best ways to mitigate the effects on humans, their livestock, crops and property.

Closer integration of the research efforts on climate change under the Convention on Climate Change (including the IPCC) and those on desertification should be promoted by closer links between the IPCC and the UNCCD (Grainger et al., 2000).

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Chamberlain, A.C. 1975. *The movement of particles in plant communities*. In: *Vegetation and the Atmosphere* Vol. 1 (J.L. Monteith, Ed.) Academic Press, London.

Chepil, W.S. and Woodruff, N.P. (1957) *Sedimentary characteristics of dust storms II. Visibility, and dust concentration*. Amer. J. of Sci. 255: 104-114.

Glenn, E. Stafford Smith .M. and Squires. V. (1998). *On our failure to control desertification: implications for global change issues and a research agenda for the future*. Environmental Sciences Policy 1: 71-78.

Grainger, A. Stafford Smith, M., Squires, V. and Glenn, E. (2000) *Desertification and climate change: the case for greater convergence*. Mitigation and Adaptation Strategies for Global Change 5: 361-377.

Goudie, A.S. & N.J. Middleton 1992. *The changing frequency of dust storms throughout time*. Climatic Change, 20: 97-225.

Lancaster, N. 1996. *Geoindicators from desert landforms*. In Berger, A.R. & W.J. Iams (eds). *Geoindicators: Assessing rapid environmental changes in earth systems*: 251-268. Rotterdam: A.A. Balkema.

Lourensz, R.S. and Abe, K. (1983). *A dust storm over Melbourne*. Weather 38: 272-275.

McTainsh, G. Lynch, A.W. and Tewes, E.K. (1998) *Climatic controls upon dust storm occurrence in eastern Australia*. J. Arid Environ. 39: 457-466.

Middleton, N. J.(1984) *Dust storms in Australia: frequency, distribution and seasonality*. Search, 15: 46.

Pastore,G. and Giampietro, M. 2000. *Ecological approach to agricultural production and ecosystem theory: the amoeba approach*. In: *Agro-ecosystems, natural resources management and human health related research in East Africa.* ILRI Proceedings, Nairobi pp. 15-30.

Pye, K. 1987. *Aeolian dust and dust deposits.* London: Academic Press.

Raupach, M.R. (1993) *Dry deposition of gases and particles to vegetation*. Clean Air 27: 200-203.

Raupach, M.R., McTainsh, G. and Leys, J. 1994. *Estimates of dust in recent major Australian dust storms*. Austral. J. Soil Water Conserv. 7 (3): 20-24.

Shao, Y. 2000 *Physics and modeling of wind erosion.* Atmospheric and Oceanographic Science Library, Vol. 23 Kluwer Academic, Dordrecht, the Netherlands.

Shao, Y., Munro, R.K. Leslie, L.M. and Lyons, W.F. 1996. *A wind erosion model and its application to broad scale wind erosion pattern assessment*. International Soil Conservation Association, Bonn.

Shao, Y., Raupach, M.R. and Leys, J.F. (1996) *A model for predicting aeolian drift and dust entrainment on scales from paddock to region*. Aust. J. Soil Res. 34: 309-42.

Squires, V.R. *La secheresse en Australia et le pastoralism: phenomenes instructifs ou occasion perdue* Secheresse 6 (1): 127-134 (French).

Squires, V.R. (1998*) The world's drylands and global change in the 21st century: challenges and prospects*. Journal of Arid Land Studies 7S: 1-13.

Squires, V.R. 1998. *Sustainable agriculture and pastoralism as a means of combating desertification: which road do we take?* Desertification Control Bulletin No. 33; pp. 11-15.

Squires, V.R. (in press) *Desertification, climate change and the world's drylands*. In: *Desertification in the Third Millennium.* (eds A.S. Alsharhan, W.W. Wood, A. Goudie, K.W. Glennie and E.M. Abdellatif) A.A. Balkema, Rotterdam, the Netherlands (in press).

Thomas, D.S.G., Glenn, E.P. and Squires, V.R. 1997. *The North American dust Bowl and desertification: economic and environmental interactions*. In: *World Atlas of Desertification* Edward Arnold/UNEP 2nd ed. pp. 149-154.

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Chapter Fifteen

MITIGATING THE EFFECTS OF DISASTROUS SAND-DUST STORMS: A CHINESE PERSPECTIVE

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Keywords: vegetation, species selection, soil type, gobi, sand dune fixation, irrigated agriculture, dryland cropping, rotation, land abandonment, aerial seeding, firewood collection, medicinal plants, mining, heavy metals, salinity, land reclamation, cultivation, soil fertility, human-induced desertification, railways, highways

SYNOPSIS

The key approaches being adopted by China to reduce the frequency and severity of sand-dust storms are focussed on the protection and improvement of the local ecology. There is recognition that protection should be a priority but that rehabilitation is also important. Legal and policy issues are also important to ensure that policy conflicts and contradictory practices do not work against ecological restoration. Harmful practices should be stopped and measures put in place to relocate people whose livelihoods have been destroyed by sand-dust storms and desertification.

This chapter outlines the types of measures successfully tried in various situations within China's arid Northwest. These include protection forestry around irrigated oases, revegetation of loess soils under dryland farming, stabilization of dunes and protection of transport routes such as highways and railways.

KEY POINTS

1. *The development of agriculture through the establishment of irrigated oases on the desert fringe, and the conversion of rangelands (including steppe and desert) has not always been rational. There is a need to regulate agriculture and reform cropping systems.*
2. *Re-afforestation is a priority but its limitations are realized. More use of grasses and shrubs can be effective in certain situations. Choice of species and the methods of planting need particular care.*
3. *Better understanding of the physics and mechanics of windbreaks and shelterbelts has allowed improved design and the new arrangements give better protection.*
4. *Control of sand sources along traffic routes and around mining sites is a major focus in some counties.*
5. *Human factors are vitally important in causing the present problems but more importantly, in solving them.*

1. INTRODUCTION

Sand-dust storms are the outcome of interactions between weather process and processes on the ground. Because human ability to control weather is very limited the key approaches to reduce the frequency and intensity of sand-dust storm disasters are focused on the protection and improvement of ecology. The principles of ecological protection and improvement of *"put prevention first,"* emphasize protection as the priority and lay stress on both the prevention and rehabilitation. Legal and policy systems for protection and restoration have to be established and put into effect to stop all activities that cause further deterioration of the ecological environment. For example, a new approach to ecological immigrants[15] should be adopted in the affected areas where carrying capacity is completely destroyed. Economic levers have to be used to save water resources by compulsory means in the upstream and middle reaches of inland rivers to protect and restore the ecological environment downstream and rehabilitate and re-build the fragile ecology of the sand-dust source regions.

Because of the existence of sand and gobi[16] deserts over vast areas, the full control of sand-dust materials is impossible. Sand-dust storms are natural phenomena that have existed throughout geological and historical periods. However, human population growth has destroyed vegetation and exposed new sand sources that have contributed to today's problems. This disastrous process can be slowed down through readjustment and coordination of human activities, rational utilization of soil and water resources, protection and revegetation. The newly-approved national action programmes and state projects of Preservation of Natural Forest, NAP to Combat Desertification and Withdraw Dryland Farming for Revegetation of Forest and Grass are the strategic arrangements to slow down and control sand-dust storms.

1.1. Human factors

In addition to the broad scale destruction of vegetation referred to above, human factors are manifested as artificial accumulation (mine wastes) and disturbance. Artificial accumulation, such as mine tailings[17], contains more than 43% of fine sand or dust (*Table 1*). The newly opened-up farmland contains a high content of fine sands and dust particles (approximately 70%). Both of these human disturbances supply sand materials for sand-dust storms.

Table 1: Grain size of tailing sand in Jinchang (mm)

Depth (cm)	Mid-sized sand 0.5-0.25	Fine sand 0.25-0.125	Very fine sand 0.125-0.063	Dust sand 0.063-0.002
0-5	0.13	12.1	38.1	43.2
5-100	0.83	5.23	44.5	55.83

1.2. Human disturbance has brought about reactivation and exposure of sand material on land surface

The reactivation process and exposure of surface sand composition is not only related to the physical conditions, but also closely related to human factors. On the one hand, human disturbances are manifested by vegetation destruction caused by over-cultivation and opening-up of rangeland, over-grazing and undue collection of firewood, medicinal herbs and deforestation, particularly the issue of high stocking rate on rangeland. Uncontrolled development has destroyed vegetation that people had protected for many years. On the other hand, irrational utilization and development of both surface and underground water has brought about cutting off of water flow and the lowering of underground water tables. The land surface has dried up, the lakeshores have retreated (or even dried up completely) and desertification is spreading and worsening day by day.

These human disturbances destroyed vegetation that once protected the soil from wind erosion and denudation. Vegetation prevents soil from erosion in the following three forms: a) covering the land surface

[15] Ecological immigrants (sometimes called ecological refugees) are those people who leave their land and re-locate because of the destruction of the environment and its inability to support them and provide household food security.

[16] In China, the term gobi refers to deserts that have a mantle of small stones or gravel. The Gobi desert is an area of such desert on a large scale.

[17] Tailing refers to the waste rock and sediments from ore crushing, or coal dusts and other fine materials that accumulate as a by-product of mining operations.

to avoid wind erosion; b) dispersing and weakening the wind force above ground and increase surface roughness; c) prevent eroded materials from movement. Human disturbances caused exposure of land surfaces and the severity of exposure is significantly related to wind erosion (*Table 2*).

Table 2: Relationship between vegetative coverage and soil erosion

Sam. No.	Veg. cover (%)	Threshold velocity (m/s)	Sampling size (cm^2)	Wind velocity (m/s)	Erosion (kg)	Wind erosion modeling	
						g/cm. m	t/mu. h
1	69.7	10.23	28×25	14.0	0.14	0.020	8.0
				21.6	0.49	0.070	28.0
				24.0	0.82	0.117	46.8
2	58.5	8.70	20×25	14.4	0.25	0.050	20.0
				19.6	0.88	0.176	70.4
				22.4	0.90	0.180	72.0
				23.6	2.28	0.456	182.4
3	27.4	8.27	36.5×25	10.2	0.07	0.008	3.2
				16.7	0.87	0.095	38.0
				20.6	1.95	0.214	85.6
				24.4	4.93	0.540	216.0
4	10.8	7.84	34×25	10.6	0.43	0.050	20.0
				15.5	1.77	0.208	83.2
				21.5	2.36	0.278	111.2
				24.9	4.56	0.538	2.15.2

Based on the above description, preventive effects of vegetation on soil can be classified into the following three types, namely, when the vegetative coverage is higher than 60%, then slight erosion or zero erosion appears; when vegetation is 60-20%, medium erosion appears; and when the vegetation is less than 20%, severe erosion occurs. According to the mobile wind tunnel experiment, in comparison of the sandy loess without human disturbance, the erosive capacity of sandy loess with human disturbance is 8.9 times higher. The erosive capacity of the disturbed black sandy soil is 1.2 times higher than that of the undisturbed black soil.

Irrational utilization of water resources brought about diminished water flow of rivers, decline of underground water and the contraction of lakes. Some lakes dried up and this contributed to the further spread of desertification. In the downstream reaches of inland rivers, insufficient river water flow also caused land desertification. For example, along the Tarim River and Heihe River, water was consumed in great amounts for irrigated agriculture in the upstream and middle reaches of rivers. Downstream there was a lack of water supply or even a complete cessation of water flow. This consumption of water resources resulted in the death of vegetation and the spread of land desertification. From 1958-78, the area of *Populus euphratica* forest along the Tarim River was reduced to 16,400 ha (from 54,000 ha) and 5 state-owned agriculture farms downstream were abandoned. About 8,600 ha of arable land of the 5 farms was abandoned of which 2,000 ha was buried by shifting sand. In particular, since the establishment of the Da Xihaizi Reservior in 1972, water flow in the southern section of Alagan obviously decreased and the underground water table declined about 8-10 metres in the 1980s from the former 3-5 metres in the 1950s. Downstream of the Heihe River, especially along the western section of the river and outside fringe of the eastern section of the river, a huge amount of *Eleagunus augustifolia, Tamarix spp. and Populus euphratica* forests died and land desertification accelerated. In 1985, annual water flow in Zhengyi Gorge was only 790 million metres^3, no water flow could reach downstream sections and Sogo Nor was completely dried up in August 1986. Since the 1950s, the underground water in the northern part of Jianguoying at the western section of the Heihe River declined by 2-9 metres. The same situation occurred along the Shule River. Reservoirs stored and intercepted all water flow and the river course dried up, underground water along courses declined, vegetation withered and died, large areas of barchans dunes developed in the eastern part of Anxi County and now threaten irrigation canals and invade the country side.

Over exploitation of underground water caused a drop in water tables and brought about land desertification. Minqin County is located at the downstream of the Shiyang River. On the one hand, large-scale development of water resources upstream resulted in a decline of water flow downstream; on the other hand, there was blind exploitation of underground water that was pumped to supply the deficiency in water. As a consequence, the underground water table deepened and vegetation was destroyed. It is estimated that the water flow entering into Minqin Oasis was 573 million m^3 in the 1950s, 445 million m^3 in the mid-1960s and 322 million m^3 in the 1970s. Underground water storage in Minqin Oasis was 1.58 billion m^3 in the 1950s, 1.2013 billion m^3 in the 1960s, and 976 million m^3 in the 1970s.

Change in moisture results in a change of water-holding rates of surface material. The change of water-holding rates brings about aridity of the land surface and the aridity is closely related to the wind erosion. The water-holding capacity in soil is higher; the tension between water elements and soil particles will strengthen the cohesion amongst soil particles. As a result, erodibility of soil is reduced. It can be concluded that the higher the water-holding rate, the higher the threshold wind velocity will be while the erodibility of soil is reduced. *Table 3* shows the experimental results.

Table 3: Relationship between wind erosion rates and water-holding capacity of soil under different wind velocities

Water-holding capacity (%)	Erosion rate g/min under different wind velocity			
	10 m/s	15 m/s	20 m/s	25 m/s
2.67	73.04	761.96	1,582.23	2,480.00
4.14	66.19	210.86	881.32	1,568.69
5.20	24.72	145.82	239.42	390.59
5.69	12.94	81.86	172.26	280.42
6.20	0.10	52.03	107.03	244.04
7.13	0.00	27.79	53.53	158.47
7.87	0.00	10.45	47.06	133.92
8.18	0.00	8.76	42.65	90.26
9.52	0.00	5.01	22.83	50.06

Change of water-holding rates determines the intensity of soil erosion. Initially, the increase of the water-holding rate decreases the erosion rate. When the water-holding rate increases up to a certain percentage (threshold), even a small percentage of soil moisture will cause large-scale reduction of soil erosion rates. Hu Mengchu (1991) concluded that the 2% of water-holding content of sandy soil is the threshold. When the water-holding capacity is <2%, the ability of erosion resistance is high and when it is >2%, the ability of erosion resistance is stable. When the water-holding capacity of sandy soil reaches saturated water-holding of 4.73%, the maximum ability of erosion resistance is 14 m/s, namely wind of force 6-7 (Beaufort scale) will be resisted.

Table 4: Effects of dune exclosures and grass plantations around and inside oases

Regions	Year	Main varieties	Vegetative coverage (%)
Newly cultivated oasis in north Of Ulan Buh Desert, Inner Mongolia	5	*Artemisia ordosicas, Artemisia sphaerocephala, Psammochloa villosa* Bor	40-50
Jinta Oasis in Hexi Corridor, Gansu	3-4	Alhagi sparsifolia *Shap. ex Kell. Et shap. Phragmites australis*(Cav) Trin. Exsteudel, *Achnatherum splendens* (Tvin.) Nevski	45
Oasis at south edge of Tengger Desert, Gansu Province	5	*Artemisia arenaria* DC., *Kalidium foliatum* Pall. Moq., *Suaeda glauca* Bge.,	50

		Nitraria tangutorum Bobr.	
Turpan Oasis, Xinjiang	3	*Alhagi sparsifolia* Shap. ex Kell. Et shap., *Reaumuria soongorica (*Pall.) Maxim.	60

2. GUARDING AGAINST CALAMITIES, HAZARDS AND PROPERTY DESTRUCTION

2.1. Human safety and property protection

Sand-dust storms, especially the black storms, occur with violent wind and drifting sand and dust and visibility is near zero. Human beings, particularly children, often panic and animals and poultry are easily thrown into chaos. Fire is a possible outcome when a sandstorm occurs and is not easy to control. Some costly lessons from past sand-dust storms show that more concern should be focused on the protection of people's life and property. *Box 1* includes recommendations considered essential.

Box 1: Protection of human life and property during black sand-dust storms

A. Prevent from falling into water
Weather forecasting is an essential service. When sand-dust storms occur, all pumping wells should be covered as soon as possible and irrigation channels should be shut down to prevent people from falling in. As the storm is passing, pedestrian and field workers should take care of themselves and walk away from water channels and other water bodies and find a safe place to lie down. Pedestrians are advised to stop running along channels, on dams or on highways and bike riders are reminded to stop riding immediately when they see the storm approaching. During the storm, all schools must be closed and children will not be allowed to walk out of the gate. The casualties in past disasters are mostly teenagers and children. Teachers and parents have to take warning.

B. Avoid sheltering near broken walls and in ruins
Sandstorms and black storms are destructive disasters prevailing under wind force 7-8 (Beaufort scale). Pedestrians are reminded not to hide near broken walls and in ruins thereby avoiding injury or death when these structures collapse. Citizens in towns are reminded to avoid walking near buildings. Broken glass and falling objects are dangerous and deaths have occurred from these.

C. Protect poultry and animals
Weather forecasting services in rural areas should be set up. When storms come, all poultry and small animals should be back in sheds. Grazing animals should be circled in the inter-dunes or low lying areas to avoid sand blasting and other harm.

D. Control of fire
Sand-dust storms cause damage to wires, poles, transformers and other electricity facilities. When a storm comes, all towns, settlements, mining fields and enterprises have to cut off electrical power in time. Power stations have to stop power supply to avoid electrical fires.

2.2. Ecological measures designed to mitigate the impact of sand-dust storms

2.2.1. Establishment of nature preservations

The establishment of nature preservations at desert peripheries, in dried up lakes and basins and in downstream reaches of inland rivers is an urgent priority to stop vegetation destruction and restore plant communities and foster revegetation. For instance, the *Populus euphratica* nature preservation of Badaoqiao, Ejinna County in western Inner Mongolia plays obvious roles in increasing natural growth of species and in revegetating degraded areas. When the nature preservation is enclosed, tree density becomes higher and seedlings grow faster. The effective area of an old tree with root system regeneration is 0.15 ha and 134 individual seedlings were regenerated from this old tree. After six years of enclosure, this piece of nature preservation became dense forest. In Liangucheng nature preservation of Minqin, vegetative coverage of *Tamarix spp.* and *Reaumuria soongorica* (Pall.). Maxim is as high as 30%, mobile dunes have been initially stabilized and dust sources were covered with biological mulch; the sand invasion of the southern movement of the Tengger Desert is blocked from this corner.

2.2.2. Establishment of protective oasis shelterbelts

Oases in China have a scattered distribution and are adjacent to undulating sand dunes and eroded lands at the periphery of gobi and sand deserts. Inside oases, there is some distribution of mobile, fixed and semi-fixed dunes. Some arable lands are composed of sandy soils or sandy loam that is easily eroded. Therefore, once sand-dust storms occur, farming production inside an oasis will suffer damages. Sands invade oases and come from the following four sources: a) Movement of mobile dunes that buries arable land, accumulates in irrigation canals and damages crops; b) Sand drifts, caused by denudation and deflation of fixed and semi-fixed dunes, attack crops, shifting sands occupy crop fields and canals; c) sands blown by wind on the gobi inside or around oasis harm crop fields; d) sandy soils of ploughing layers in oases lose fertility under impacts of erosion.

Experience has shown that the sand sources of mobile dunes, semi-fixed sandy lands and eroded fields inside or surrounding oases or arable lands suffering from sand accumulation and sand drifts invasion can be rehabilitated through enclosure of natural psammophytes[18], establishment of sandbreaks, windbreaks and farmland protective shelterbelts.

2.2.3. Sand stabilization enclosures at oasis periphery

In Northwest China, besides the megadunes and dense barchans, most sand lands are vegetated more or less with plants. Along inland rivers, lakes, low lying areas and oases, because of good soil and water conditions, there were wide distributions of natural *Populus euphratica* Oliv., *Haloxylon ammondendron* C.A.Mey, *Tamarix spp.* forests and *Nitraria spp.* shrubs, bushes and forbs and grasses. As a result of long-term over-grazing and collection of firewood, vegetation and oasis plants were seriously destroyed and even disappeared. Land surfaces were exposed, fixed dunes were reactivated, shifting sand areas increased, desert steppe was decreased and sands blown to the oasis became severe. However, the area where vegetation was luxurious or where there are still some residuals of sparse vegetation, potential for natural regeneration to occur exists.

Since the 1950s, along with large-scale establishment of sandbreaks, windbreaks and protective shelterbelts, *"sandy land exclosure for grasses and protection of natural vegetation"* was regarded as one of the major approaches to control shifting sands and some progress has been made. Normally, a sand exclosure belt of 1-2 km or 10-20 km wide was fenced at the windward side of oases and at the adjoining areas of desert, gobi and eroded lands. Vegetation coverage was increased from the former 10-15% to 40-50% at present. A combined artificial belt coexisted as a barrier to prevent oases from erosion.

However, the maintenance of desert forest and natural psammophyte vegetation was poorly managed and vegetation was destroyed by human disturbances, particularly in the 1960-70s. During the process of developing new oases, psammophytes inside or surrounding oases were exploited for firewood. People living

[18] Psammophytes are sand-loving plants, including trees such as *Tamarix* and *Haloxylon* as well as shrubs and grasses.

around the new oases cut vegetation for cooking and heating. According to a survey, desertified lands caused by vegetation destruction in the western regions of Helan Mountain are approximately 80,574 km². Land desertification and rehabilitation coexist but the destructive rate is higher than the rehabilitation rate. This phenomenon does not only threaten the development of oasis protective shelterbelts, but also promotes the damage of sand-dust storms to agriculture, mining and traffic lines.

Since the 1980s, along with the implementation of the *"Three North Regions"* Shelterbelts System, more importance was attached to exclosure of natural vegetation and appropriate grazing management. Prevention and rehabilitation are stressed as essential approaches. The phenomena of converting desert for irrigated agriculture, over-grazing, collection of firewood and harvesting of medicinal herbs have been kept within limits. Up to 1988, more than 10,000 km² of degraded areas have been enclosed and revegetated (Gansu and Xinjiang account for 6,700 km²). At the same time, the target of exclosure and revegetation is increasing year by year.

2.2.3.1. Function of sand stabilization enclosure at oasis periphery

Practice shows that, without exclosure of natural psammophyte outside oases, the establishment of sandbreaks composed of trees just at the oasis periphery cannot control sand movement invading the oasis from outside. This is why tree sandbreaks are often in decline and wither due to ecological deterioration at the oasis periphery. At same time, these cultivated mesophyte trees and shrubs cannot regenerate themselves and they normally occupy arable land or potentially arable land. These sandbreak varieties can be regenerated only through an artificial approach. However, the natural shrubs and small bushes on fixed sand dunes and sandy lands at the oasis periphery and inside oases are relatively stable and regenerate themselves due to long-term suitability of the local environment. Consequently, enclosure of sand land for grass growing and the protection of natural vegetation are the basic measures to control sand invasion and desertification spread in oases.

Several principles have been established:

Principle 1: *The enclosure of sand can promote the regeneration of natural vegetation*. Beside individual sections, the most parts of desert, eroded land and gobi adjoining oases are occupied by sand dunes and small undulating sand sheets overlying the clay desert. Small size, wide inter-dune areas and thin aeolian sand cover on smooth sandy land characterize these dunes or sand sheets. The soil composition underlying inter-dune areas and aeolian sands is thick and the underground water table is usually 2-3 metres or maximum depth is 6-7 metres. If necessary, some drainage water from farmland can be used to irrigate these inter-dune areas for planting trees and shrubs. Therefore, the ecological conditions of sand dunes, gentle sandy lands, eroded land and gobi around the oasis or inside the oasis are advantageous to restoration and regeneration of natural vegetation. In the sections with residuals of natural vegetation, an appropriate enclosure system is needed and natural vegetation can be multiplied when unwise collection of firewood and medicinal herbs and deforestation is stopped and when unlimited grazing is controlled.

Principle 2: *Variation of enclosed vegetation is determined by habitat.* In many regions, most of the enclosed sand mounds are vegetated with *Tamarix ramosissima* Ledeb., *T. laxa* Willd*, T. taklamakanensis* M.T. Liu, *Nitraria tangutorum* Bobr*., N. roborowskii* Kom.. In the inter-dune areas or on gentle sandy land, the following varieties are observed: *Glycyrrhizauralensis* Fisch., *Glycyrrhizauralensis inflata* R. Br*., Alhagi sparsifolia* Shap. ex Kell. et shap*., Sophora alopecuroides* L.*, Thermopsis schischkinii* Czefr., *Artemisia ordosica* Krasch., *A.arenaria* DC., *Karclinia caspica* Lass*, Psammochloa villosa* Bor., *Inula salsoloides(*Turez.)Ostenf., *Suaeda glauca* Bge*., Achnatherum splendens*(Tvin.) Nevski, *Phragmites australis*(Cav) Trin. Exsteudel*, Salsola spp., Calligonum spp., Reaumuria soongorica* (Pall.) Maxim*., Salsola paserina* Bge., *Kalidium foliatum* Pall. Moq.,and other small bushes.

Principle 3: *Enclosure can reduce wind threats*. Observation shows that, in a comparison of fixed, semi-fixed and mobile dunes and exposed eroded land, when the enclosure of sand for grass growing was conducted wind velocity 2 metres above ground will be reduced by 50%. At the western side of the Minqin Oasis in Western Gansu, annual drift sands in low hollows of mobile barchan chains is 14 m^3/m, but the annual sand transport through enclosed sand areas is 0.7 m^3/m representing one twentieth of mobile barchan chains. Furthermore, these enclosed sands are covered by *Nitraria spp.* and *Tamarix spp.* and accumulate drift sands around sand mounds and stop sand invasion. At the outside-periphery of enclosed sand areas, the average annual drift sand transport is 11 m^3/m. But inside the vegetated belt with coverage of 60% and 300 metres away from the leeward side, drift sand transport is only 0.5 m^3/m covering one twenty-second of mobile barchan chains. One *Tamarix* sand-mound at a height of 5 metres and a diameter of 4.5 metres can stabilize and control 2,500 m^3 of aeolian sands. One sand-mound covered by *Nitraria spp.,* at a height of 2 metres and a diameter of 10 metres, can fix 2,300 m^3 of shifting sands. In the undulating gentle sand enclosure area with 70% of vegetation, it is estimated that 1.05-2.25 million m^3 of shifting sands can be stabilized and controlled per km^2.

It is thus evident that when natural vegetation inside oases or in enclosed sand areas was restored, shifting sands accumulated and stabilized. Even if the vegetative coverage is insufficient, sand drifts or locally occurring shifting sands can be blocked by psammophytes on the downwind side, and in addition, wind velocity close to the ground was obviously reduced and the invasion by remnant sands into oases and sandbreaks will be very limited. Therefore, all oases, from the Ulan Buh Desert and Tengger Desert in the east to the Taklimakan Desert and Gurban Tonggut Desert in the west, surrounded by large windbreaks and sandbreaks connected with sand enclosure belts just behind, can be well protected from shifting sands and invasion by mobile dunes. Also the phenomenon of sand accumulation around sandbreaks, woodlots and dense plant communities at an oasis periphery is rarely observed.

Oases under protection of sandbreaks, windbreaks, large shelterbelts and sand enclosures for growing grass were basically free of attack by sand drifts on the May 5th 1993 sand-dust storm (*see Chapter 3*). There are 400 km^2 of *Tamarix spp.* sand mounds in the north of Huahai Oasis, Yumen of western Gansu. These vegetated sand mounds are well protected; coverage is 40-50% and humus on surface is normally 10 cm thick and they were free of threats of the black sandstorm on May 5th 1993. This sandstorm brought about severe damage to the gorge and newly reclaimed areas where the biological protective system was insufficient, along the Hexi Corridor of Gansu, in Alxa Prefecture in Inner Mongolia and some parts of the Ningxia Plain. Taking Jintai-Gulang newly cultivated area of Gansu as an example, during the conversion to cultivation natural vegetation on fixed and semi-fixed dunes at the northern fringe of the Tengger Desert and inside the oases were over-grazed and cut and some vegetated sand mounds were opened up and as consequence, farmlands and irrigation canals near the sand source were all buried by shifting sands during the May 5th 1993 sandstorm. Topsoil of newly ploughed land was deflated and eroded. Mean erosion depth was 10 cm and seeds and crop tender seedlings were blown away. The estimated sand transport was 1,000 m^3 per ha. Therefore, for either old oases or newly reclaimed oases, more concern should be paid and maintenance should be given to natural vegetation surrounding or inside oases through strict prohibition of firewood collection and over-grazing.

Principle 4: *Sand enclosures can promote the soil formation process*. On sand enclosure sections, through dust accumulation, withered leaves, secreted matters, moss and lichen mulching, a crust will be gradually formed on sand surfaces and the process of soil formation is promoted. The crust is characterized by some compaction and has a reasonable ability to resist wind erosion. Even if inappropriate grazing breaks some crusts, it can resist wind erosion. In some fixed sand dune areas enclosed for a long time, due to the decline of water moisture, plant communities will probably be degraded, but there will be some survival of forbs[19] and grasses that can control the reactivation of fixed dunes.

2.2.3.2. Management and utilization of sand stabilization enclosure area at oasis periphery

Since the early 1950s, 1,300 km^2 of psammophyte vegetation has been revegetated through sand enclosures in the Minqin Oasis. Of which 200 km^2 adjoins the psammophyte belt of the oasis and where the oasis protective system is well established. This is a guarantee that the Minqin Oasis can survive in many black storms, particularly the May 5th sand-dust storm of 1993 (*see Chapter 3*).

[19] Forbs are broad-leafed herbs (non-woody plants with no persistent parts above ground).

According to practical experience in different regions, the following measures can be adopted to manage and utilize sand enclosure areas in old and new oases in Northwest China.

Measure 1: *The design of the width of sand enclosure belts.* Sand sources on the windward side of oases and residuals of psammophyte are the basis in determining the width of enclosure belts. At the initial stage, because of vegetation scarcity and strong sand movement, the width of enclosure belts connecting oases with deserts, eroded land and gobi areas should be 500-1,500 metres. Grazing, collection of firewood and medicinal herbs and forage harvesting should be strictly prohibited in the enclosed belts. The outer fringe of enclosed belts is the transitional zone of sand sources and enclosed belt and should be determined as the secondary enclosure areas. Grazing should be limited and firewood collection should be prohibited to multiply and regenerate the psammophyte. Sand sheets, sandbelts, eroded lands and gobi terraces inside the oasis should be fenced to multiply natural vegetation through efforts of dune stabilization and re-afforestation. This is an effective measure to control sand encroachment and protect farmland and crops from sand accumulation and wind damage.

Measure 2: *Close combination of sand enclosure for grass growing with sandbreaks enhances the effects of the enclosure.* Because of repeated destruction, the psammophyte in the enclosed area is unevenly distributed and a network of dunes is inter-distributed. The less vegetated sand terrain and low-lying inter-dunes are the potential sand sources to attach oases under sandstorms or black storms, even though vegetation has been restored in the enclosed area. For instance, in the Aiding Lake region of the Turpan Oasis of Xinjiang, due to insufficient vegetation, a black storm with wind velocity of 20 m/s swept the region for 30 hours from April 7th 1975. Even if there were farmland shelterbelts, wheat crops 300-400 metres away from the sand enclosure were buried or blown away. Therefore, drainage water from farmland should be appropriately used to irrigate the sand terrain and inter-dune areas inside the sand enclosure for planting biological communities, woodlots and stripe-shaped forest. Dense sandbreaks should be established at the oasis fringe. Oasis protective barriers should consist of enclosed natural vegetation and artificial plantation (*Figure 1*) to control invasion of sandstorms and attack from black windstorms.

Measure 3: *Irrigation is necessary at the initial stage for promoting the restoration of vegetation.* Inside the sand enclosure area, if underground water is deep and not available, 1-2 artificial irrigations of low-lying areas and sandy terrain is necessary at the initial stage for accelerating the recovering of psammophyte. Then irrigation once every year or so should be arranged. This irrigation does not only enable seeding, sprouting, spreading and recovering of the residual sparse natural vegetation, but also defers the decline, degradation and withering of the plant community. In the enclosed area of the Minqin Oasis, after irrigation, the density of naturally seeded *Tamarix spp.* in inter-dune areas was as much as 1,050 stands per ha; tree height was 1.2-1.7 metres and canopy was 1-2 metres. These plant communities intercepted transit wind-sand flows. Under the irrigation condition, tree plantation should be arranged in the inter-dune areas and at the same time, seed growing of the following varieties should be conducted in low terrain, such as *Artemisia campestris, Nitraria tangutorum, Calligonum mongolicum, Hedysarum scoparium* and *Caragana korshinskii,* to increase vegetative coverage.

Measure 4: *Appropriate grazing enables the restoration of vegetation in the enclosed area*. The oasis animal industry is different from desert nomadic grazing and is invariably characterized by neighborhood grazing near the oasis. After several years of enclosure, when natural vegetation is more than 50-60% and sand surfaces are fixed, then appropriate grazing can be arranged. Otherwise, the plant resources in the enclosed area, especially the bush and shrubs, will be destroyed. But the annual forbs and grasses surviving the rainy season will soon dry off and be otherwise wasted year by year. Both domestic and international research shows that the nutrient value of desert psammophyte is higher than many plants in semi-arid steppes and animal products are of higher quality than that in semi-arid and humid zones. Limited grazing in the enclosed area is very important to the development of the oasis animal industry.

Measure 5: *As for* Tamarix spp., Caragana spp. *and* Nitraria spp. *communities, it is necessary to cut branches every 2-3 years for firewood.* The branches of *Tamarix* can be used to make baskets or other hand-made weaves. Reasonable cutting and appropriate grazing can promote the sprouting of bush and shrub communities and avoid a decline in ion vigor and withering. Practice shows that long-term enclosed psammophyte loses vigor and that appropriate utilization can help the plants regenerate. Of course, excavation of medicinal plant root systems must be prohibited or pits must be refilled. This is an essential way to control sand encroachment on steppes.

Measure 6: *Legal and administrative management must be stressed.* The existing institutions should be strengthened and managing agencies and monitoring stations should be established on the basis of state-owned agriculture, fodder and forest farms, or township owned or Community-based Organizations. Local coordination and cooperation should be emphasized. For example, in the Hexi Corridor, Gansu Province, close cooperation amongst 35 state-owned forest farms, 5 desert control stations and 32 psammophyte protection stations at the local level protect in total 2,600 km² of natural psammophyte. The effects of sand enclosures are significant.

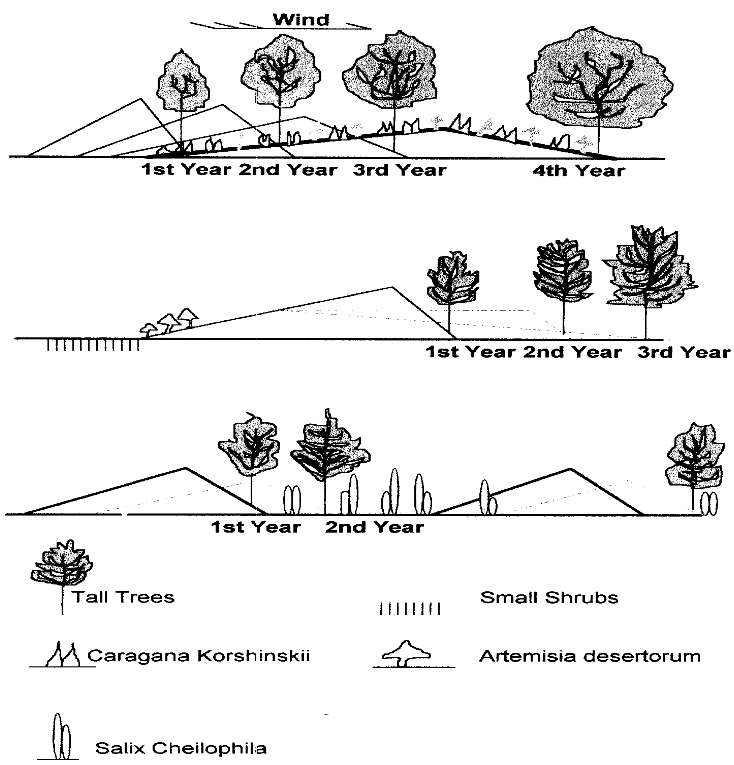


Figure 1: Oasis protective barriers

2.2.3.3. Enclosure cultivation and protection of natural desert plant communities

Plants cover most of gobi-type deserts and in some areas this may be as high as 30-40%. Gobi areas have been invariably used as grazing steppe. Except for appropriate grazing on gobi, all activities related to desert plant destruction during oasis enlargement, settlement construction, road building and mining exploitation should be strictly prohibited for the purpose of protection of gobi steppe. Because of arid climate (annual rainfall is less than 100 mm or even below 40-50 mm in many regions), vegetation in desert regions in Northwest China is sparse and shifting sands occupy vast areas. But the undisturbed gobi ecosystem is in equilibrium. Deserts and oases are mostly separated by vast gobi deserts. Gobi vegetation plays an important role in controlling the occurrence and development of sand-dust storms and black windstorms and to limit the spread of land desertification. Maintenance and protection of gobi xerophyte cannot be neglected while taking care of desert ecology improvement.

Mobile sand dunes and shifting sands occupy 75% of the total area of desert in Northwest China, nevertheless the vegetated area is only 150,000 km². The area of the Taklimakan Sand Desert is 337,600 km² and megadunes cover 85% of its total area, but desert river course forests and *Tamarix taklamakanensis* are widely distributed in river valleys. The total area of the Kumdag Sand Desert and the Baidan Jinlin Sand Desert, the

Tengger Sand Desert and the Ulan Buh Desert on the Alxa plateau is 220,200 km², all of which are occupied by shifting sands and mobile dunes. Around lakes in these deserts, fixed and semi-fixed dunes are densely distributed and are invariably used for grazing animals. The Gurban Tonggut Desert covers an area of 48,800 km² and its climate is similar to the Central Asian deserts. Rainfall in spring and snow in winter are essential and annual precipitation varies from 100-150 mm. *Haloxylon ammodendron, Haloxylon persicum, Artemisia spp.* and other annual plants cover sand dunes and longitudinal dunes. Sand deserts and eroded lands in the Qaidan Basin cover an area of 34,900 km² and desert plants can be found here.

Since historic times, desert vegetation and gobi plants have been more or less disturbed and destroyed by oasis agriculture and nomadic desert grazing, and even some have been partly destroyed and turned into desert or sand land. However, due to less population, inconvenience of transport and distance from any oasis, large areas of desert river course forests, *Haloxylon spp.* forests and *Tamarix spp.* and *Nitraria spp*. sand mounds had remained intact until the end of the 1940s. Since the 1950s, along with widespread agriculture development, mining industry and infrastructure construction and enlargement of urban and rural settlement, many of the larger desert plants were plundered and destroyed while creating new oases and/or enlarging old oases. Limited by lack of ecological awareness, traditional land-use and economic conditions, *Haloxylon* spp. forests in rural regions have also been unfortunately cleared. Some people work on sand control, but others contribute to new enlargement of sand land and land desertification. The rate of gain is not keeping up with the rate of loss.

In order to accelerate the progress of ecological improvement centred on sand control and desertification rehabilitation in Northwest China, administrative means and legal measures should be adopted. Deforestation and firewood collection must be strictly prohibited and wide-scale medicinal herb collection must be stopped. Natural *Haloxylon* forest and desert river course forest must be entirely included in the nature preservation action programme.

3. MANAGEMENT OF *HALOXYLON SPP*. - A CASE STUDY

In deserts, gobi areas in Northwest China and other deserts in Central Asia, *Haloxylon* forests are widely distributed and therefore are termed Haloxylon desert. *Haloxylon ammondendron* can be found from the Kubqi Desert in east to Xinjiang in the west via the Alxa Plateau in Inner Mongolia, the Hexi Corridor in Gansu and the Qaidan Basin of Qinghai. But *Haloxylon persicum* can be found only in Jinghe County, Manas Lake and Qitai County adjacent to the Gurban Tonggut Desert in Xinjiang.

Haloxylon ammondendron is huge shrub or tree with maximum height of 7-8 metres and the diameter of the main trunk is 60-70 cm and can survive more than 50 years. *Haloxylon ammondendron* can grow on clay plains (clay desert), rock deserts (gravel gobi), salt deserts (dried up lake-basin), sand dunes and inter-dune areas. It depends on shallow underground water (1-4 metres). It can also survive in the area where floods flow even if ground water is deep. *Haloxylon persicum* survives usually on mobile dunes and semi-fixed dunes mixed with *Haloxylon ammodendron.*

3.1. Distribution of desert *Haloxylon spp.* forest

According to a survey conducted since the end of the 1950s to the early 1960s, there was a piece of *Haloxylon* spp. forest, covering an area of 3 km² and representing 15% of vegetation coverage, in Daiqinzhao, southwestern fringe of the Kubqi Desert. The height of *Haloxylon* tree averaged 2.5 metres, the diameter was 9 cm and canopy was 2-4 meters.

From the Baiyin Gobi of Ulate Qianqi of Baiyan Nor Prefecture of Inner Mongolia to the Baiyun Chahan Desert, the Haili Desert and the Bokedi Desert along the China-Mongolia border, an extended *Haloxylon spp.* forest, stretching 200 km long from east to west and 5-10 km wide from south to north, covered an area of 1,700 km² (only 833 km² remains, as indicated by survey in 1974). As a consequence of long-term firewood collection and over-grazing, this *Haloxylon* spp. forest was disturbed and antelope and the wild donkey population gradually disappeared. Among the total, the Baiyun Chahan Desert *Haloxylon spp.* forest grows in dried-up lakes where the underground water table was 1-3 metres, density of forest was 600 individuals per ha and tree height was 3 metres and canopy was 3.5 metres. Bokedi Desert *Haloxylon spp.* forest grows on dried up lakes, eroded terrain and mobile dunes where the underground water table was 1-3 metres and density of forest was high. Haili Desert *Haloxylon spp.* forest grown on mobile dune at the desert fringe, dried up lakes, dried river course and eroded sandy gullies where the underground water table was 1-4 metres, density was 200-250 individual per ha and tree height was 1.5 metres and canopy was 2 metres. Sparsely distributed *Haloxylon* spp. growing on gravel gobi desert had a low density and tree height was lower than 1 metre.

The total area of *Haloxylon* spp. forest in Alxa, western Inner Mongolia is 7,000 km². Among the total, *Haloxylon* spp. forest around Jilantai Salt Lake at the southwestern part of the Ulan Buh Desert covers 2,270 km² representing 22% of the total area of the Ulan Buh Desert. *Haloxylon* spp. grows well on dunes lower than 10 metres. In the Zaketu District of the eastern Tengger Desert and Shitou haizi District of the western Tengger Desert, the underground water table among the inter-dune area was 1 metre and *Haloxylon* tree density was 390 individuals per ha and tree height was 1-3 metres, but the naturally seeded and regenerated density was 75 individuals per ha.

Haloxylon spp. are widely distributed on the vast area in the western part of the Bokedi Desert, the eastern side of the Baidan Jilin Desert, the northern part of the Yamaleike Desert and the southern region of the China-Mongolia border. Among the total area, three patches of *Haloxylon spp.* forests along the Suhongtu, Har Oribugay and Shugui Lake cover an area of 3,046 km² with a density of 30-90 individual per ha. These sparse *Haloxylon spp.* trees are mostly growing on the fringes of mobile dunes and around lakes where underground water is deeper. The *Haloxylon spp.* forest in Ejinna County, western Inner Mongolia covers an area of 2,000 km², of which the *Haloxylon spp.* belt in Guaizi Lake stretches 125 km long from east to west and 6 km wide from south to north, totally occupying 380 km². *Haloxylon spp.* forest in Gurinai Lake stretches 180 km long from south to north and 10 km wide from east to west covering an area of 1,330 km². The interspersed *Haloxylon spp.* forests around Sogo Nor, in the eastern part of the Mazong Mts. and on the gobi area on the western part of the Ruoshui River covers an area more than 330 km².

Haloxylon spp. forests are also interspersed in Yongchang County, Anxi County, Dunhuang County and Akese Khazak Autonomous County of the Hexi corridor of Western Gansu. There are also *Haloxylon* spp. forests in the Qaidam Basin and the inter-basin area of Tarding and Mangya. *Haloxylon* spp. forests mostly grow on salinized soil, gravel gobi and sand-gravel gobi. The *Haloxylon* spp. forest on salinized land along the northern foothills of the Nuomuhong Farm stretches 130-150 km long and 3-4 km wide covering an area of 330 km². *Haloxylon* spp. forests are found along Akesu in the north of the Taklimakan Desert and the southern part of the Kumtag Desert, on sand-gravel Gobi in the eastern part of the Hami Basin, on Gashun Gobi, on Nuofan Gobi and the central Gobi.

Junngar Basin in Xinjiang is the area with the most *Haloxylon spp.* forests in China. In the 1950s, there were 70,000 km² of *Haloxylon spp.*forests growing usually on mobile dunes, inter-dune areas, clay desert, sand-gravel gobi and dried up lakes where underground water was shallow. *Haloxylon persicum* was growing on mobile dunes and semi-fixed dunes where underground water was deeper and associated with *Haloxylon ammondendron*. *Haloxylon persicum* is mainly distributed in the Gurban Tonggut Desert and in the sand area of the eastern part of the Aybi Lake. There is some sparse growth of the species on dunes along the Ulungu River and the Erqisi River and this piece of forest is well preserved due to its remote location, but acreage is limited. *Haloxylon spp.* forest in Ganjia Lake is well protected covering an area of 533 km² and is enclosed as a nature preservation. The protected area was extended to 900 km². *Haloxylon ammondendron* and *Haloxylon persicum* are mixed and inter-planted with a mixture forest of *Populus euphratica* and *Tamarix spp*.

Another well preserved *Haloxylon spp.* forest is located on the western side of the Gurban Tonggut Desert, the northeastern part of the Subugur Desert and the southern part of Dabasong Nor, namely the locally termed Harzake (Black Haloxylon) *Haloxylon spp.* forest. This piece of the forest is a maximum of 65 km long from east to west and a maximum of 42 km wide from south to north covering an area of 1,570 km². The *Haloxylon spp.* forest growing on sandy loam and Tykir soil in the central and southeastern parts of the desert produces high biomass (standing crop is about 5-13 tons per ha), but *Haloxylon spp.* forests on the fixed and semi-fixed dunes in the northern, the western and the southern parts have a standing crop of approximately 3-8 tons per ha.

3.2. Management and utilization of desert *Haloxylon* spp. Forests

Destruction of desert *Haloxylon spp.* forest that took place during historic times in China was restricted to natural oases and their adjacent areas. The forests in the less populated interior of desert and rural desert regions, up until the 1950s, were completely preserved with stands of huge and high *Haloxylon* trees. This fact shows that nomadic herdsmen did not bring any problems of deforestation and over-exploitation of firewood. According to a survey during the early 1960s, the preserved *Haloxylon* spp. forest area was 117,000 km², about 10% of the total area of desert and gobi in China.

Along with the development of irrigated agriculture, mining industry and transport infrastructure, particularly during the 1960-70s, all *Haloxylon* spp. forests were cut on a large-scale and at a high rate that that had never happened before. In all areas connected with highway or roads, over-exploitation of the species brought about bald-headed land surface. *Haloxylon* trees were cut without restriction and transported to markets for sale as quality firewood. All sectors in the Junngar Basin, the Qaidam Basin and the Alxa prefecture cut and transported firewood free of charge from the interior of deserts and gobi and the damage was disastrous.

Since the 1950s, agriculture of desert land in Northwest China has gained great achievements and shelterbelts and farmland protective networks have been improved and implemented in recent years. However, *Haloxylon* spp. forests were seriously destroyed while developing agriculture. In the north of the Ulan Buh Desert, large scale agricultural cultivation during the 1960-70s destroyed almost all *Haloxylon* spp. forests at beginning years and *Reamuria soongorica* and *Nitraria tangutorum* and more than 2,000 km² of natural *Haloxylon* spp. forests have been cleared.

It is well known that the Gurban Tonggut Desert is characterized by fixed and semi-fixed dunes vegetated with *Haloxylon spp.* forests and covers an area of 48,800 km². In the 1950s, shifting sands occupied only 3% of the total area of the desert and the controlling area of *Haloxylon spp.* forest was 70,000 km². Later on, under the impact of human disturbances, only 38.6% remained, namely 27,000 km² has survived. Along a 500 km long belt from Mulei in the east to Kuitun in the west at the southern fringes of the Gurban Tonggut Desert, because of agricultural cultivation and crop farming expansion, fixed dunes were reactivated, sand sheets appeared and invaded into newly cultivated oasis, farmland and traffic lines were disrupted and sandstorms frequently occurred. Taking Mosuowan as an example, since 1958, 47,000 ha of wasteland was converted into a new cultivated oasis and it became an important base of cereal and cotton production. There was no shifting sand or dunes in that area densely vegetated by *Haloxylon spp.* forests.

At the initial stage of reclamation and cultivation, people collected *Haloxylon* as firewood on their rented and reclaimed lands and further collection of *Haloxylon* firewood from nearby to some distance far away soon followed. At the same time, overgrazing caused a spread of shifting sands and sheep/goats sheds were moved several times from one place to another. Large-scale opening-up of wasteland and blind cultivation caused abandonment of cereal cropping lands due to a lack of water resources and soil infertility. Abandonment of infertile soil caused further opening-up and wider cultivation (8,000 ha) and such plunder-like exploitation was repeated several times; serious wind erosion and sand movement finally took place. It is estimated that, from 1960-80, about 32,000 ha of *Haloxylon* forests at the southern fringe of Gurban Tonggut Desert were deforested and destroyed. As a consequence, deforestation of *Haloxylon* caused severe sand damage and desert steppe productivity rapidly decreased and the number of sand-dust storms went from 6 times a year in the past to 22 times a year now. On May 21-22nd 1983, a strong sand-dust storm at force 8 (Beaufort scale) lasted for 9 hours. Approximately 16,000 ha of cultivated cropping lands, of which 10,000 ha was cotton, were damaged and 30% of young wheat plants were cut by drift sands. Sand accumulated to a thickness of 6 cm in wheat fields.

Desert *Haloxylon spp.* forest in China is one of plant species that produces high biomass production in desert and Gobi regions. *Haloxylon* cannot only control wind and stabilize sands, but also is of high economic value. Desert *Haloxylon* forest was invariably used for grazing land for camel breeding. *Haloxylon* firewood is quality fuelwood with strong flame-power and less smoke. For this reason, desert *Haloxylon* forests in China were, in comparison with other forests, entirely destroyed. *Haloxylon* is also the parasitic root of *Cistanche deserticold* Maemend, a famous special medicine in Northwest China. The annual production of *Cistanche deserticold* Maemend in Alxa only is 150 tons and is being exported to adjacent countries. The digging and collection of *Cistanche deserticold* Maemend brought about severe destruction of *Haloxylon* forests.

For the past several decades, desert haloxylon forests in China were overexploited and deforested and as a result, the *Cistanche deserticold* Maemend plant has been completely demolished. Effective approaches should be adopted to manage and protect these plants. Legal measures should be developed to control the exploitation and deforestation of desert vegetation. At the same time, appropriate enclosure and rotation grazing systems should be carried out for the purposes of recovering (through natural seeding) the residual *Haloxylon* forests. Young trees and seedlings are vulnerable and they will be browsed and trampled by animals. The National Three North Regions Shelterbelts Development Project has incorporated *Haloxylon* recovery into its Key Natural Vegetation Scheme. The Haili and Ganjia Lake *Haloxylon* forests have been designated as Nature Preservations. However, the following concerns should not be neglected: a) increasing appropriate investment for managing the *Haloxylon* forest; b) strengthening the studies of *Haloxylon* forest to explore regularity of recovery and natural regeneration of *Haloxylon* forest; c) developing nurture and cultivation techniques for enlarging its coverage; and d) working out approaches for grazing management, as well as sustainable programmes for cutting and digging *Cistanche deserticold* Maemend on *Haloxylon* forest lands.

4. MANAGEMENT OF DESERT RIVER COURSE FOREST - A CASE STUDY

Desert river course forests in Northwest China consist of green corridors along inland rivers and become biological barriers to limit desert expansion. These forests are composed of trees and shrubs. *Populus euphratica* covers the major percentage, but there are also some other varieties, such as: *Populus pruinosa* Schrenk, *P. canescens* (Ait.) Smith, *P. alba* L., *P. nigra* L., *P. laurifolia* Ledeb. *and Elaeagnus augustifolia* L. The shrubs include: *Tamarix spp., Nitraria spp.*, *Halimodendron halodedron* (Pall.) Voss., *Lycium ruthenicum* Murr. and others. The forbs and grasses are: *Glycyrrhizauralensis* Fisch. *Alhagi sparsifolia* Shap. ex Kell. et shap. *Sophora alopecuroides* L. *Poacymum* spp. *Phragmites australis* (Cav) Trin. Exsteudel, *Calamagrostis epigeis* (L.) Roth and *Achnatherum splendens* (Tvin.) Nevski. Soil of desert river course forests is of high fertility and rich in moisture enabling trees and shrubs to grow densely. This specific ecological environment suits human social and economic activities. This is why most desert river course forests were developed and cultivated as irrigated oases and a small percentage now remain.

4.1. Distribution of desert river course forests

In old oases in Northwest China, although the self-regeneration ability of desert river course forests is high, the area of forests was in a hopeless situation as a result of long-term deforestation, undue cutting and overgrazing. Now, in the northern part of the Ulan Buh Desert, the Hexi Corridor and the Qaidan Basin, there are only some isolated *Populus euphratica* trees, root-multiplied woodlots and sparse stands of forest. Along the Ruoshui River in Western Inner Mongolia, the Shule River in Western Gansu Province, other rivers in the Tarim Basin and the Junngar Basin, some well preserved desert river course forests can be found. According to rough statistics, the area of desert river course forests in 1958 was 13,000 km² and this declined to 4,857 km² in 1976 (62.6% has been destroyed).

Desert river course forest is found on flooded land and its regeneration process and succession trend is determined by the water regime. Usually, *Populus euphratica* and other *Populus spp.* and other trees and shrubs grow on river-flooded alluvium where the underground water is 1-2 metres down. Where the ground water is deeper, the trees quickly wither and die. As a result of river course changes of the Tarim River in the Taklimakan Desert, the northern and southern river banks upstream of the ancient river valley are up to 120 km wide, the middle reach of the river is 190 km wide and downstream it is 30-40 km wide. All the *Populus euphratica* forests at the dried-up river course withered away or were buried by sands. This means that when the river course was changed or water flow ceased because of storage in reservoirs upstream, the original forest disappeared.

According to dominant variety of river course forest in Northwest China, it can be classified as *Elaeagunus angustifolia* that grows upstream of the Heihe River in the Hexi Corridor and some parts of the Yerqiang River, the Hetian River and the Keriya River. These forests are fixed with *Populus euphratica*., a species that was widely distributed in Northwest China and mainly grows in valleys and oases, particularly along the two sides of rivers in Southern Xinjiang.

4.2. Management and maintenance of desert river course forests

Desert river course forest is a special forest ecosystem that possesses important roles to keep the eco-balance of river alluvial plains and oases, to develop desert farming and animal breeding and traffic infrastructure, and to control the threat of desert spread and sand-dust storms to valleys and oases. Since historical times, farmers and herdsmen in desert regions used river course forests as their living and production bases and developed many large and small oases. However, since the 1950s less importance was attached to these forests and poor management resulted. Because of the human disturbance, many luxurious river course forests were turned into desertified lands due to lack of artificial nurture and regeneration.

In order to protect and enlarge the existing river-course forests, special supervision and monitoring systems should be set up to manage the forests and control deforestation, uncontrolled cutting and inappropriate grazing management. At the same time, in combination with the agricultural development plan, rational allocation of water supplies should be arranged for agricultural, forest and animal production purposes upstream, in the middle- and downstream, reaches of the rivers. A certain amount of water flow should be discharged to river-course forests and other flooded land vegetation at downstream.

These river-course forests should be appropriately enclosed and grazed for the purpose of natural seeding and expansion of its area. Grazing should be carefully regulated both as to the timing and the stocking pressure.

5. PLANTATION OF SANDBREAKS AND WINDBREAKS AROUND OASIS

Since the 1950s, the initiatives for controlling desert and stabilizing dunes in Northwest China have been focused on a combination of sand enclosure and the establishment of large shelterbelts in the transitional zones of oases, deserts, gobi and eroded lands to slow down the invasion of sand encroachment and control sand drifts. At the northern fringe of the Ulan Buh Desert, sandbreaks 175 km long and 30-400 metres to 1-2 km wide have been planted from Ershili Liuzi to Taiyangmiao at the northeastern fringe in the 1950s that cover an area 6,700 ha in total. This green belt effectively stops the eastward invasion of shifting sands and 150 settlements and villages are under the protection of this belt. In Dengkou County, surrounded by sands at three sides, 6,000 ha of sand-buried farmlands were reclaimed into cultivated land under the protection of the sandbreaks.

Along the Hexi Corridor, 1,204-km long large-scale windbreaks and sandbreaks have been planted around artificial oases. These cover an area of 120,000 ha. This length of sandbreaks occupies 70% of the total length of the sand boundaries of the Corridor, which control approximately 200,000 ha of shifting sands and mobile dunes. About 1,400 villages are under prevention from threats and attacks of shifting sands. In the past 10-20 years, more attention was paid to the construction of sandbreaks and windbreaks around oases while planting protective farmland shelterbelts. Practices in Northwest China show that the establishment of sandbreaks and windbreaks around oases is of significant in controlling and weakening the disaster of sandstorms to oases, particularly the black windstorms.

Soil and water conditions enable the growth of trees and shrubs and canopy density will be high enough after 3-5 years of effort. Once the sandbreaks and windbreaks form, mobile dunes and sand drifts at the windward side can be controlled and wind velocity at the leeward side will be reduced for a distance of 20 times the tree height (*Box 2*). In order to control and weaken the calamity of sand-dust storms on oases, the existing sandbreaks and windbreaks at oases should be further strengthened. In the future, the establishment of large sandbreaks and windbreaks should be implemented while developing irrigated agriculture.

Box 2: Some guidelines for establishing sandbreaks and windbreaks

1. The sandbreaks and windbreaks should consist of woodlots, catchment forests and stripe-shaped forests and distributed and dotted one with another. In light of the principle of *"adaptation to local conditions and setting up damage prevention,"* tree and shrub plantation and grass growing should be arranged in the inter-dune areas, eroded lands and terrain near oases. Soil and water conditions in the desert habitat cannot enable the survival of afforestation. In arid oases, pumping water costs too much and therefore artificial revegetation should be conducted within close proximity to irrigated oases.

2. *"From near to far and first easier to harsher second*" is the principle for planting sandbreaks and windbreaks. It means that plantation should be done near oases and then expand its outer edge. In dunes, revegetation should be conducted in the inter-dune areas to push wind-sand in front and pull sand behind (accumulate sands on windward slopes and flatten dunes at the leeward side). Catchment woods should be planted to surround dunes to separate dune chains. Along with sand encroachment and leveling of dunes, trees should be planted at leeward slopes to increase biological barriers. Without mechanical sand barriers, dotted and interspersed forest pieces can also form dense sandbreaks and windbreaks to control sand movement and sand transport.

3. Sandbreaks and windbreaks should consist of interplanting of trees and shrubs. At the outer source of oases, percentage of shrubs and bushes should be increased to form a dense structure for accumulating shifting sands outside the biological belts. These dense belts protect arable lands inside oases and at leeward side from sand encroachment and sandstorm attacks.

The following tree and shrub varieties should be selected as the main species for establishing oasis sandbreaks and windbreaks in Northwest China. Trees include: Eleagunus angustifolia, *Populus simonii* Carr. *P. gansuensis* c. Wang et H.L.Yang*, P. alba L. var. pyramidalis* Bge*, P. nigra L. var. italica* (Muenchm)Kochme*, P. nigra L. var. thevetina* (Dode) Bean*, P. canadensis* Moench*, P. cathayana* Rehd.*, Salix matsudana* Koidz*, S. alba* L.*, Ulmus Pumila* L. Shrubs and bushes include: *Haloxylon ammondendron, Tamarix spp., Hippophae rhamnoides* L., *Caragana korshinskii, and Calligomum spp.*

4. The width of sandbreaks and windbreaks is determined by the status of sand source. The front area of oasis where sand accumulation covers arable land should be used completely to plant biological barriers. The width of biological barriers should be as wide as 800-900 metres or even 1,000 metres, but no less than 200-300 metres. But in the connecting area of sand dunes and oasis where sand dunes are dense parallel to oasis they should be circled to plant trees belts within widths of 50-100 metres. On the fixed dunes adjacent to oasis and sand dunes, tree belts should be planted in a width of 30-50 metres.

In the adjacent zone of oasis and sand source, if land surfaces are fixed dunes, semi-fixed dunes, sandy terrain and eroded lands, sandbreaks and windbreaks should be planted along the edge of oases in a width of 10-20 metres or maximum 30-40 metres, as aeolian sands are insufficient at the oasis edge. In the Turpan Basin, 3-5 rows of tamarix shrubs were planted on the windward side to accumulate the drift sands from Gobi and eroded lands. After longer accumulation of sands, a fixed tamarix sand longitude was formed to protect the tree belts on the leeward side.

5. The establishment of large sandbreaks and windbreaks should be combined with the sand enclosure and fenced grass plantation. Drainage water from croplands should be brought to irrigate natural vegetation on dunes, Gobi and eroded lands. A complex biological barrier composed of multiple layers of trees, shrubs, bushes and grasses should be planted to block and fix sands. The dotted and scattered dunes inside the project site of sandbreaks and windbreaks should be stabilized individually by adoption of botanical measures.

5.1. Dune stabilization in oases

Sand encroachment and dune movements bury oases, canals and settlements and bring about damage to agriculture and animal development. For decades China has practiced different measures of biological barriers, mechanical vertical barricades and chemical approaches for stabilizing sand dunes and drift sands inside or around oases. However, the biological barrier is the fundamental approach and engineering measures are a supplementary approach just for the temporary purpose for *"fixing"* the sand surface.

The functions of biological approaches include:

a) Once the mobile dunes are fixed with artificial vegetation, they can last for longer periods of time. They can progress into natural vegetation in more stable conditions even if the artificial one was degraded.
b) Artificial vegetation can promote the formation of biological crusts and fertilized soil on sandy surfaces. These crusts can mulch sand source and prevent land surfaces from erosion under wind force 8.
c) When the dunes are revegetated, local ecological environment can be improved.
d) These revegetation areas possess the ability of self-regeneration and recovery and they can provide fodder, forage, firewood and even small timbers.
e) Along with the improvement of the ecological environment of the revegetated sand area, some arable fields for cash crops or orchards can be opened and even a few new and small settlements can be created inside the sand revegetation.

Different from megadunes of sand deserts, the mobile dunes at the oasis fringe or inside the oasis are covered by natural vegetation and they are under threats of further desertification due to human disturbances. These dunes can be revegetated and turned into fixed ones when appropriate measures were adopted.

5.2. Re-afforestation to fix sands in the inter-dune areas

The reforestation and biological stabilization of sand dunes was initiated in Northwest China in the 1950s. Artificial catchment forests, small woodlots and individual forest stands were planted in the inter-dune areas and biological plantations isolated sand dunes one by one. This practical approach is acceptable and needs only reasonable financial investment and manpower input. This approach is still in use in dune stabilization inside or outside oases.

Reforestation in the inter-dune or low-lying areas should be conducted in different phases. After the first phase of plantation, every 1-2 years later, some new blowouts will occur and develop at the lower parts of the windward slope due to sand encroachment and dune movement. This is termed *"sand retreat shore."* Then the second or third phases of plantation should be arranged to gradually enlarge the area of plantation and chunk-shaped woodlots and reduce the area of shifting sands. Initially, the plantations and chunk-shaped woodlots are insufficient to block sand encroachment and thus some new dunes may occur inside the plantation. The wind force reduced significantly, wind erosion obviously decreased, the natural grass growing process accelerated and dunes were finally covered by native psammophytes in dunes that are isolated by plantations and chunk-shaped woodlots.

Depth of underground water tables of inter-dune areas or low-lying areas inside or near oases is different. It is 1-3 metres in the wet inter-dune area and appropriate irrigation is needed for first plantation. In the dry inter-dune areas, underground water is a not available and thus drought-resistant shrub and bushes should be planted with necessary irrigation.

Because of favourable soil and water conditions, artificial plantation and re-afforestation in inter-dune areas inside and near oases in Baiyan Gol Prefecture (Great Bay of the Yellow River) of Inner Mongolia were well conducted and the trees survived. *Populus simonii* Carr. and other *Populus* spp., *Salix matsudana* koidz and *Elaeagnus angustifolia* L. are the pioneer varieties and growth rate is high. In the inter-dune areas in the Hexi Corridor of Western Gansu Province, *Populus gansuensis* c. Wang et H.L. Yang and other *Populus spp.* can be planted. In the areas with deep ground water, supplementary irrigation is needed even for the variety of *Eleagunus angustifolia* plantations to avoid further withering. Thus, in the Hexi Corridor and other western regions, it is strongly suggested to plant drought-resistant bushes and shrubs in the inter-dune areas.

5.3. Dune fixation and revegetation

In Northwest China, mobile dunes inside or nearby oases threaten farmlands, irrigation canals and settlements. Without pre-installation of artificial sand-barriers or vertical barricades, the biological plantation on mobile dunes is easily blown away or denuded. Thus, the direct plantation of biological barriers on mobile dunes should be supplemented with artificial barricades.

According to practical experience, in the northern part of the Ulan Buh Desert, the southeastern fringe of the Tennger Desert, the Hexi Corridor of Western Gansu, the mobile dunes inside and nearby oases can be mulched some months in advance by using local materials, such as clay and straw, to fix the sand surface and then biological plantation should be done.

With regard to clay barricades, clay or loam should be taken from inter-dune areas or low-lying areas to pave horizontal ridges on windward slope. The clay ridge is 20-25 cm high, the ridge base is 40 cm and the inter-ridge distance is 1.2-2 metres or even 2-4 metres. This is locally called a parallel clay barricade. On the lower barchan dunes, some small vertical clay ridges should be paved on the top and on two sides while paving parallel clay barricades on the windward slope to prevent them from denudation.

Parallel clay barricades, if necessary, should be supplemented with a pavement of secondary clay barricades (transverse-shaped clay ridge) and distance between secondary barricades is 2-4 metres. If a mobile dune is as high as 7-8 metres, two thirds of the lower windward slope dune should be paved with a parallel clay ridge or a transverse-shaped clay ridge barricade. When the top of a dune is flattened under wind force, parallel clay ridges should be made on the flattened part.

After one wind season, the exposed surface among the clay barricades becomes denuded and blowouts appear. Where the distance between clay barricades is greater, the denudation is deeper. But the maximum depth of denudation does not exceed one tenth of the distance of the small clay ridge. When the surface between clay ridges is denuded, the sand surface will be stable and then biological barriers can be planted in the blowouts.

Clay barricades are easily washed out to form a crust on the sand surface between clay ridges. This crust influences the infiltration of runoff and reduces discharge of water supply to sand soil. At the same time, small runoff on the crust flows down and deflates the slope. This deflation is easily eroded under wind force. Therefore, the clay barricades can last for a longer period of time, but its' ecological effect is much weaker than the artificial straw barriers.

According to the experiences in the Jintai Oasis of the Hexi Corridor, when shifting sands or mobile dunes occur on gobi desert, gravel between dunes can be taken to mulch the sand surface and 10 cm is an appropriate depth.

Straw barriers or hay checkerboards are common measures to control sand encroachment and dune movement in Northwest China (PHOTO x). In The Shapotou district at the southeastern fringe of The Tengger Desert where The Baotou-Lanzhou Railway crosses through, wheat semi-concealed straw barriers have been planted since the end of the 1950s. Afterwards, the measure was widely practiced along railway lines, highways, around oases and near reservoirs to fix shifting sands and mobile dunes.

Wheat straw is abundant hay in any oasis and can be used to mulch sand surfaces with lower investment than any other materials. Wheat straw is pliable hay and can be paved easily on sand surfaces without digging any furrow. Straw is horizontally spread in a shape of interval stripes and thickness is 2-3 cm and width is 40-50 cm. Along the centre of the straw belt, space is used to step down the hay into The sand layer for 10-15 cm and then fill sands behind the straw stands. The straw barrier is 15-20 cm high and 5 cm thick. This parallel short and vertical straw barrier should be vertically planted to the prevailing wind direction on the windward slope of dunes. Supplementary straw barriers should be planted perpendicularly to the main barriers.

Along railways or highways, square-sized straw checkerboards should be planted. On the basis of experience in the Hexi Corridor of Western Gansu, parallel vertical-row straw barriers are an effective design and distance between rows should be 2-3 metres. Either parallel vertical-row straw barrier or straw checkerboards, the erosive depth of sand surface between barriers is one tenth of the distance between barriers. After one wind season erosion, beside the top portion of the windward slope of dunes, the blowouts between barriers will be stable. A straw barrier can usually last for 4-5 years and second replacement must be done if the artificial biological barriers cannot control the shifting sand and dune movement.

In oases of the Qaidan Basin and the Tarim Basin, dried reeds and *Achnatherum spp.* can be collected locally for making the sand barricades. These materials are stiff stuff and a small furrow has to be opened on windward slopes with burying depth 20-30 cm and height above ground 40-50 cm. Distance between parallel barriers is 2-

4 metres and transverse barriers is 2-3 or 3-4 metres. After the vertical barriers are planted in summer or autumn of the previous year, biological plantation can be completed in the spring of the next year. Native plants are the priority selection of varieties for stabilizing sands. Exotic species can be adopted only after several years' introduction.

On sand dunes inside or nearby oases in the northern part of the Ulan Buh Desert, the Great Bay area of the Yellow River and the Hexi Corridor, under the protection of clay and straw barriers, some varieties can be planted as biological barriers, such as *Haloxylon persicum*, *Tamarix laxa* Willd*, Hedysarum scoparium, Caragana korshinskii, Calligonum arboresens, Calligonum caput-medusae, Calligonum mongolicum* and other shrubs. Distance between individuals is 1 metre and row distance is determined by distance between barriers, usually 2-4 metres. Root systems should be buried into the wet sand layer and must be watered with 1-2 kg of water while planting the aforementioned species. By doing so, the survival rate can reach 70-80% and the space between individuals will be densely closed after 3-4 years' efforts and then sand dunes can be biologically stabilized.

It should be pointed out that a large area of *Haloxylon ammondendron* has been planted since the 1960s on mobile dunes, combined with clay barriers, in the western part of the Minqin Oasis. During the first 7-8 years, these plants grew luxuriously. However, they were withered and dying later on. By investigating causes, the following three conclusions have been summarized.

a) Shallow ground water was excessively exploited during oasis development and the underground water table declined from 2-3 metres in the 1950s to 8-9 meters in the 1990s. Underground water was not available to the growth of *Haloxylon ammondendron*.
b) The water-holding capacity of sand layers of mobile dunes was 2-3% and gradually declined to 1% because dense root systems and moisture were insufficient to the survival of the plants.
c) Annual precipitation here is only 100 mm and water discharge to sand layers was consumed by *Haloxylon ammondendron*. Meanwhile, the crust formed after clay barriers on the dune surface affected infiltration and runoff and water discharge to sand layers was limited. Therefore, in areas with deep underground water inside or near to an oasis in Northwest China, supplementary irrigation to inter-dune areas must be arranged once *Haloxylon ammondendron, Tamarix* spp. and other shrubs have been planted.

In the Turpan Basin and the oases at the southern and western fringes of the Taklimakan Desert, annual precipitation is only 30 mm. Biological plantation on megadunes is impossible. Appropriate irrigation is necessary to artificial plantation in low-lying areas or inter-dune areas. Under the protection of reed barriers, the following species can be planted to control shifting sands: *Calligonum klementzii, Calligonum arboresens, Calligonum caput-medusae, Calligonum leucocladum, Calligonum rubicundum,* and *Tamarix ramosissima.*

6. REGULATION OF AGRICULTURAL STRUCTURE AND REFORMATION OF CULTIVATION SYSTEMS

6.1. Change the traditional cultivation mode of extensive seeding and low yield harvesting and manage fundamental arable land

When land unsuitable to dryland farming is abandoned, grass growing and tree plantation should be well arranged and those pieces of land with better moisture and soil fertility should be chosen for self-sufficient crop cultivation. In the traditional practice of dryland farming, bio-climatic conditions and characteristics of crops were taken into account, but the soil composition was neglected. In future land classification and capability assessment, topsoil should be considered as an important criterion for cultivating dry farming.

6.2. Adopt mulching approach in winter and spring seasons to reduce surface exposure to wind

Agricultural approaches should be adopted to prevent land from wind erosion. According to the characteristics of strong wind force and frequency of sand-dust storms in Northern China, preserving crop-stubble, inter-cropping, inter-planting and minimum tillage systems should be initiated to reduce the exposure period of farmland.

6.3. Develop modern agriculture with advanced technology

Solar energy plastic sheds and greenhouses should be installed. Plastic mulching should be introduced to save water, prevent topsoil from erosion and sterilize soil.

6.4. Establishment of protective farmland shelterbelts networks

As one component of oases protective systems, farmland protective shelterbelts cannot only control wind denudation and sand drifts of sandy arable land and reduce sandstorm damage on farmland, but must also improve the microclimate of farmland. Meanwhile, protective farmland shelterbelts can play a role of biological drainage in salinized oases. Therefore, since the 1950s, the establishment of oasis protective farmland shelterbelts in Northwest China was adopted as one of basic measures enabling stable and high agricultural production. Through decades of efforts, old oases were basically protected under tree networks, but deficiency is still common issue in many regions. Protective farmland shelterbelts are under construction. Taking the Hexi Corridor as an example, the total area of tree networks of various sized oases is 50,000 ha and 320,000 farmlands are under the protection of tree networks that cover 63.3% of the total effective irrigated lands and 77.3% of the planned irrigated areas of farmland. There is still a great amount of arable land and newly expanded cropping fields that are exposed without shelterbelt protection.

The interaction of transverse systems of farmland protective shelterbelts effectively reduces wind velocity and sandstorm damage. In an open field with strong winds of 17 m/s, approximately 37.3% of wind velocity is reduced by the first tree network on the windward side of an oasis, about 39.1% by the second tree network and nearly 42% by the third tree network. Precisely because of this, according to investigations of the May 5th 1993 black windstorm conducted by the Gansu Desert Control Research Institute, erosion depth of sandy farmland inside protective shelterbelts in the Minqin Oasis was 0.1 cm, damaged melon seedlings were 5% and destroyed plastic mulching of melon fields were 1%. By contrast, erosion depth of sandy farmlands without protective shelterbelts nearby was 5 cm, damaged melon seedling was 35% and destroyed plastic mulching of melon fields was 40%. The most serious impacts of the black windstorm on agriculture took place on newly opened arable land and newly developed oases that were without protection of shelterbelts. All the damage on agriculture caused by sandstorms in history in Northwest China is closely related to the performance of tree networks. For instance, in the Turpan Basin that is termed *"Wind Gorge"* or *"Flame Oasis,"* strong winds prevail and sandstorms are frequent.

The whole oasis system is suffering from sand attacks from open eroded lands, vast gobi areas and 20,000 ha of mobile dunes. Cultivated soil is mainly composed of sandy loam and erosion is severe. In May 1961, a serious sandstorm occurred in the Turpan Basin. It was estimated that 85% of cropping lands in oases was damaged, the unit yield of wheat was only 60-75 kg/ha, 3,300 ha of cotton land was totally destroyed (no harvest) and 127 underground canals were buried under shifting sands. After this disaster, serious measures were adopted, including constructing the sand enclosure belts, sandbreaks and windbreaks and protective farmland shelterbelts. These biological plantations have turned the habitat of sand deserts into cultivated land with high yields. Now, even if black windstorms occur, all oases are safe and sound.

At present, we are not able to control the occurrence and development of black windstorms, nor can any one else in the world. However, we can in light of our experience in designing sandbreaks and windbreaks, emphasize our aim directly at the establishment of protective farmland shelterbelts in old and new oases to control and reduce the threats and damage of sand-dust storm to farmlands and oases.

The establishment of protective farmland shelterbelt systems in Northwest China can be summarized in the following points:

A. Ventilation structure and penetration structure are the best effects of protective farmland shelterbelts

According to the difference of wind penetration, shelterbelts can be classified into three main types: a) compaction (closure) structure shelterbelts; b) penetration structure shelterbelts; c) and ventilation structure shelterbelts. Besides these, there are some sub-types like transitional structure shelterbelts, where the canopy is closed and the trunk part is ventilated, or where the canopy is ventilated and the lower part is closed.

The compaction structure shelterbelts refer to the biological belts that are composed of dense branches and leaves that are basically non-ventilated. The canopy and trunk parts of belts are closed and composed of complex vertical belts (three biological layers) of trees, sub-trees and shrubs. Air currents will not be able to cross the closed belts and can cross over the top canopy of belts while a non-wind zone is formed behind. The effective protective distance of shelterbelts is less than 40 times the height of shelterbelts.

The penetration structure shelterbelts are characterized by distance and penetration conditions of shelterbelts. The penetration of whole shelterbelts is well distributed when consisting of 1-2 rows of narrow canopy trees. Air currents cross partially over the top of shelterbelts and partially cross through the shelterbelts. The effective protective distance is 40-45 times of the height of shelterbelts.

The ventilation structure shelterbelts are characterized by an upper dense canopy and negative penetration. The trunk (lower) part of shelterbelts is ventilated. These shelterbelts consist of 3-5 rows of high trees only and effective protective distance is 50 times the height of shelterbelts.

In order to promote the anti-wind function of shelterbelts, ventilation structure and penetration structure narrow shelterbelts are the best selections. However, it does not matter what kind of structure shelterbelt it is, for at a distance 15 times the height of tree belts, wind velocity behind the belts will be reduced 40-50% and at a distance 20 times the height of tree belts, wind velocity behind tree belts will be weakened by 20%. Moreover, wind season in Northwest China starts from February-May and during this period, even if the shelterbelts are densely structured ones, they are easily penetrated because of the dormancy and the leaflessness of the shelterbelts.

B. Design of protective farmland shelterbelts

Regarding establishment of protective farmland shelterbelts, it should be combined with the construction of stripe-shaped farmlands (strip-cropping) and square-shaped fields. An integrated plan of water, land and shelterbelts should implemented and square-shaped farmlands, irrigation canals, roads and shelterbelts should be integrated. When the shelterbelts are grown up, because of lateral seepage of irrigation water and shallow ground water, no more irrigation is usually needed.

C. Optimum function of narrow belts and small networks for preventing farmland from erosion

Regarding shelterbelt arrangement, in consideration to wind frequency and intensity of occurrence and development of sand-dust storms in Northwest China, narrow tree belts and small networks are the best choice. Generally speaking, the space between key tree belts (inter-belt distance) is 200-300 metres and that of secondary belts is 500-600 metres, namely the size of each block of farmland inside the shelterbelt network is 10-17 ha. On sandy soil, the inter-belt distance can be 150-200 metres while that of secondary belts is 400-500 metres and acreage of each networked strip-shaped farmland is 6-10 ha. Narrow tree belts consist of 2-3 rows of trees or a maximum of 5 rows.

D. Fast growth trees for networking farmland shelterbelt belts

In oases, soil and water conditions are favourable to the plantation of fast-growth tree networks. Shelterbelts in newly cultivated farmland areas in the northern part of the Ulan Buh Desert and in the irrigated areas of the

Great bay of the Yellow River consist of *Salix matsudana, Populus canadensis, Populus simonii, Populus nigra* L. *var. italica, Populus alba, Populus nigra* L. *var. Thevetina.* A variety of shelterbelts in irrigated areas at the southeastern edge of the Tengger Desert is *Populus nigra* L. *var. Thevetina.* The species of shelterbelts in the Hexi Corridor are *Populus gansuensis, Populus alba.* In the Qaidan Basin, tree species of shelterbelts are mainly *Populus cathayana.* In all oases and newly cultivated areas of Xinjiang, varieties of tree shelterbelts include *Populus alba, Populus nigra* L. *var. italica, Salix alba* L. and others.

E. Coverage of protective farmland shelterbelts

Including all sandbreaks, windbreaks, timber forests, cash forests and settlement plantation inside oases, the total coverage is estimated at about 10-15%. Because of lateral water seepage, the tree belts along the two sides of the canal grow fast and can be 4-5 metres after 3-5 years' growth. These canal tree belts play an obvious function in controlling wind. Plantation along canals and roads does not only save arable land, but also plays a role of biological drainage and controls the salinization processes along the two sides of road.

7. UTILIZING APPROPRIATE FARMING TECHNIQUES TO CONTROL WIND EROSION AND SAND DENUDATION

All oases in Northwest China, before the establishment of protective shelterbelt systems (natural psammophyte gardens, sandbreaks, windbreaks, farmland protective shelterbelts) – particularly the new oases – will experience a process of wasteland reclamation and a process of sand stabilization. During these processes, appropriate utilization of agricultural cultivation techniques can also control and weaken the damage of drifting sands, sandstorms and black windstorms. On the bases of local practices and position-station studies of the Institute of Desert Research, Chinese Academy of Sciences, the following three points are acceptable agricultural techniques.

7.1. Cease further opening-up at the transitional belt of desert

Threatened by severe sand-dust storms, in the newly cultivated sandy arable lands in the Jintai and Gulang Counties of Gansu Province, the depth of erosion was 10 cm and in some sections, the plough bottom exposed following erosion. It is calculated on the basis of an average 10-cm erosion depth, that erosion intensity was 1,000 m^3/ha (*see Chapter 3*). This wind erosion did not only blow away seeds and young seedlings, but fine sand accumulation also buried field ridges, canals, newly planted tree stands and crop fields and caused significant damage to local people and their productive activities. On the newly opened sandy land in the Tangxi District of Qingtongxia City of Ningxia, wind erosion depth of the black windstorm of May 1993 was 10-20 cm. It can be seen that without biological protection, opening-up of wasteland and steppe will bring about not only land surface erosion and seed and seedling damage, but also serious aeolian sand accumulation of the adjacent cropping fields and irrigation canals.

7.2. Turn over and transform sandy soil for strengthening resistance against erosion

The northern part of the Ulan Buh Desert is the alluvial plain of the Yellow River and the depth of clay and clay loam is 1 metre. There is a wide distribution of low sand mounds, bush communities and dotted sand sheets on this clay alluvial terrain. Yellow River water is pumped for flood irrigation here. Since the new cultivation and opening-up in the 1960s, almost half of the clay plain (bare terrain) and wasteland covered by thin sand mulch on the surface have been turned into arable lands.

The practice of cultivation in the north of the Ulan Buh Desert shows that if the clay or clay loam underlying the thin sand-covered wastelands cannot be ploughed and turned over to mix with sands on the surface, then erosion will be severe once a sandstorm occurs. Damage rates of seeds and seedlings under such erosion threats will be as high as 80-90%. When ploughing bush-covered sand mounds, the surface mulch of sand is 30-40 cm thick and a 50-cm thick topsoil should be ploughed and turned over to ensure that the mixing of the clay/clay loams with surface sands. This ploughing is aimed in transforming sandy soil and increases the anti-erosion ability of cultivated soil. It is observed that the effect is sound.

7.3. Rational selection of varieties and inter cropping system

The damage of the black windstorm is manifested by wind erosion and sand severance. Taking the Hexi Corridor as an example, the tree-networked farmlands were protected under densely grown-up winter wheat when the black windstorm occurred and damage caused by the sandstorm was slight. However, on the sparsely networked farmlands, particularly on the open and newly cultivated sand farmlands without tree networks, all cash crops, such as seed melon, watermelon, beets and cotton were completely severed and blown away. In Zhangye prefecture of Gansu Province, the total damaged area of melons, vegetables, soybean, cotton, capsicum, oil-crops and other cash crops was as much as 30,000 ha. In the Minqin Oasis, 10,000 ha of seed melon, cotton and fennel were damaged.

Practice shows that, due to the differences in density, individual shape, stem and leaf strength, regenerative ability and habit, each crop has a different ability to resist erosion and sand blasting. Strong wind is frequent in April-May in Northwest China and also sandstorms occur during this season. Cotton and melon crops are just at the sprouting time in this season and are impossible to regenerate if damaged and severed by sand drifts at this stage. Because of early sowing and dense seedlings covering the land surface, wheat can resist wind erosion. Even though sand drifts severed wheat seedlings, they can quickly recover vitality under irrigation and the death rate is lower. Therefore, sandy arable lands should be used to grow wheat. Even under the protection of tree networks, cotton and melon are unsuitable varieties to grow. If farmers insist in growing the mentioned cash crops, it is suggested that these cash crops should be intercropped with wheat in a strip-cropping arrangement to reduce the area of wind erosion.

8. REVEGETATION OF SAND SOURCE AREAS IN THE NORTH OF THE LOESS PLATEAU

The wind-sand-affected region in the north of the Loess Plateau is situated in the eastern part of the Helan Mts. at the middle reaches of the Yellow River. Annual precipitation in the central and eastern parts of the affected region varies from 250-400 mm and belongs to steppe area. The western part of the affected region belongs to semi-desert (desert steppe) and annual rainfall varies from 150-250 mm. The total land area of the affected region is 206,855.1 km², of which desertification-prone lands are comprised of landforms of shifting sands, semi-fixed and fixed dunes and cover an area of 117,962.2 km² representing 57% of the total land area of the affected region. The Kubqi Desert, the Mu Us Sandy Land and the Sand Lands on the East Terrain of the Yellow River in Ningxia are located in the affected region covering an area of 57,891.1 km², of which shifting sands, semi-fixed dunes and fixed dunes total 47,358.7 km² covering 81.8% of the total area of the three deserts and sandy lands.

This affected region is one of the most severely damaged areas where wind is strong and sandstorms are frequent in the semi-grazing zones in Northern China. Since the 1950s, re-afforestation and artificial plantation, sand enclosures, fundamental farmland construction and steppe and rangeland improvement were initiated as the main targets of the national desert control plan in the region. Initial achievements have been gained. Now, the fourth phase of the *"Three North Regions' Shelterbelts Protective System"* is under implementation in this region and annual progress is averaging 100,000 ha.

In wind-sand affected regions in the north of the Loess Plateau, sand sources are abundant, strong winds prevail from November-April/May and human disturbances are active. The phenomenon of coexistence of rehabilitation and destruction can be found everywhere. As a consequence, windstorms, particularly strong sand-dust storms, brought about severe damage to agriculture and industry in the affected regions. In order to control sandstorms and slow down wind-sand impacts, agricultural development orientation must be readjusted and land resources should be rationally utilized while implementing the programmes to combat desertification and the project to control land degradation.

8.1. Techniques for controlling wind erosion in dryland farming areas

From the 1950-70s, in the eastern part of the Kubqi Desert and the northeastern part of the Mu Us Sandy Land, historical lessons were neglected and three large-scale conversions of wasteland were launched without consideration to existing physical conditions. As a consequence, *"harvest benefits in the first year, erosion harms in the second year, and sands move in the third year."* At the same time, revegetated dunes were cultivated, over-grazing and uncontrolled cutting of firewood increased and the desertification process rapidly accelerated during that period of time.

During the recent two decades, overexploitation of wastelands, over-grazing and deforestation were basically under control. However, traditional dryland farming practices of *"shallow cultivation and extensive management"* and *"rainfed cropping on hand sowing and zero fertilization"* are still popular. These practices do not only result in serious damage to drylands and yield of cereal less than 50 kg/ha, but also bring about destruction of the steppe.

The cultivated area in the Kubqi Desert, Mu Us Sandy Land and Sand Lands in the eastern part of the Yellow River in Ningxia has been reduced from former the 670,000-1,300,000 to the present 340,000 ha. Annually, the impacted dryland under wind-sand damage is 134,000 ha. Therefore, the cycle of ploughing followed by abandonment of dryland farming should be further limited (*see below*). Collection of runoff water (water harvesting) should be encouraged to enable stable and high yield farmland.

8.2. Dryland types under wind erosion

1) *Rotation abandonment terrain land*. All the dryland opened from fixed and semi-fixed dunes for rotation cultivation is called rotation terrain land. Recently, low terrain lands and gentle dunes were opened up for sowing cereals without fertilization. After 1-2 or maximum 3 years' cultivation with production of 300-450 kg/ha, these opened up lands were abandoned. Wind erosion of the abandoned dryland is most severe and damage rates of seeds and young seedlings are high. Each abandonment will cause an entire loss of topsoil. Denuded breakthroughs and blowouts and even shifting sands are popular on the land surface.

2) *Secondary sand land*. It is located mostly on hard ridge land covered by sands, sandy soil and sandy loam. This land was used to grow millet and other cereals without fertilization and unit yield was only 450-600 kg/ha. Soil erosion is serious on this kind of land and it is steady cropping field. However, sometimes it was abandoned to allow natural recovery of its fertility through self-restoration of grasses. There are vast distributions of secondary sand lands in the Lingwu and Yanchi Counties of Ningxia and from March-April, sand ripples and desert landforms are the main surface manifestation of this type of land.

3) *Dried beach and plain sand terrain*. It refers to light chestnut soil of sandy meadowland with deeper underground water. Topsoil was almost exhausted and the seeding layer was filled with sands. This is basically dryland for rainfed farming of millets, potato, sunflower and beans and unit yield was only 600-750 kg/ha. Erosion is relatively slight and land is usually not abandoned.

4) *Lime tubercle dryland*. It is hard ridge land with yellowish sandy soil. Through years of ploughing, the primitive soil layer was almost or partially blown away. The land surface and sowing layer is filled with lime tubercles. It is used to grow millets and other cereals with or without fertilization and unit yield is 450-600 kg/ha. The residuals of lime tubercles on the land surface restrain erosion. However, ploughing in spring every year causes wind erosion and transport of fine soil. It is steady dryland for rainfed farming. Sometimes, abandonment is practiced to restore fertility.

5) *Sand gravel dryland*. It belongs to a hard land type. Through years of cereal cultivation and wind erosion, huge amounts of gravel and pebbles were left on the land surface and on the B-horizon. It is steady dryland for rainfed farming and sometimes abandoned. It is used for growing cereal crops with or without fertilization and unit yield is normally 450-600 kg/ha. Residuals of gravel and pebbles on the land surface prevent it from wind erosion.

9. TECHNIQUES FOR CONTROLLING WIND EROSION ON RAINFED FARMLAND

In order to control the occurrence of sandstorms, to slow down development of desertification and reduce sand damage on agriculture, rotation dryland farming abandonment system should be completely stopped. The scale of rotation abandonment for dryfarming should be reduced and anti-wind erosion approaches should be adopted.

9.1. Crop residues

Millet and other cereals should be horizontally grown against the dominant wind direction and at least 10-20 cm high crop residues (stubbles) should remain in the field to protect the soil from exposure and erosion in winter and spring seasons. These crop residues have to be kept until the sowing in May. Research shows that if the roughness of the land surface was increased by three times and wind velocity near ground level was weakened by 50%. In the windy season, topsoil erosion in the exposed land surface was estimated as high as 63,450 kg/ha. By contrast, fields with crop residues have accumulated 3,745 kg/ha of fine sands and dust silts. Aeolian fine sands and dust silts are organic matters and are locally termed *"fertile sands."* Villagers say the *"crop residues keep manure and shorten restore time limit."* It is clear that the crop residuals on erosive drylands play an effective role in controlling and weakening wind erosion. But unfortunately, because of cultivation traditions and lack of fodder and firewood, most of the crop residues (stalks and roots) were harvested in winter and spring seasons. Retention of crop residues is unpopular in China and farmers should be guided to raise awareness on the importance of crop residues.

9.2. Inter-planting

Erosive drylands are unsuitable to be cultivated on a large scale. In Ih Ju Prefecture of Mu Us Sandy Land, the inter-planting system is well popularized to control wind erosion. It refers to interval strip-cultivation. On erosive land, a certain width of natural *Artemisia ordosica* vegetation remains to play a role of protective barricade. *Artemisia* interplanting was horizontally arranged to the dominant wind direction on rotational abandoned fields and steady drylands in a width of 1-2 metres. The width of *Artemisia* interplanted cereal fields is 10-20 metres in average, which is 10-20 times the height of *Artemisia* communities. In light of investigation, if the interplanting system is designed in a width of 8 metres and cereal fields in a width of 8-17 metres, wind erosion will then be negligible. Narrow interplanting systems and wider cereal fields cannot control and weaken wind erosion under strong wind force.

Interplanting systems are not a reliable measure. Once windstorms occur, sand drifts and wind erosion are possible. Erosive drylands with harsh soil and water conditions cover large areas and are used for grazing animals as steppe after abandonment and biological plantation or shelterbelt establishment on such soil is unacceptable. Therefore, crop residuals of natural psammophyte or artificial plantation of interplanting natural psammophyte can weaken wind erosion to a certain extent. Meanwhile, abandonment of interplanting cereal fields can accelerate the process of natural regeneration of grass.

9.3. Planting bush community belts

Rotation cultivation is a practical system in erosive drylands in wind-sand-affected areas and where farmland protective shelterbelts are unsuitable. Wind and sand disasters are common and the extent of calamity is more severe once sand-dust storms occur and when damage rate of cereal crops is more than 50%. Practice shows that, because of harsh soil and water conditions, the plantation of tree networks is unacceptable, but the plantation of bush-community belts is feasible. Bush communities grow fast and can quickly prevent soil from erosion. For instance, in Sishililiang Township in Hangjin County in Mu Us Sandy Land since the 1960s, people started planting bush communities and after 20 years' effort, all erosive drylands are under the protection of bush communities. In the past years, 3-4 seedings in the sowing season were essential, but now, unit yield is doubled without repeating seeding.

During the plantation of bush communities, *Caragana intermidia* and *Caragana korshinskii* are drought-resistant and suited to ridges. *Salix psammophila* suits sandy land. The width of *Caragana intermidia* vertical to the dominant wind direction is 2-5 metres and narrow stripe-shaped cereal field is 15-20 metres. On the erosive ridge in the Central Ordos Plateau, *Caragana korshinskii* is a pioneer variety with tall communities and the width of narrow stripe-shaped cereal field can be widened to 20-30 meters.

Around settlements and villages in Ih Ju prefecture, Inner Mongolia, *Salix spp.* bush community belts were planted on erosive sandy dryland and these belts consisted of 1-3 rows of bushes and the space between belts is usually 20-40 to 50-60 meters. Under the protection of *Salix spp.* belts, seedling destruction and wind erosion on sandy cropland were essentially eliminated. Sowing can be done at the right time and this can save more arable land.

Bush community belts consist of Salix *spp*. planted on erosive dryland and are characterized by the following:

- Suitability of harsh soil fertility and fast growth on sandy land, long life and easiness in recovery and regeneration.
- 90% survival rate and so replanting is unnecessary. Plantations of cuttings can reach 70-80 cm high in the first year and 2 metres in second year and can soon form a protective barricade.
- Potential ability to sprout. It can be cut after the first two years of growth and then cut one time every two years. Biomass productivity is high and cut community can reach 3-4 metres height after 4 years of growth. Large communities can be cleared out to half density and its function in controlling wind velocity is unaffected.
- No significant impact to crops at two sides of bush belts and the impact scope is only 1-2 metres.
- Significance of fuel wood sources and fodder supply.

In Yulin county of Shaanxi and Yanchi and Lingwu counties of Ningxia, hundreds of thousands ha of erosive drylands are used for cereal cultivation and wind erosion is severe. Large-scale plantation of bush community belts is an effective and feasible approach to slow down rapid development of land desertification.

10. PROMOTION OF BASIC FARMLAND CONSTRUCTION

In wind-sand affected regions in the northern Loess plateau, overexploitation of wastelands and extensive cultivation caused destruction of natural vegetation. Land desertification and soil and water erosion are extremely severe and the eco-balance is disturbed. Up to now, dryland farming is still one of the leading human factors in causing occurrence and development of land desertification. In order to strengthen the ecological improvement in these affected regions, extensive rotation cultivation must be readjusted and the area of dryland farming must be reduced. Essential water conservation and irrigation systems should be installed to guarantee the fundamental arable lands.

Soils on Yinchuan Plain, in the Great Bay area of the Yellow River, along Wuding River and terrains of Mu Us Sandy Lands are fertile. Water is available for irrigation and construction of fundamental farmland is feasible. It is calculated that 60,000 ha of paddy fields can be reclaimed on Yinchuan Plain. 33,000 ha of paddy fields and irrigated fields can be enlarged in Yulin of Shaanxi Province. And 210,000 ha of irrigated lands can be opened up in Ih Ju Prefecture and Dengkou County of Inner Mongolia and Taole County of Ningxia. The unit cereal yield of irrigated land is equal to 2-3 times of that of the saved steady dryland and 10-12 times that of the erosive rotation dryland cultivation.

For many years, in combination with sand control, abundant soil and water resources were fully utilized to reclaim paddy fields by *"pumping surplus water of rivers in winter to flatten sand dunes and building dykes to expand irrigated fields"* on shifting sand lands and low mobile dune areas of the Yulin Prefecture in Mu Us Sandy Land. The total area of rice cultivation is 47,000 ha and unit yield is 9,000 kg/ha. Pumping wells have been installed for developing irrigated agriculture on terrain and inter-dune areas where underground water is sufficient. In total 52 farms of 330 ha and 17 large farms of 6,667 ha have been established. The total area of spring wheat is as much as 170,000 ha and unit yield is 4,500 kg/ha. Practice shows that human factors causing gradual land desertification in the wind-sand affected areas in the northern part of the Loess Plateau can be completely eliminated by developing irrigated agriculture and building fundamental farmland. Dryland cropping on the Loess Plateau was regarded as the leading historical factor in causing soil and water erosion, land degradation and desertification.

Inside the Kubqi Desert, the Mu Us Sandy Land and the Sand Lands in the eastern Terrain of the Yellow River in Ningxia, regardless of irrigated fields or steady rainfed lands, the topsoil is composed of sandy soils and with regard to control wind erosion, protective farmland shelterbelts have to be planted to prevent soil denudation. The experiences can be summarized as following:

a) On moister terrain and inter-dune beaches with irrigation conditions, trees can grow for 15-20 metres. Farmland protective shelterbelts must be planted along canals, farmland dykes and roads; the space between main tree belts horizontal to the dominant wind direction should be 300-400 metres and the space between secondary belts should be 200-300 metres. On severe erosive lands, the size of shelterbelts should be designed in a smaller size and the space between main belts should be 100-150 to 200-300 metres and the space between the secondary belts should be 200-300 metres. Generally speaking, the space between main belts on erosive cultivated lands can be determined on the basis of 15-20 times the height of tree belts.
b) Both the main belt and secondary belt consist of 2-3 rows of trees in a width of 5-6 metres. This is aimed to occupy as little of arable land as possible.
c) In order to control the erosion of cultivated soil effectively, some bush community belts should be planted appropriately among the main and secondary tree belts while planting farmland protective shelterbelts.
d) Regardless of irrigated fields or rainfed farmlands, if they are besieged by mobile dunes, shifting sands or semi-fixed dunes, sandbreaks and windbreaks should be planted at the margins of these fields and sand-holding varieties should be planted on dunes to control sand encroachment and dune movement to cereal fields.
e) *Salix matsudana, Ulmus pumila* are pioneer species of trees to plant farmland protective shelterbelts. *Salix Psammophila* is a suitable bush species.

11. ENCLOSURE AND PROTECTION OF PSAMMOPHYTE FOR APPROPRIATE GRAZING ACTIVITIES

The wind-sand affected regions in the north of the Loess Plateau at the middle reaches of the Yellow River are covered with sandy loess, fine mulching sand loess and aeolian sands. There are 4.05 million people and 8.094 million heads of animals, averaging 2 heads of animals per capita. The available grazing area is 73,740 km² and there is an average 1.3 ha per animal. Because all of the grazing lands (steppe) are desertified, productivity is very low. Steppes are heavily overloaded, denudation is severe and sandification is accelerating. Once strong winds prevail, the grazing lands will become the sand source of sandstorms. This affected region is a semi-arid area: strict prohibition of wasteland opening-up, control of rotation cultivation and appropriate grazing should be practiced. Steppe enclosures and rangeland improvements will promote the quick recovery and regeneration of natural vegetation and steppe forage will be increased to a great extent and edible forage grasses will be gradually raised.

During the 1940-50s, the Mu Niegai district of Yijinhuoluo County in Mu Us Sandy Land was a ranch with luxurious forage grasses. Because of over-exploitation of steppe, rotation cultivation of dryfarming, over-grazing and firewood collection, the area of land desertification enlarged to 1,919.9 ha covering 79.4% of the total area of the district. Now, only 48 heads of animals are left and 330 ha of rotation dryfarming cultivation remains with a unit yield of 150 kg/ha. Winds prevail and sand-dust storms sweep across the area in winter and spring seasons. Both steppe and cereal cultivation are unavailable. Later on, sand enclosure and grass recovery efforts were initiated using *Artemisia,* a psammophyte, and vegetation was quickly restored. As a result, grazing land increased up to 1,896 ha covering 78.3% of the total land area of the district and both agriculture and animal production was recovered. In Mu mainly *Artemisia ordosica* communities to a height of 35 cm and a canopy width of 30-35 cm naturally restored Us Sandy Land, fixed dunes and gentle sand terrain. After enclosure of 3-4 years, the cover was as high as 60-70%.

In Etuoke County in Mu Us Sandy Land, annual precipitation is 300 mm and wind erosion is serious on the cultivated steppes. Once cereal growing is abandoned, natural vegetation can be quickly restored. Abandonment of 1-2 years will allow *Eragrostis pilosa, Setaria virides, Chenopodium album, Tribulus terrestris,* and other forbs and grasses to naturally grow up and coverage will be 70%. After a further 3-5 years, enclosure will regenerate *Leymus secalinus* and *Pernnisetum centrasiaticum*. After 6-10 years, aboriginal vegetation will be restored and *Artemisia frigida, Lespedeza davruica, Astragalus mililotoides, Stipa glareosa, S. .brevifolra* will be the dominant species.

According to investigation and observation in recent years, vegetation coverage of steppe enclosed for five years in Ushenzhao of Ushen County increased up to 55% from 35% in past years. Dried forage production was raised to 1,3387.5 kg/ha from the former 862.5 kg/ha. After 8 years of enclosure, sandy steppe vegetative coverage doubled to 60% from 25% and dried forage production increased up to 697.5 kg/ha from 202.5 kg/ha. Sand mulched ridge steppe in the Honghaizi district of Yijinhuoluo County was enclosed for four years and vegetation coverage doubled to 50% from 25% before enclosure. Dried forage production was raised from 309 kg/ha to 420 kg/ha.

Research and studies show that the appropriate enclosure of degraded rangeland and steppe in the wind-sand affected regions in the north of the Loess Plateau is one of the most effective and economic measures to control land desertification and to improve grazing land. This issue is not determined by physical conditions, but by management skills, population pressures and social and economic conditions.

In order to enclose and protect grazing land and arrange rational grazing activities, rangeland management in the wind-sand affected regions in the north of the Loess Plateau must be perfected and separating fences should be installed. As for the cheap materials for making fences, local materials, such as branches of *Salix* spp. and other bushes, are available. They can be used to plant vertical fences and these can last for 7-8 years. Wire fence is effective but costly. It can stand a long time with significant results. Mud-made wall is fragile, but *Artemisia ordosica* and *Achnatherum splendens* can reinforce it. The mud wall-fence can cause some destruction of steppe and it should not be encouraged.

12. STABILIZATION OF SHIFTING SANDS

In wind-sand affected regions in the north of the Loess Plateau, there are approximately 36,000 km² of mobile dunes, shifting sands and eroded lands that are covered by less than 10% of vegetation occupying 30.3% of the total area of sand land and eroded land. These sand and eroded lands are the sand sources of sand-dust storms. Relatively speaking, rainfall in this region is more and moisture conditions in the inter-dune areas, flooded beaches and terraces of rivers are shallow and available to plant growth.

12.1. Revegetation of shifting sands

Mobile dunes consist of three portions: the windward slope, the leeward slope and the inter-dune area. The leeward slope is steep and dry and the sand layer is thick. The lower part of the windward slope covers one third of the slope length and wind erosion in this portion is severe. The middle of the windward slope occupies one third of its length and is a sand creeping section under wind force. The upper part of windward the slope covers one third of its length and is the mobile section. The inter-dune area is not subject to wind erosion or wind erosion is slight, but it is always subject to sand encroachment. In consideration to effects of sand stabilization, different methods and various varieties should be adopted and selected according to the features of different parts of mobile dunes.

a) *Re-afforestation in the inter-dune areas*. Moisture is relatively high in inter-dune areas and is available to plant trees and bushes in clumps to surround and isolate sand dunes. After 1-2 years of plantation, some terrain or plain beaches will surely be exposed under the former foothills of mobile dune windward slopes. Thus, second or third plantations can be arranged on these terrain or plain beaches to increase the area of woodlots and to reduce the area of sand encroachment. Sand encroachments accumulate in the artificial plantations in inter-dune areas and lower the height of sand dunes; thus the landform becomes gentle. The trees and bushes buried under sand encroachment have a wide root system and moist conditions of habitat are improved to enable the growth of plants in the initial stages. In Mu Us Sandy Land, *Salix spp.* and *Populus spp.* cuttings are pioneer varieties to stabilize shifting sands in the inter-dune areas and their coverage can be as high as 30-50%.

b) *Direct plantation of sand-holding species on mobile dunes*. Artificial plantation of sand-holding varieties on windward slopes of these mobile dunes can be arranged without making artificial sand barriers and direct plantation can play a double role of sand barrier and biological stabilization of dunes. In spring, dense rows of *Artemisia ordosica* and *Salix psammophila* cutting, or *Amorpha fruticosa* seedlings should be planted at the middle and lower parts of dunes. Once the middle and lower parts of the dunes are controlled under biological plantation, after 1-2 years' erosion, the middle-upper parts of dunes will be gradually flattened by wind and then by densely planting sand-holding varieties. By trying 2-3 times plantation, or maximum 4-5 years efforts, the mobile dunes and shifting sands will be stabilized.

c) *Biological plantation under prevention of artificial vertical barriers*. Since the 1980s, in order to protect reservoirs, irrigation channels and other important facilities, wheat straw (or other hays) checkerboards were planted on mobile dunes or steep slopes of dunes to fix the sand surface. On semi-fixed sand dunes, *Pinus sylvestris* L.*var.mongolica* and *Pinus tabulateformis* Carr were planted together with artificial barriers. As for semi-arid zones, the combination of biological stabilization and artificial plantation can certainly greatly accelerate the fixing process of mobile dunes. It should be pointed out that large areas of *Pinus spp.* plantation are under operation in wind-sand affected regions in the northern part of the Loess Plateau and this tree plantation is easily eroded and damaged by shifting sands during the initial 2-3 years, therefore, appropriate artificial barriers should be planted to assist the *Pinus* spp. plantation.

The result is more effective if the above-mentioned biological stabilizations are used in combination. Biological plantation in inter-dune areas, pertaining to sand encroachment, can be called *"front blocks"* or *"pushing sands on windward slope."* On leeward slopes, biological stabilization can be developed under sand barrier protection at middle-lower parts. Biological stabilization without artificial plantation will form *"rear hauling"* or *"pulling sands on leeward slopes"* to control dune movement. The middle-upper part of windward slopes of dunes moves forward under unceasing wind erosion and thus the height of dunes is lowered and even some blowouts will occur just above the portion of the first biological plantation. At this time, another biological plantation can be arranged again in the blowouts. By doing so in proper order, all dunes will be flattened and covered with plants. This biological stabilization (using complex barriers composed of trees, bushes, shrubs and grasses) is termed *"front blocking and rear hauling."* This method is of value and should be extended to other areas. Its advantages are significant as follows:

- The combination of inter-dune area re-afforestation and biological stabilization on windward slopes can quickly enlarge the area of artificial vegetation to control mobile dunes.
- On the windward slope of dunes, without artificial sand barriers, direct dense plantation of sand-holding species can control wind erosion, particularly in the semi-arid zones with sufficient rainfall.
- The middle-upper part, especially the upper part of high dunes, with help of wind force, can be cut and flattened. It is favourable to the growth of plantations and the recovery of natural vegetation. Biological stabilization on these flattened dunes can improve the ecological environment.
- Some small dunes moved into artificial plantation in the inter-dune area will promote the growth of sand-buried biological individuals. At the same time, sand invasion in the wet or heavy clay soil covered inter-dune areas will play a role of soil transformation.
- After maximum 5-6 years, the planted sand dunes and shifting sand area will be basically stabilized and vegetation coverage will be more than 50%.

13. AIR SEEDING FOR REVEGETATING SANDS

Through many years experiments in the wind-sand affected regions in the north of the Loess Plateau, air seeding of sand-holding species was tested in some large and less populated areas. Air seeding was successful during the 1970-80s. Now the annual expansion of air seeding is 60,000 ha and promotes dune stabilization and forage-farm improvement.

Annual precipitation in Mu Us Sandy Land is 350-450 mm and ensures great success of biological stabilization of shifting sands and mobile dunes through air seeding. Both the dense transverse dunes and sparse barchan dunes are of the potential condition to regenerate natural vegetation. In the shifting sand areas, psammophytes like *Artemisia ordosica* had almost disappeared and the coverage of *Artemisia spharerocephala* is normally less than 2-3%. *Artemisia sphareroc ephala* produces abundant seeds, but rodents take them as daily food consumption. Only very few seeds can be blown to wind shadow and buried under shifting sands, and thus natural regeneration is very limited. Right choices of varieties and season for arranging air seeding after the windy season and before the rainy season enables the successful recovery and regeneration of natural herbs in the shifting areas. In fact, air seeding is one of the methods to promote the natural growth of native herbs in shifting sand areas. If the condition in shifting sand areas is harsh for revegetation, it will be impossible to recover the vegetation by use of air seeding.

Experiments and practice shows that the most feasible season for air seeding in Mu Us Sandy Land is from middle May to middle June. In this season, strong northwest winds prevailing in winter and spring are will be ended and a southeastern monsoon with weak force will appear. Air seeding in this season, due to the windward slope of dunes formed under northwestern winds, can resist wind erosion and can survive because of large amount of seed preservation. Under the influence of a southeastern monsoon, the top part of sand dunes will move northwestwards. The floating fine sands moved by sand drifts on top dunes will accumulate as a thin mulching sand layer to cover seeds on the middle-lower part of dunes. This is just the time that the rainy season comes. The depth of dry sand mulching is 10 cm and one medium-rain (or 2-3 days in succession – even small rain) will enable the sprouting and establishment of the mulched seeds.

The main species used for air seeding in the eastern parts of the Mu Us Sandy Land Kubqi Desert are *Hedysarum laeve* Maxim *,* *Artemisia sphareroc ephala* and *Hedysarum scoparium.* In shifting sand areas, natural annual herbs like *Agriophyllum squarrosum* can regenerate naturally in the rainy season and become inter-distributed with the air seeding plants. *Agriophyllum squarrosum* can control wind erosion effectively in winter and spring seasons. It is a pioneer plant to control sands and natural seeding is better than air seeding. Generally speaking, mixed air seeding is better and seed requirement is *Artemisia sphareroc ephala* 45-60 kg/ha, *Hedysarum laeve* Maxim or *Hedysarum scoparium* is 75-105 kg/ha. In the very year of air seeding, sprouts are feasible only in the inter-dune areas and middle-lower parts of windward slopes and height of young seedlings are about 10 cm. This short but dense young seedling coverage can control wind erosion in the winter of the first year and in the spring of the next year. After 2-3 years of biological stabilization, *Hedysarum laeve* Maxim can spread through root development. Because of sand enclosures and grazing controls, air seeded plants and residues of natural vegetation can seed and regenerate themselves. Under such circumstances, after 5-6 years air seeding, large areas of shifting sands can be turned into fixed dune areas. Under wind flattening, the upper part of dunes will be leveled and become blowouts and eroded low-lying areas. This will enable root spreading and regenerating of sand-holding species, like *Hedysarum laeve* Maxim.

Air seeding of *Astragalus adsurgens* in Mu Us Sandy Land can be done at the lower-bottom part of dunes, inter-dune areas, semi-fixed dunes and less vegetated eroded lands for the purpose of harvesting fodder and forage. But *Astragalus adsurgens* is unable to seed and regenerate itself and it will decline in vigor and wither after 5-6 years growth. In consideration to only sand stabilization, *Astragalus adsurgens* is not recommended to control sand encroachment or dune movement in air seeding.

Annual mean precipitation in Baiyanhot at the eastern fringe of the Tengger Desert is 200 mm and it is classified as semi-desert. The success of air seeding sand-holding species in this semi-desert is related to the fact that a) the gentle undulating dunes and windward slope are 70-80 metres long and the lower part of the dune is covered with *Allium mongolicum.* Meanwhile, scattered and dotted distribution of *Rsammochloa villosa* can be observed in the whole shifting area. In the rainy season, annual herbs can multiply quickly in great amounts; b) eroded mounds and muddy gobi composed of dark soil residuals can be observed and they are perhaps the results of modern land desertification; c) under the protection of the Helan Mts., wind velocity is relatively weak; d) the selected *Artemisia sphaerocephala* and *Calligomum spp.* are native species and are pioneer varieties with strong multiplying abilities; e) there are cases of floods in the summer season from the Helan Mts.

The best season for air seeding in the Baiyanhot district is from late June to early July, because of the late arrival of the rainy season. Amounts of seed for air seeding is 175 kg/ha for mixed seeding of *Artemisia sphaerocephala* and *Calligonum mongolicum.* Seed requirements for single seeding of both *Artemisia sphaerocephala* and *Calligonus mongolicum* are 175 kg/ha respectively. After 3-4 years air seeding, 40-50% of the air seeded area will be biologically covered. The upper part of the windward slope of dunes will become gentle and both *Artemisia spaerocephala and Calligonum mongolicum* can be naturally sown and regenerated. Landscapes of fixed and semi-fixed dunes will appear after 5-6 years of effort. Experiments show that the installation of a wire-fence 1-2 years before the air seeding will increase the natural coverage of *Agriophyllum squarrosum, Allium mongolicum* and *Rsammochloa villosa*. Continuity of 3-4 years prohibition of grazing after air seeding will enable the development of biological stabilization.

In the Mu Us Sandy Land or eastern fringe of the Tengger Desert, air seeding for dune fixation is aimed at creating grazing land or fodder farms. After 3-4 years, the air-seeded area can be used for grazing animals or for harvesting dried forage or fuel wood.

14. CONTROL OF SAND SOURCES ALONG TRAFFIC LINES AND AROUND MINING SPOTS

In Northwest China, traffic lines, mining fields, town construction and other economic installations are under threat and impacts of sand-dust storms. Once a sandstorm or black windstorm occurs, these infrastructure facilities are easily damaged. Furthermore, road construction, gas pipes and oil pipe pavements, open mining, oil-gas drilling, high-voltage wire installation and settlements arrangements are generally conducted with heavy machines and vehicles that bring about large area disturbances and often result in large-scale destruction of vegetation. Soil surfaces are exposed and artificial accumulation of waste soil pile up. In addition, coal ash accumulation of electricity power stations, tailings of ore dressing fields and fine metal materials accumulation are the industrial tech-genetic sand sources that can also cause land desertification and sandstorms. Greening activities should be arranged around settlements and mining fields. Construction companies should reduce the damaged areas as much as possible when making oil-gas pipelines, building roads, and exploiting minerals. Waste construction materials, coal ash, tailings and other artificial accumulation of waste materials should be mulched with engineering methods or biological cover. Artificial plantation is essential in controlling these man-made deteriorations.

All sandstorms, particularly black windstorms, have brought about severe damage to railways and highways in Northwest China. Apart from some sand drifts on the shoulders of highways, there are no serious sand accumulations on road embankments and road surfaces. This is because the smooth surfaces of gobi and other eroded lands and fixed dunes enable the sand drifts to pass through without any sand accumulation or damage to moving vehicles. Therefore, design of highways permits the transit of sand drifts on road surfaces under wind force; the road surface can transport sand automatically. Railway lines are different, the pavement rocks, pillow-timber and steel tracks are objects accumulating sands while sand drifts are crossing the railway lines. Sand accumulation threatens operational quality and causes danger to safety. Therefore, the design of railways does not permit any sand transport and other measures must be put in place to counter this.

Highways that pass through shifting sand areas are easily buried by sand encroachment. More sand accumulation on road pavement can also cause traffic barriers. When the road base of highways is zero and the two-sides of highways are occupied by gobi, eroded lands, semi-fixed dunes or large area of erosive drylands, sand drifts can sweep across the highway without any accumulation in the windy season from winter to spring. However, if there are some tree lines or bush communities of 10-20 metres in width along the two sides of the highway, more and more sands will be accumulated in these sections. Sand drifts moving across form longitudinal dunes at the two sides and threaten the safety of highways. Therefore, highway construction and implementation of sand control projects in wind-sand affected regions should take acceptable measures suited to local conditions in light of consideration of the movement patterns of wind and sand drifts. Otherwise, artificial clearing-up of sand accumulation on highways will cost too much. The experience and techniques for controlling sand damage along railways is available to control sand drifts on highways.

Since the early 1950s, in order to meet the needs of economic development, more than ten railway lines were built in Northwest China and these lines now extend over 5,000 km. Of these, 700 km is subject to threats of sand movement and sand drifts in wind-sand affected regions and gobi areas. The Lanzhou Railway Bureau, the Huhhot Railway Bureau and the Urumqi Railway Bureau have made great contributions to control sand damage along the Baotou-Lanzhou Railway Line, the Lanzhou-Xinjiang Railway Line and the Gantang-Wuwei Railway Line. Dune stabilization and sand control along these traffic lines have amassed rich practical experience and gained great success enabling the smooth operation of railways in wind-sand affected regions. However, sand disasters are still serious in some sections of railway lines. Only one sandstorm, on May 5th 1993, caused sand accumulation on railway tracks and in total 150-200 km of railway tracks were closed for clearing up and maintenance. The railways of the Zhongwei-Baoji Line, the Baotou-Shenmu Line and others are under construction and face similar problems of sand accumulation and other related threats.

Railway lines cross over desert, gobi and wind eroded lands over long distances and harsh environmental conditions. Rehabilitation of reactivated dunes and control of sand damage along railway line is more difficult than at desert oases. In some sections of railway tracks, even biological measures are not suitable to establish protective systems along the tracks. Some contemporary engineering measures to fix and block sands have to be adopted. Once these measures lose their effectiveness, repeated procedures are needed and some special railway lines have to clear up the sand accumulation through manpower. The paragraphs below deal with the introduction of controlling measures along railway lines.

14.1. Protection of railways

The construction of a railway base on local materials (from gravel gobi and sandy land) is feasible and safe operation is guaranteed without any submerging of the foundation. But the problem is that the basement and track shoulders made of sand and gravel are easily eroded, so this must be prevented. According to experience in building the Baotou-Lanzhou Railway Line and the Lanzhou-Xinjiang Railway Line, almost all materials collected from local sources (macadam and pebbles) in sizes of 10-15 cm in diameter were used to mulch the slopes of basements. Square pebble checkerboards were made in sizes of 1 x 1 metre or 1.5 x 1.5 metres and then mulching macadam and pebbles (diameter of 7-8 cm) inside the squared checkerboards. This pebble-made slope of basements plays a role of tidy and durable mulching to prevent the slope from erosion and denudation. Even under conditions of strong sand-dust storms or black windstorms, the slope and shoulder of the basement will be safe.

Along the Lanzhou-Xinjiang Railway Line and the Jining-Erlianhot Railway Line, stone pieces were used to pave slopes of railway basements. At 3 metre high slopes of the basement, a layer of 10 cm gravel was mulched on slopes; it plays an excellent function in controlling wind erosion and denudation. In wind-sand affected region in the north of the Loess Plateau, due to relatively high rainfall, biological checkerboards were planted on the slope to protect it from erosion and these biological checkerboards can encourage vegetative coverage on the slope to avoid erosion. This is an example of *"a stitch in time saves nine."*

14.2. Sand controlling measures along railway lines

Where the railway crosses wind-sand affected regions, due to sand damage along the tracks, it will be necessary to implement a programme of rehabilitation. In order to keep the smooth operation of trains, sand accumulation along the tracks can be minimized through the adoption of some contemporary measures. On gobi, eroded lands, fixed and semi-fixed dunes and sand mounds with bushes, sand drifts will accumulate normally on the track-beds when they cross the railway line. At the same time, sand accumulation brought from sand drifts and dune movement in artificial gullies at the two sides of the railway line, the residual pits for paving railway basements, are the sand sources for sand accumulated railway beds and basements.

In order to reduce the volume of sand accumulation on track beds, pillow-timbers under the steel tracks were emptied to allow free space for sand passing through the tracks without any accumulation. This contemporary method is significant for clearing up sand accumulation and enabling normal operation of the railway. The disadvantage of this method is that it cannot reduce the sand volume on the slopes of the two sides of the railway and these will become the sand source that accumulates on the railway tracks when wind velocity is up to the threshold velocity. Because of this, some gravel, clay and other materials have to be used to mulch the sands at the two sides of the basement. This mulching activity will cost both financial resources and manpower. In gobi areas, sand sources are normally far from the railway. Along the Lanzhou-Xinjiang Railway Line, in order to stop the sand drifts at a distance, pits and gullies have been made 50 metres beyond the basement on the windward side and the gravel, stones and macadam were artificially piled up as a dyke just along the furrow. This furrow and dyke method will hold sand drifts to accumulate on site and these will be filled up in 3-4 years and then artificial digging of gravel materials is needed to mulch the accumulated sands or dunes. Repeated digging and formation of dykes is an effective measure to reduce sand accumulation on railway lines.

But this system costs resources and track beds are always under threat of some sand deposits and so this is not a permanent arrangement.

14.3. Engineering a protective system of railway lines

The railway along the northern side of the Qarhan Salt Lake of the Qinghai-Tibet Railway Line crosses over four sections of mobile longitudinal dunes and shifting sand covered terrain. Annual rainfall is only 20 mm and salt content is very high so that biological stabilization of mobile sands is impossible. In a length of 2.5 km of railway, annual consumption of manpower for clearing up sand deposits is more than 800 man-days. Since 1988, a sand stabilization belt consisting of reeds, wheat straw and salt crusts has been made to control creeping sands and two rows of vertical bamboo-made bars have been planted just outside the stabilizing belt. These bars blocked and deposited sands to avoid further sand invasion into the stabilizing belt. The width of the sand stabilizing belt at the dominant wind side is 80-200 metres and the sand barriers made of reeds has a size of 1.5 x 3.0 metres with height of outcrop being 30 cm. The height of the bamboo-made bars is 1 metre and wind ventilation is 45-50%. The space between two rows of bamboo bars is 25-30 metres. This protective engineering system, although it has to be replaced every 4-5 years, is a practical method in pure deserts, particularly in salt desert regions.

14.4. Protective biological system along railway lines

The Shapotou section of the Baotou-Lanzhou Railway Line crosses over the mobile dune area at the southeastern edge of the Tengger Desert. A sand stabilizing belt 400-500 metres in width at right angles to the dominant wind direction and in a belt 100-200 metres wide at the other side has been planted. Wheat straw checkerboards have been made in the stabilizing belt and some sand-holding varieties have been planted inside the mentioned straw checkerboards, like *Artemisia ordosica, Hedysarum scoparium, Caragana korshinskii, Caragana imtermidia* and other species. Artificial revegetation was established and vertical sand barriers were erected outside the sand-stabilizing belt to stop dune movement and control sand invasion into the belt. Practice and research shows that, under circumstances of non-irrigation conditions in semi-deserts, the establishment of this protective biological system, aimed firstly at stabilization and a combination of sand stabilization and sand block as a complex system, cannot only control sand damage, but also bring about significant effects. During the black windstorms, this section of railway was safely operated and trains were not blocked.

The Yumen section of the Lanzhou-Xinjiang Railway Line crosses over gobi and eroded lands and causes serious sand damage. On April 22nd 1966, as result of sand drifts and dust storms, the track bed was filled up with sand and passenger express train No. 53 was derailed and drove for 288.3 metres on the pillow-timber in Zhoulijin-Gongchanghe Section. After that accident, 2-3 rows of windbreaks and sandbreaks were planted in the belt 30-50 metres beyond the basement. By using branches and withered twigs of these sandbreaks and windbreaks, 2-3 rows of vertical barriers were erected outside the sandbreaks and windbreaks to stop and accumulate sand drifts inside the biological belts. On the leeward side of the railway, one belt with irrigation should be planted to stop sand drifts. The black windstorm and other sandstorms that occurred before May and after May did not cause any sand accumulation on the track bed in the Yumen section. But over a distance of 100 km of gobi area (from Liuyuan in Gansu to Shanshan in Xinjiang) sand accumulation and deposit was severe, trains were delayed and interrupted and the economic loss was enormous.

The Baotou-Lanzhou Railway Line, Gantang-Wuwei Railway Line and Qinghai-Tibet Railway Line cross over gentle sand lands and terrains where natural vegetation is insufficient to control surface sand drifts and therefore, a protective belt of 200-300 metres was planted along the two sides of the railway. Meanwhile, grazing and firewood cutting is prohibited to promote the regeneration of natural vegetation. For some sections with sand sheets, clay or gravel mulch is needed, or a pit or gully has to be dug in the dominant wind direction to protect the railway from sand invasion and surface accumulation.

15. MANAGEMENT OF MINE TAILINGS

The tailings of Jinchuan Company in the Hexi Corridor are located 4 km from the north of the Ore Dressing Depot. On gobi areas, gravel, rocks and stones were collected to make a dyke (tailings dam) covering an area of 2.94 million metres^2. Since its operation from 1964 to June 1991, 38.87 million tons of tailing sands were artificially piled up. Due to infiltration and evaporation, the tailings dried up and became exposed under strong wind erosion and frequent sand-dust storms that brought about serious threats to soil, water bodies, roads, buildings and crops and resulted in atmospheric pollution and even impacts to human health. In order to control this pollution source, gobi gravel, rocks and stones were used to mulch the exposed tailings to a depth of 6 cm. The gravel mulch cut off the sand source of sandstorms and provided stable conditions for seeding and protected the tender seedlings of natural vegetation. After the first rains in the same year of stone mulching, vegetative coverage increased 15-30% and in some areas was as high as 50%. This stone mulch guarantees the spread of natural plants around tailings and in mining areas.

16. CONCLUSIONS

Prevention is not only better than a cure but it is more cost-effective. The past experiences of the Chinese people, including both those who make policy decisions and those who suffer the consequences, have led to a realization that much has been done in the relatively recent past to upset the ecological balance in China's north and north west. As part of national efforts to develop the western region, to honor its commitments to the various International Conventions on Desertification, Climate Change and biodiversity and as a result of the hard work of the scientists who have researched the causes and treatment of desertification and sand-dust storms, it is now possible to implement a coordinated and focussed programme to combat desertification, mitigate the effects of sand-dust storms and in so doing raise the living standards of the local peoples.

Desertification and its concomitant frequent and calamitous dust storms impact heavily on people. The government has a role: to provide know how, technical advice and the wherewithal to put effective programmes in place. The National Action Plan (NAP) to combat desertification in China, along with various other government initiatives, will be extremely useful in preventing sand-dust storms in the future. It is only by coordination of efforts and the development of sound policies that this objective can be achieved. The road is long, the journey will be painful and slow but the goal is in sight.

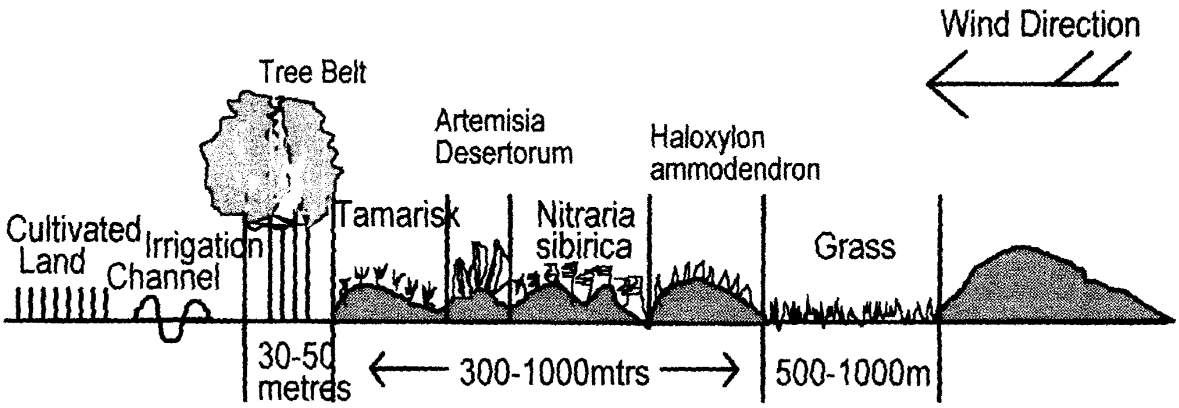
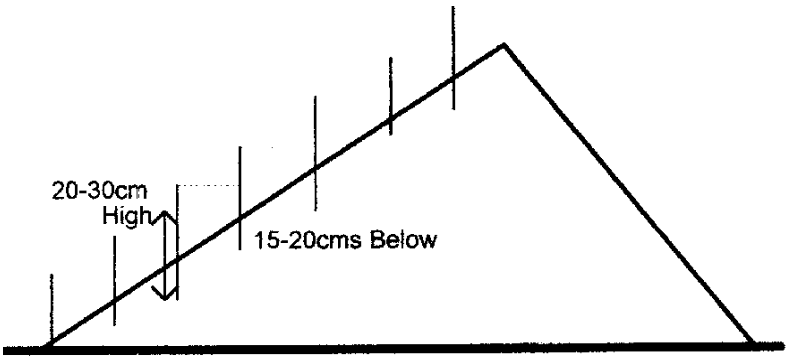


Figure 2: An example of sand stabilization in Gansu Province of Northwest China. Here shelterbelts provide a screen and local species of trees and shrubs are used to revegetate the dunes



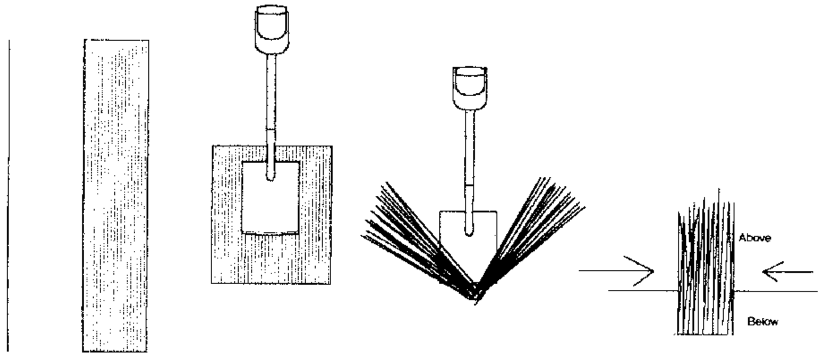


Figure 3: Sand stabilization is accomplished by putting down mats of straw at intervals up the slope of the dune as shown in the top figure. The actual procedure involves laying down a mat and creating a *"v"* as shown in the lower figure

17. REFERENCES & FURTHER READING

Chen Longheng, 1993, *Damage of Strong Sandstorm in Ningxian and Alxa of Inner Mongolia and Control Strategy*, Journal of Desert Research, (3), 9.

Chen Mingjian, 1993, Study and Discussion on Black Windstorm, Gansu Meteorology, 11 (3).

Cheng Daoyuan, 1994, *Atmospheric Dust Source and Dust Storm*, World Desert Research, (1) 5.

Dept. of Geosciences, Chinese Academy of Sciences, 2000, *Root Causes of sand-dust Weather in Northern China and Controlling Strategy*, Impact of Science on Society, 4.

Dong Zhibao, 2000, *Base for Studying the Occurrence and Control of Sandstorm*, Impact of Science on Society, 4.

Fu Youzhi, et al, 1993, *Root Causes and Prediction of Black Windstorm in Hexi of Gansu*, Gansu Meteorology, 11 (3).

Jiang Fengqi, et al, 1993, *Investigation Report of Strong Sandstorm in Ningxia*, Applied Ecology, 4 (4).

Liu Yuzhang, 1992, *Wind Tunnel Experiments on Main Causes Impact Soil Erosion*, Journal of Desert Research, 12 (4).

Qian Zheng'an, 1993, *Investigation Report on 5.5 Strong Sand-dust Storm in Gansu and Ningxia*, Atmospheric Information, (4) 3.

Su Yucheng, 1993, *Analysis on Sandstorm on May 5th 1993 in Hexi Corridor*, Gansu Meteorology, 11 (3).

Wang Jiaying, 1963, *China Geological History*, Science Press, p. 110.

Wang Jixi, 1993, Analysis on Causes of Black Windstorm on May 5th 1993 in Gansu, Gansu Meteorology, 11 (3).

Xia Xuncheng, Yang Gengsheng, et al, 1996, *Sandstorm Disasters in the Northwest China and their Prevention*, China Environmental Science Press, p. 63-71.

Yang Gengsheng, 1996, *Black Windstorms in Northwest China and Calamity Reduction Approaches*, Journal of Desert Research, 16 (2).

Yang Gengsheng, 1993, *Developmental Process of 5.5 Black Windstorm and Controlling Strategy*, Journal of Desert Research, 13 (3).

Yang Gengsheng, 1993, *Disastrous Status and Strategy against Black Windstorm on May 5th 1993 in the Northwest China*, Gansu Meteorology, 11 (3).

Yang Gengsheng, 2000, *Sandstorms and Dust Storms in Northwest China*, Impact of Science on Society, 4.

Yang Gengsheng, 1997, *Tailing Sands, Formation Mechanism and Selection of Engineering Measures Controlling Sand Damage*, Journal of Desert Research, 17 (4).

Zhao Xingliang, 1993, *Damage of Strong Sand-dust Storm in Gansu and Countermeasures*, Journal of Desert Research, 13 (3).

Zhu Zhengwen, 1993, *Report on Black Windstorm on May 5th 1993 in Gansu*, Gansu Meteorology, 11 (3).

GLOSSARY

Aeolian Borne, deposited, produced, or eroded by the wind

Afforestation The act or process of establishing a forest especially on lands not previously forested

Aral Sea Brackish lake in Central Asia lying between Kazakhstan and Uzbekistan

Beaufort Scale The standard way of measuring wind force. Wind velocities above force 6 are significant in transport of sand and dust

Biodiversity Biological diversity in an environment as indicated by numbers of different species of plants and animals

Capacity building strengthening the technical and administrative skills of local agencies

Coping strategies To deal with and attempt to overcome problems and difficulties

Desertification Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities

Desert arid land with usually sparse vegetation; such land having a very warm climate and receiving less than 25 centimeters (10 inches) of sporadic rainfall annually and where evaporation greatly exceeds precipitation

Drought A period of dryness especially when prolonged that causes extensive damage to crops or prevents their successful growth

Dunes (sand) A hill or ridge of sand piled up by the wind

Dust storm A severe windstorm that sweeps clouds of dust across an extensive area, especially in an arid region

Ecological immigrants (sometimes called ecological refugees) are those people who leave their land and re-locate because of the destruction of the environment and its inability to support them and provide household food security

Entrainment To draw in and transport (as solid particles or gas) by the flow of a fluid

Evapotranspiration The rate at which water vapour can be transported away from the surface under the prevailing meteorological conditions

Fixation (sand dune) Establishment of a vegetative cover to stabilize the sands to resist erosion by wind. In some situations, non-biological methods such as petroleum products may be used to achieve this

Forbs broad leafed herbs

Forecasting To predict (weather conditions) based on correlated meteorological observations

Fuelwood Wood grown or used for fuel

Gobi The term gobi refers to a stone-covered desert surface. The so-called Gobi desert in China is a vast expanse of such stony desert but smaller areas of a similar landform occur in scattered patches throughout NW China

Grassland Area in which the vegetation is dominated by a nearly continuous cover of grasses

Heritage Something transmitted by or acquired from a predecessor

Human influences Influences caused by human actions, effects

Infrastructure The underlying foundation or basic framework (as of a system or organization)

Irrigation To supply (land) with water by artificial means

Land degradation The process of degrading, from a former state

Land tenure The act, right, manner, or term of holding land

Land-use The manner in which land is used

Livestock husbandry The scientific control and management of a branch of farming and especially of domestic animals

Meteorology Science that deals with the atmosphere and its phenomena and especially with weather and weather forecasting

Networking The exchange of information or services among individuals, groups, or institutions

Non-equilibrial systems Ecological systems that do not progress in a gradual and orderly manner from *"pioneer"* to climax vegetation assemblages instead, they fluctuate between states of interrupted equilibria.

Oasis is a term used to describe irrigated agriculture on the desert fringe. Sometimes these oases were an expanded version of a natural oasis but more commonly in China they were created in the last 50 years by diverting rivers and installing irrigation schemes

Optical qualities The properties of utilizing light instead of other forms of energy

Participatory approaches Policy or mechanism involving participation (on many levels)

Particulates Of or relating to minute separate particles

Periodicity The quality, state, or fact of being regularly recurrent

Precautionary principle Measures taken in foresight to prevent harm

Rangeland Is a type of land rather than a type of use. Yet traditionally the term applies to any extensive area of land that is occupied by native herbaceous or shrubby vegetation that is grazed by domestic or wild herbivores

Reforestation The action of renewing forest cover by planting seeds or young trees

Remote sensing Remote-sensing techniques, particularly those that use satellites, allowing great potential for observation

Revegetation To provide (barren or denuded land) with a new vegetative cover

Salinity The degree of salt content, especially in soil and water and at a level deleterious to crops

Sandstorms A windstorm (as in a desert) driving clouds of sand before it

Satellite imagery Imagery obtained through satellite photography and/or other measures

Seasonality Affected or caused by seasonal need or availability

Socio-economics Of, relating to, or involving a combination of social and economic factors

Sociology The systematic study of the development, structure, interaction, and collective behavior of organized groups of human beings

Soil erosion The action or process of eroding, through wind, rain, or other methods

Solonchak Any of a group of intrazonal strongly saline usually pale soils found especially in poorly drained arid or semiarid areas

Steppe Short-grass prairies at margins of deserts and transition zones

Sustainable development Relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged in the long-term

Trace elements A chemical element present in minute quantities, especially one used by organisms and held essential to their physiology

Traditional knowledge Inherited, established, or customary pattern of thought, action, or behavior (as a religious practice or a social custom) in technology

Water points Sources of water, especially for livestock

Waterlogging A situation where soil is constantly wet, often as a result of poor drainage and/or rising water tables

Weather refers to the environmental conditions being experienced on a day-to-day (even hour-by-hour) basis

Weather patterns Patterns in the state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness

Windbreaks A growth of trees or shrubs serving to break the force of wind

KEYWORD INDEX

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FURTHER READING

1. Land Use -- Land Degradation and **Desertification**
CIESIN Thematic Guides *DRAFT* Land degradation has been defined as a reduction in the soil's capacity to produce in terms of quantity, quality, goods, and services.
http://www.ciesin.org/TG/LU/degrad.html [more from this site]
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Land Use > Desertification

2. African Deforestation and **Desertification**
Table of Contents: This unit will employ the geographic perspective to identify, analyze and predict solutions for the geographic issues of deforestation and **desertification** in Africa.
http://multimedia2.freac.fsu.edu/fga/academy/afdefor.htm [more from this site]

3. **Desertification**
United Nations Conference on Environment and Development: Status of **Desertification** and Implementation of the United Nations Plan of Action to Combat **Desertification.**
http://grid2.cr.usgs.gov/des/deshome.htm [more from this site]

4. UNDP Dryland Web - Office to Combat **Desertification** and Drought (UNSO)...
The Office to Combat **Desertification** and Drought (UNSO) works in the overall framework of UNDP's sustainable human development mandate to support dryland development and the implementation of the C...
http://www.undp.org/seed/unso/ [more from this site]
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Land Use > Desertification

5. CARRE at SDSU - Aral Sea **Desertification** Study
The following images show the drastic environmental changes that have occurred during the last few decades. As water from the Syr Darya and Amu Darya rivers has been diverted (primarily for irriga...
http://www.geology.sdsu.edu/facilities/carre/carre_study.html [more from this site]

6. Against **desertification**
Draft Documents from the NGOs Forum Listen to the NGOs and Governments representatives: speeches and interviews From 29 September til 10 October 1997 will be held in Rome the First Conference of t...
http://www.eurplace.org/diba/coopera/indesert.html [more from this site]

7. **Desertification**: Monitoring & Forecasting
None Available
http://www.gps.caltech.edu/~arid/ [more from this site]

8. Len Milich: **Desertification**
LE FastCounter Discussed at length during the 1992 United Nations Conference on Environment and Development, and driven by the renewed interest of the United Nations Environment Program (UNEP, 199...
http://ag.arizona.edu/~lmilich/desrtif.html [more from this site]

9. **Desertification** Information Network of China DENGKOU Station SHAPOTOU Station UNDP Project: Distribution Maps of China **Desertification** Lands: 1, 2 Documents & Publications **Desertification** is one of the major environmental issues in the...
http://www.din.net.cn/ [more from this site]

10. Convention to Combat **Desertification**
Over the past two decades, the problem of land degradation in dryland regions has continued to worsen. The Convention to Combat **Desertification** in Those Countries Experiencing Serious Drought and/...
http://www.unep.org/unep/secretar/desert/home.htm [more from this site]

11. UNEP/IUC - leftframe **desertification**
Maintained by: iuc@unep.ch Basel Convention Biological Diversity Climate Change Information Kit Press releases Migratory Species Montreal Protocol
http://www.unep.ch/iuc/submenu/ccdiuc.htm [more from this site]

12. UN Convention to Combat **Desertification**
The United Nations Convention to Combat **Desertification**: A New Response to an Age-Old Problem The Environmental Problem - **Desertification** and Its Causes
http://www.un.org/ecosocdev/geninfo/sustdev/desert.htm [more from this site]

13. Land Degradation and **Desertification** Website
The Land Degradation and **Desertification** Website The Working Group on Land Degradation and **Desertification** of the International Union of Soil Sciences
http://www.nhq.nrcs.usda.gov/WSR/Landdeg/papers.htm [more from this site]

14. IDRC Focus Collection: Grassroots Indicators for **Desertification**
Grassroots Indicators for **Desertification** Experience and Perspectives from Eastern and Southern Africa edited by Helen Hambly and Tobias Onweng Angura
http://www.idrc.ca/books/focus/794/ [more from this site]

15. **Desertification**; Middleton Nicholas J; Paperback
Desertification by Middleton Nicholas J; Paperback
http://www.netstoreusa.com/sabooks/019/0199133697.shtml [more from this site]

16. United Nations Secretariat of the Convention to Combat **Desertification**
United Nations Secretariat of theConvention to Combat **Desertification** Starting Points Sand dune fixation project, Jodhpur, Rajasthan, India (click photo to enlarge)
http://www.unccd.int/main.php [more from this site]

17. **DESERTIFICATION** of EARTH and FERAL HUMANS
DESERTIFICATION OF EARTH AND FERAL HUMANS
http://www.quietmountain.com/dharmacenters/buddhadendo/DESER... [more from this site]

18. Ongoing Projects: Desert and **Desertification** Project 1995-1996
Desert and **Desertification** Project 1995-1996 > > DESERT AND **DESERTIFICATION** PROJECT > 1995-1996 School Year > > During the 1994-1995 school year, we conducted a year-long > intern...
http://archives.gsn.org/pr/ongoing/1995/0006.html [more from this site]

19. Tiempo issue 8: **Desertification**: the scourge of Africa
Michael Bernard Kwesi Darkoh discusses the complex factors underlying the threat to Africa's drylands. WITHIN THE LAST DECADE or so, 25 countries in Africa have faced drastic food shortages as a r...
http://www.cru.uea.ac.uk/cru/tiempo/issue08/desert.htm [more from this site]

20. First meeting of UNCCD Parties sets up global system to fight dese...
On 10 October, after two weeks of intense negotiations at FAO headquarters, the first meeting of the parties to the United Nations Convention to Combat **Desertification** (UNCCD) agreed on the establi...
http://www.fao.org/NEWS/1997/971008-e.htm [more from this site]

21. PRC **Desertification**: Inner Mongolian Range Wars and the Ningxia Popula...
Widespread harvesting of valuable grasses in western regions of Inner Mongolia is devastating the grasslands. Rapid population growth in Ningxia and so a decline in available land per farmer may be...
http://www.usembassy-china.org.cn/english/sandt/desmngca.htm [more from this site]

22. Information name: Towards Solving the Global **Desertification** Problem (...
Towards Solving the Global **Desertification** Problem (2) -Research on the Evaluation of Interaction between **Desertification** and Human Activities-Prepared by
http://www.nies.go.jp/english/eic-e/eiguide_e/d0000e.htm [more from this site]

23. sd_csd Combating **Desertification**: Connecting Science with Community Action Summary of Bureau of Land Management Meeting (Tucson) Available in PDF or ASCII format.
http://www.iisd.ca/sd/sd_csd.html [more from this site]

24. GLSJ V3, N1 - Danish
Kyle W. Danish<1> The media was once filled with images of encroaching deserts and starving populations. Attention has since shifted to other issues, but the problems remain.
http://www.law.indiana.edu/glsj/vol3/no1/danish.html [more from this site]

25. United Nations Conference on **Desertification Desertification** Associa...
United Nations Conference on **Desertification Desertification** Associated Case Studies Presented at the United Nations Conference on **Desertification** 29 August to 9 September 1977 Nairobi kenya
http://www.booksdvd.net/0080235816_ba1I_baex1.html [more from this site]

26. United Nations Conference on **Desertification - Desertification** Assoc...
Books by United Nations Conference on **Desertification** - informations about **Desertification** Associated Case Studies Presented at the United Nations Conference on **Desertification** 29 August to 9 Se...
http://www.booksvideodvd.net/0080235816_ba1I_baav1.html [more from this site]

27. **Desertification**
The Sahelian drought that began in 1968 was responsible for the deaths of between 100,000 and 250,000 people, the disruption of millions of lives, and the collapse of the agricultural bases of five...
http://pubs.usgs.gov/gip/deserts/desertification/ [more from this site]

28. Netscape Search Category - **Desertification**
Netscape Search combines the Open Directory Project with Google to deliver an exceptional Internet search engine experience
http://directory.netscape.com/Science/Environment/Global_Cha... [more from this site]

29. INFOTERRA: DECEMBER 1998: INFOTERRA: GL: 41% of land threatened by des...
http/www.africanews.org/science/stories/19981214_feat5.html 41 PERCENT OF EARTH'S SURFACE EATEN UP BY **DESERTIFICATION** December 14, 1998 Dakar, Senegal (PANA) - Forty-one percent of the earth's s...
http://www.www.ee/lists/infoterra/1998/12/0044.html [more from this site]

30. Devel-L: Second In Series of Occasional Papers On **Desertification**
Pacific Center For International Studies (mailto:pcis@IX.NETCOM.COM) Thu, 10 Aug 1995 08:07:11 -0700 Message-ID: <199508101507.IAA28907@ix9.ix.netcom.com> Date: Thu, 10 Aug 1995 08:07:11 -07...
http://library.wustl.edu/~listmgr/devel-l/Aug1995/0040.html [more from this site]

31. Clim-Econ 96 disc: **Desertification** Occasional Papers
Sun, 14 Jan 1996 11:17:25 -0600 GreenLife Society: North American Chapter (wcburns1@students.wisc.edu) Announcement of Publications: GLSNA International Environmental Law Occasional Paper Series C...
http://csf.colorado.edu/clim-econ/96/0000.html [more from this site]

32. Senate ratifies **Desertification** Treaty, 22 others
eco-logic ---- on-line ---- (M) indicates member section eco-logic report On December 8, Senator Thomas' office called to explain that it was he who happened to be on the floor late in the after...
http://www.sovereignty.net/p/land/treaties.shtml [more from this site]

33. Mailing List ENVCEE-L: INFOTERRA: Losing the battle against desertific...
alternativ@oehserv.boku.ac.at Sun, 14 Feb 1999 22:36:00 +0100 Date: Sun, 14 Feb 1999 22:36:00 +0100 From: alternativ@oehserv.boku.ac.at Subject: INFOTERRA: Losing the battle against desertificatio...
http://ecolu-info.unige.ch/archives/envcee99/0060.html [more from this site]

34. Untitled
International Convention to Combat **Desertification** in Countries Experiencing Serious Drought and/or **Desertification**, Particularly in Africa Final text of the Convention, following completion of th...
http://users.ox.ac.uk/~wgtrr/ccd.htm [more from this site]

35. **DESERTIFICATION**: 130 million hectares of land lost for ever
IPS news reports appear daily in English, German, Finnish, Norwegian, Spanish and Swedish. To subscribe, please contact us at: Africa, Asia, Caribbean, Europe, Latin America, North America.
http://www.oneworld.org/ips2/oct/desertification.html [more from this site]

36. Effects of **Desertification** in Africa
The Effects of **Desertification** in Africa Dustin Greiman Ryan Greiner Chris Madsen Jen Holtkamp Brad Bovy Kyle Mehmen **Desertification**, or land degradation in arid regions, affects close to 25% of t...
http://www.agron.iastate.edu/courses/agron342/reports/s00/de... [more from this site]

37. Senate ratifies **Desertification** Treaty, 22 others
eco-logic ---- on-line ---- (M) indicates member section eco-logic report On December 8, Senator Thomas' office called to explain that it was he who happened to be on the floor late in the after...
http://sovereignty.freedom.org/p/land/treaties.shtml [more from this site]

38. Combating **Desertification**
NepalNet an electronic networking for sustainable development in Nepal Combating **Desertification** Report of the National Seminar on **Desertification** and Land Improvement
http://www.panasia.org.sg/nepalnet/ecology/desert.htm [more from this site]

39. General Information on **Desertification**
General Information on **Desertification** Definitions, causes, consequences and remedies The term "desertification" is much misused [SARDC, 1994] but there is increasing acceptance of a vie...
http://www.wcmc.org.uk/dynamic/desert/emg_main.html [more from this site]

40. Enda - RIOD Afrique and **Desertification**
Welcome to the Riod Africa homepage. This page complements the RIOD homepage hosted at ELCI in Kenya, the RIOD Global Focal Point. The following information is available
http://www.enda.sn/energie/desertif/desertif.htm [more from this site]

41. **Desertification** INC For the Elaboration of an International Convention to Combat **Desertification**: Year End Update Land Use -- Land Degradation and **Desertification**
http://ramat-negev.org.il/desertif.htm [more from this site]

42. **Desertification** **Desertification** Backgrounder **Desertification** is a process whereby the productivity of drought- prone land decreases because of a variety of factors including deforestation, overcultivation, drought...
http://www.lehigh.edu/~kaf3/books/reporting/desert.html [more from this site]

43. Agenda 21, Chapter 12 URL = http/www.igc.apc.org/habitat/agenda21/ch-12.html Managing Fragile Ecosystems: Combating **Desertification** And Drought 12.1 Fragile ecosystems are important ecosystems, with unique features ...
http://www.igc.org/habitat/agenda21/ch-12.html [more from this site]

44. USGS Programs in Nebraska
The USGS provides maps, reports, and information to help others meet their needs to manage, develop, and protect America's water, energy, mineral, and land resources.
http://water.usgs.gov/wid/html/ne.html [more from this site]

45. Devel-L: Reversing **Desertification**
Merriott" <mailto:102450.3200@COMPUSERVE.COM> Subject: Reversing **Desertification** To: Multiple recipients of list DEVEL-L <mailto:DEVEL-L@AMERICAN.EDU>
http://library.wustl.edu/~listmgr/devel-l/Aug1995/0048.html

46. Sustainable Development - Issues/**Desertification**
Issues - **Desertification** and Drought Deserts are among the "fragile ecosystems" addressed by Agenda 21, and, specifically, "combating **desertification** and drought" is the subject...
http://www.un.org/esa/sustdev/desert.htm

47. Devel-L: Occasional Papers on **Desertification**
GreenLife Society (mailto:pcis@IGC.APC.ORG) Wed, 10 Jul 1996 09:57:59 -0700 Message-ID: <2.2.16.19960710095746.831fb836@pop.igc.org> Date: Wed, 10 Jul 1996 09:57:59 -0700 From: GreenLife Soc...
http://library.wustl.edu/~listmgr/devel-l/Jul1996/0024.html

48. Clim-Econ 96 disc: **Desertification** Occasional Papers
Sun, 14 Jan 1996 11:17:25 -0600 GreenLife Society: North American Chapter (wcburns1@students.wisc.edu) Announcement of Publications: GLSNA International Environmental Law Occasional Paper Series C...
http://csf.colorado.edu/clim-econ/96/0000.html

49. Senate ratifies **Desertification** Treaty, 22 others
eco-logic ---- on-line ---- (M) indicates member section eco-logic report On December 8, Senator Thomas' office called to explain that it was he who happened to be on the floor late in the after...
http://www.sovereignty.net/p/land/treaties.shtml

50. Mailing List ENVCEE-L: INFOTERRA: Losing the battle against desertific...
alternativ@oehserv.boku.ac.at Sun, 14 Feb 1999 22:36:00 +0100 Date: Sun, 14 Feb 1999 22:36:00 +0100 From: alternativ@oehserv.boku.ac.at Subject: INFOTERRA: Losing the battle against desertificatio...
http://ecolu-info.unige.ch/archives/envcee99/0060.html

51. Expert Meeting on Synergies among the Conventions on Biodiversity, Cli...
Expert Meeting on Synergies among the Conventions on Biodiversity, Climate Change, Combating **Desertification** and the Forest Principles Sede Boqer, Israel, 17-20 March 1997
http://www.bgu.ac.il/BIDR/events/synergy.html

52. UNCCD--Desertification Information Network Project--Entry Page
Desertification information: Database of organizations around the world working on **desertification** issues; a product of the Information Network Project of the United Nations Convention to Combat De...
http://ag.arizona.edu/OALS/CSTCCD/

53. Tiempo issue 9: **Desertification** and climate change
Mick Kelly and Mike Hulme address the complex and often uncertain links between climate change, prolonged aridification or desiccation, and **desertification.**
http://www.cru.uea.ac.uk/cru/tiempo/issue09/desert.htm

54. ENVTECSOC sorted : International Workshop: Women and **Desertification**
Gilbert (blazing@igc.apc.org) >Dear Friends: >An international Workshop on Women and **Desertification** is going to be held in Nariobi, Kenya. The workshop is being organized by ELCI.
http://csf.colorado.edu/mail/envtecsoc/98/0175.html

55. Implementation of The Plan of Action to Combat **Desertification**
Report of the Secretary-General Studies requested by General Assembly Resolution 44/172 on the Implementation of The Plan of Action to Combat **Desertification**
http://grid2.cr.usgs.gov/des/desfintoc.php3

56. INFOTERRA: AUGUST 1995: 7th PREPARATORY SESSION FOR **DESERTIFICATION** CO...
INTERIM SECRETARIAT OF THE CONVENTION TO COMBAT DESERTIFICATIONSECRETARIAT INTERIMAIRE DE LA CONVENTION DE LUTTE CONTRE LA **DESERTIFICATION** For use of the media only:not an official document
http://www.www.ee/lists/infoterra/1995/08/0007.html

57. Land Cover Conversion, Land Degradation and **Desertification** in African...
Land Cover Conversion, Land Degradation and **Desertification** in African and Math & Natural Sciences Project country Sahelian region, Namibia, South Africa, Zimbabwe, Botswana, North China, Mongol...
http://www.lu.se/intsek/interlund/InterLund_095.html

58. ENVTECSOC sorted : INFOTERRA: WWW: New feature on climate change, biod...
Forwarded message: >From owner-infoterra@pan.cedar.univie.ac.at Sat Dec 27 07:57:08 1997 X-Authentication-Warning: pan.cedar.univie.ac.at: majordom set sender to owner-infoterra using -f Message...
http://csf.colorado.edu/envtecsoc/97f/0171.html

59. Untitled International Convention to Combat **Desertification** in Countries Experiencing Serious Drought and/or **Desertification**, Particularly in Africa Final text of the Convention, following completion of th...
http://users.ox.ac.uk/~wgtrr/ccd.htm

60. Combating **Desertification**
NepalNet an electronic networking for sustainable development in Nepal Combating **Desertification** Report of the National Seminar on **Desertification** and Land Improvement
http://www.panasia.org.sg/nepalnet/ecology/desert.htm

61. General Information on **Desertification**
General Information on **Desertification** Definitions, causes, consequences and remedies The term "desertification" is much misused [SARDC, 1994] but there is increasing acceptance of a vie...
http://www.wcmc.org.uk/dynamic/desert/emg_main.html

62. FAO **Desertification** Web Site
FAO **Desertification** Web Site
http://www.fao.org/DESERTIFICATION/Default.htm

63. Global **Desertification** Dimensions and Costs
Reproduced, with permission, from: Dregne, H. Global **desertification** dimensions and costs. In Degradation and restoration of arid lands. Lubbock: Texas Tech.
http://www.ciesin.org/docs/002-186/002-186.html

64. Senate ratifies **Desertification** Treaty, 22 others
eco-logic ---- on-line ---- (M) indicates member section eco-logic report On December 8, Senator Thomas' office called to explain that it was he who happened to be on the floor late in the after...
http://sovereignty.freedom.org/p/land/treaties.shtml

65. Enda - RIOD Afrique and **Desertification**
Welcome to the Riod Africa homepage. This page complements the RIOD homepage hosted at ELCI in Kenya, the RIOD Global Focal Point. The following information is available
http://www.enda.sn/energie/desertif/desertif.htm

66. INFOTERRA: JUNE 1995: UNEP **DESERTIFICATION** DAY MESSAGE
FOR IMMEDIATE RELEASE UNEP EXECUTIVE DIRECTOR MARKS WORLD **DESERTIFICATION** DAY, 17 JUNE, BY CALLING FOR INVESTMENT IN PEOPLE'S NEEDS AS WELL AS IN LAND
http://www.www.ee/lists/infoterra/1995/06/0049.html

67. ALN No. 41: Waser: Web resources on **desertification**, Pt. 2
Annotated list of web resources on **desertification**, with specific emphasis on Asia, Australia and the Americas. Published in Arid Lands Newsletter No. 41, Spring/Summer 1997.
http://ag.arizona.edu/OALS/ALN/aln41/webresources41.html

68. INFOTERRA: FEBRUARY 1999: INFOTERRA: Losing the battle against deserti...
http/www.africanews.org/atlarge/stories/19990131_feat2.html The Nation Kenya E-mail: ken@africaonline.co.ke Losing the battle against **desertification** in Africa
http://www.www.ee/lists/infoterra/1999/02/0032.html

69. Tiempo Climate Cyberlibrary, Floor 0, Theme sites, On the Web: dry...
Arid Lands Newsletter http/ag.arizona.edu/OALS/ALN/ALNHome.html Informative bulletin published by the Office of Arid Lands Studies at the University of Arizona, covering the **desertification** issue...
http://www.cru.uea.ac.uk/tiempo/floor0/theme/t26web.htm

70. **Desertification** One of the impacts which global warming may have on the surface of the Earth is to exacerbate the worldwide problem of **desertification.** A decrease in the total amount of rainfall in arid and semi-...
http://www.doc.mmu.ac.uk/aric/eae/Global_Warming/Older/Deser...

71. **Desertification** Report of the Executive Director PART I. World Status of **Desertification** PART II. The United Nations Plan of Action to Combat **Desertification** Monitoring the PACD and its evaluation by the Gover...
http://grid2.cr.usgs.gov/des/uncedtoc.php3

72. World threads - soil and **desertification**
With the growing number of human inhabitants of this wonderful planet, the inhabitable area is decreasing. some thousand years ago Mesopotamia (today Iran and Iraq) and also Mali were fertile, blo...
http://www.geocities.com/RainForest/1650/e_soil.htm

73. Margins of Hope: The Challenge of **Desertification**
IDRC Briefing No. 1, June 1999 That dirt which blew off my hand, that wasn't dirt ?That was my land, and it was going south into Montana or north up towards Regina, or east or west and it was neve...
http://www.idrc.ca/media/Desertification_e.html

74. Grassroots Indicators for **Desertification**: Grassroots Indicators among...
Tobias Onweng Angura Since time immemorial, the Langi of Northern Uganda have relied on local knowledge and experience to predict events related to the environment, social life, politics, and sec...
http://www.idrc.ca/books/focus/794/angura.html

75. INFOTERRA: OCTOBER 1997: INFOTERRA: UNEP Launches World Atlas of Deser...
Robert Bisset (Robert.Bisset@UNEP.ORG) Fri, 10 Oct 1997 17:02:33 +0200 --- Begin Included Message --- UNEP News Release. For information only. Not an official record.
http://www.www.ee/lists/infoterra/1997/10/0012.html

76. GEO-1: Figure 2.15. **Desertification** and land degradation in agricultu...
Desertification and land degradation in agriculturally used drylands of South America. Source: **Desertification** and land degradation in agriculturally used drylands of South America.
http://grid2.cr.usgs.gov/geo1/fig/fig2_15.htm

77. Sahara's abrupt **desertification** started by changes in Earth's orbit, a...
FOR IMMEDIATE RELEASE: 7 JULY 1999 Sahara's abrupt **desertification** started by changes in Earth's orbit, accelerated by atmospheric and vegetation feedbacks
http://www.eurekalert.org/releases/agu-sad070799.html

78. Untitled
The United Nations Convention to Combat **Desertification**
http://www.un.org/millennium/law/xxvii-25.htm

79. Peace Corps | World Wise Schools | Lesson Plans | Teacher Guides | Sen...
Purpose: To practice basic map skills and to review the geography of Africa and Senegal Materials: Web Sites About **Desertification**: United Nations Plan of Action to Combat **Desertification**
http://www.peacecorps.gov/wws/guides/senegal/debate.html

80. Convention to Combat **Desertification**
A Clearing House for Information on the Convention to Combat **Desertification** Presented by the International Institute for Sustainable Development (IISD)
http://www.iisd.ca/linkages/ccdcop1.html

81. **Desertification**: a backgrounder for journalists
What about impacts of **desertification** in the South upon those living in the North? Three major potential impacts are discussed in scientific and political circles
http://www.idrc.ca/media/edesert1.html

82. Fight deforestation & **desertification**,create microenterprise
EnCorps promotes renewable energy resources through solar micro-enterprise sustainable developmen,fighting deforestation & **desertification**
http://home.att.net/~jw3981/encorps/Main.htm

83. Grassroots Indicators for **Desertification**: Appendix
18?9 October 1993, IDRC, Ottawa The Grassroots Indicators Initiative Agenda 21 and other outcomes of the 1992 United Nations Conference on Environment and Development (UNCED) articulated the need ...
http://www.idrc.ca/books/focus/794/append.html

84. MEDALUS - Mediterranean **Desertification** and Land Use
Mediterranean **Desertification** and Land Use MEDALUS is an international research project to investigate the effects of **desertification** on land use in Mediterranean Europe.
http://www.cru.uea.ac.uk/cru/projects/medalus/

85. **Desertification** : Natural Background and Human Mismanagement : Spring ...
Desertification : Natural Background and Human Mismanagement : Spring Study Edition by Mainguet, Monique; Hardcover
http://www.netstoreusa.com/mabooks/038/0387577467.shtml

86. PRACTICAL GUIDE FOR NON-GOVERNMENTAL ACTORS
International Convention to Combat **Desertification** SECOND CONFERENCE OF PARTIES November 30 - December 11, 1998 Dakar - Senegal PRACTICAL GUIDE FOR NON-GOVERNMENTAL ACTORS
http://www.enda.sn/ngoguide.html

87. Desert Problems and **Desertification** in Central Asia : The Researches o...
Desert Problems and **Desertification** in Central Asia : The Researches of the Desert Institute by Babaev, Agadzhan G. (Edt); Hardcover
http://www.netstoreusa.com/mabooks/354/3540656472.shtml

88. EXPERIENCES OF DEVELOPED COUNTRIES
Information Sharing Segment, First Substantive Session, Intergovernmental Negotiating Committee for a Convention to Combat **Desertification** -The Australian experience in combating **desertification** a...
http://www.unccd.int/convention/history/INCDinfoSeg/partvi.php

89. ScienceDaily Magazine -- Sahara's Abrupt **Desertification** Started B...
German scientists, employing a new climate system model, have concluded that **desertification** of the Saharan and Arabia regions was initiated by subtle changes in the Earth's orbit and strongly ...
http://www.sciencedaily.com/releases/1999/07/990712080500.htm

90. Impact on **Desertification**
Desertification occurs when land in arid or semi-arid regions is degraded by human activity including prolonged drought brought about by global warming.
http://bigmac.civil.mtu.edu/public_html/classes/ce459/projec...

91. **Desertification** Around the World
Links to articles and sites dealing with the issue of **desertification.**
http://environment.tqn.com/newsissues/environment/msubdes1.htm

92. The fight against **desertification**
Paper presented by Eden at the conference entitled 'The fight against **Desertification'** in Morocco, June 1989.
http://www.eden-foundation.org/project/semmoroc.html

93. Effects of **Desertification** in Africa
The Effects of **Desertification** in Africa Dustin Greiman Ryan Greiner Chris Madsen Jen Holtkamp Brad Bovy Kyle Mehmen **Desertification**, or land degradation in arid regions, affects close to 25% of t...
http://www.agron.iastate.edu/courses/agron342/reports/s00/de...

94. **Desertification** Monitoring: Is the Desert Encroaching?
Reproduced, with permission, from: Helldén, U. 1988. **Desertification** monitoring: Is the desert encroaching? **Desertification** Control Bulletin 17: 8-12.
http://www.ciesin.org/docs/002-178/002-178.html

95. OUP USA: World Atlas of **Desertification**
OUP Book World Atlas of **Desertification** by Middleton, Nick
http://www.oup-usa.org/docs/0340691662.html

96. International Symposium on Land Degradation and **Desertification**
Second Circular Call for papers Papers are invited on the following themes: Historical degradation and conservation of land and water. Impact of regional development on land degradation.
http://www.igeograf.unam.mx/instituto/land_deg.html

97. Grassroots Indicators for **Desertification**: Indicators in Decentralized...
Patrick Orone **Desertification** is defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.&q...
http://www.idrc.ca/books/focus/794/orone.html

98. Untitled This page introduces two publications on rangeland **desertification.** They are the result of an international workshop that was held in Iceland in September 1997.
http://www.rala.is/rade/

99. Parties to UNCCD to meet for first time in Rome
About 1 000 people, including heads of state, government ministers, mayors, diplomats and community leaders, will meet at FAO Headquarters in Rome, starting on 29 September, to address the leading ...
http://www.fao.org/NEWS/1997/970903-e.htm

100. **Desertification** INC For the Elaboration of an International Convention to Combat **Desertification**: Year End Update Land Use -- Land Degradation and **Desertification**
http://ramat-negev.org.il/desertif.htm

101. UNCED Chapter 12 - **Desertification**
Agenda 21 Report of the United Nations Conference on Environment and Development (Rio de Janeiro, 3-14 June 1992) Chapter 12 MANAGING FRAGILE ECOSYSTEMS: COMBATING **DESERTIFICATION** AND DROUGHT

http://www.cnie.org/agenda21/a21-12.htm

102. Land and environmental degradation and **desertification** in Africa
Issues and options for sustainable economic development with transformation by Prof. Nana-Sinkam of the Joint ECA/FAO Agriculture Division The views expressed in this document are those of the aut...
http://www.fao.org/docrep/X5318E/x5318e00.htm

103. TECHNIQUES FOR MITIGATING **DESERTIFICATION** PROCESSES IN MEDITERRANEAN C...
INTERNATIONAL CENTRE FOR ADVANCED MEDITERRANEAN AGRONOMIC STUDIES MEDITERRANEAN AGRONOMIC INSTITUTE OF ZARAGOZA ADVANCED COURSE TECHNIQUES FOR MITIGATING **DESERTIFICATION** PROCESSES IN MEDITERRANEAN ...
http://www.iamz.ciheam.org/ingles/tecdesert-00-pub-ing.htm

104. Environment News Service: Mediterranean Nations Share Knowledge to Hal...
COPENHAGEN, Denmark, September 27, 2000 (ENS) - Considerable areas of land bordering the Mediterranean will be lost beyond salvage to **desertification** within 50 to 75 years, a United Nations agency ...
http://www.ens-news.com/ens/sep2000/2000L-09-27-11.html

105. Sahara's abrupt **desertification** started by changes in Earth'...
American Geophysical Union NEWS July 7, 1999 AGU RELEASE NO. 99-20 For Immediate Release Contact: Harvey Leifert (202) 777-7507 hleifert@agu.org WASHINGTON -- One of the most striking climate ch...
http://www.agu.org/sci_soc/prrl/prrl9920.html

106. Erosion at the Valjean Site
Erosion, Erosion Recoverability, and **Desertification** Rates at the Valjean Site, Mojave Ecosystem Project by J. Calzia, B. Troxel, and C. EROSION RECOVERABILITY D.
http://www-wmc.wr.usgs.gov/home-esic/exhibit/erosion.html

107. enda deserification page
enda energie [en fran□is] enda home page home energy in Africa climate change **desertification** renewable energy rabede networks online documents publications links staff contact us
http://www.enda.sn/energie/desertif/desert.htm

108. FAO : SD Dimensions : Environment : Specials
12 **Desertification** 14 SARD Progress Report FAO, June 1997 Chapter 12: Managing fragile ecosystems: Combating **desertification** and drought The challenge
http://www.fao.org/waicent/faoinfo/sustdev/EPdirect/EPre0031...

109. NGO Report on the Convention to Combat...
NGO Report on the Convention to Combat **Desertification** for Rio + 5 Prepared by Richard Ledgar on behalf of the RIOD Steering Committee - January 1997Réseau International d□NG sur la D&eacu...
http://www.ecouncil.ac.cr/rio/focus/report/english/riod.htm

110. **Desertification** **Desertification** The degradation of soil, forest, water, animal and plant resources is becoming increasingly common. The results are manifested in droughts, **desertification**, decreased agricultural ...
http://www.sdgateway.net/topics/87.htm

111. Combating **desertification**
Combating **desertification** Disastrous sandstorms that hit several major cities recently in North China have alarmed the nation about the devastating consequences of the development strategy that tu...
http://chinadaily.com.cn.net/cndy/history/2000/05/d4-1com.52...

112. IMPACTS - **Desertification**
Climate Change and the Mediterranean Region Executive Summary Water shortages and poor harvests during the droughts of the early 1990s exposed the acute vulnerability of the Mediterranean region ...
http://www.greenpeace.org/~climate/science/reports/desertifi...

113. **Desertification** Backgrounder - Suite101.com
Desertification is a process whereby the productivity of drought- prone land decreases because of a variety of factors including deforestation, overcultivation, drought, overgrazing (poor rangelan...
http://www.suite101.com/article.cfm/environment/31882

114. The **desertification** of China
China's desert storm: Are the sands of time running out for Beijing
http://www.gluckman.com/ChinaDesert.html

115. **Desertification**: a backgrounder for journalists
The substance of the convention Article 2 of the Convention says: The Objective of this Convention is to combat **desertification** and mitigate the effects of drought in countries experiencing serio...
http://www.idrc.ca/media/edesert2.html

116. Satellite Watch of **Desertification** in Northern Africa
http://www.egeo.sai.jrc.it/cameleo/

117. Upcoming Conferences on Dryland Development, **Desertification** and Droug...
If there are any conferences or meetings that you think should be included on this site, please send us an e-mail. International Symposium on Land Degradation and **Desertification** 6 - 13 May, 2001,...
http://www.undp.org/seed/unso/news/conferences.htm

118. ENB:04:56 CANADA: INDIA: AUSTRALIA: NORWAY: ISRAEL: BENIN: LIBYA: FRANCE: IRAN: BARBADOS: MONGOLIA: TUNISIA: UGANDA: NIGERIA: TANZANIA: SUDAN: PAKISTAN
http://www.iisd.ca/linkages/vol04/0456000e.html

119. Mediterranean **Desertification** and Land Use (MEDALUS)
The website of the Water Resource Systems Research Laboratory at Newcastle University
http://www.ncl.ac.uk/~nwrgi/wrsrl/projects/medalus/medalus.html

120. **Desertification** Treaty: Evolution, Status, and Key Issues
This Congressional Research Service Report is made available to the public by THE NATIONAL COUNCIL FOR SCIENCE AND THE ENVIRONMENT 1725 K Street, NW, Suite 212, Washington, D.C. 20006 (202) 530-581...
http://www.cnie.org/nle/inter-50.html

121. Grassroots Indicators for **Desertification**: Pastoral Maasai Grassroots ...
Naomi Kipuri Grassroots indicators are features of indigenous knowledge systems which provide the means through which communities live, produce, conserve, and reproduce their natural resource bases.
http://www.idrc.ca/books/focus/794/kipuri.html

122. Grassroots Indicators for **Desertification**: Akamba Land Management Syst...
Wilhelmina Oduol Sustainable development in Africa has preoccupied, and indeed confounded the international community in the last decade. Development planning and implementation, which previousl...
http://www.idrc.ca/books/focus/794/oduol.html

123. romance books - United Nations Conference on **Desertification** Books
A list of United Nations Conference on **Desertification** books and a great searchengine.
http://www.desktopthemefree.com/0080235816_ba1I_bago1.html

124. ALN No. 41: Norton & Sandor: Combating **desertification** with Zuni a...
This article describes the Zuni Conservation Project, an interdisciplinary effort to combine traditional indigenous knowledge with modern scientific research in order to promote sustainable develop...
http://ag.arizona.edu/OALS/ALN/aln41/norton.html

125. BBC News | Africa | Traditional healers to help stop Niger desertifica...
The authorities in Niger have been meeting with traditional healers to try to enlist their support in the fight against **desertification.**
http://news2.thdo.bbc.co.uk/hi/english/world/africa/newsid_3...

126. Grassroots Indicators for **Desertification**: The Use of Trees, Birds and...
Claude G. In sociological and anthropological literature, we find extensive discussions on the cosmologies of different people, notably the way these people understand the world of their experien...
http://www.idrc.ca/books/focus/794/mararike.html

127. Green Cross International - Homepage
Official web site of Green Cross International. Access to Profile, Current and Future Events, Programs (Earth Charter, Legacy of Wars, Water and **Desertification**, Energy and Resource Efficiency, En...
http://www.gci.ch/

Directory: Lifestyle > Politics and Society > Environmentalism > Organizations > Intl Groups

128. desert.html The deserts of the world shift and change size over time, in response to both natural and anthropogenic fluctuations. Possible feedbacks between desert margin changes and the regional climate have...
http://grads.iges.org/res/proj10/proj10.html

129. **Desertification**
Desertification is the conversion of productive rangeland or cropland into desertlike land. It is usually caused by a combination of overgrazing, soil erosion, prolonged drought and climate change.
http://ps.ucdavis.edu/classes/ire001/env/desert.htm

130. **Desertification**: Modelisation des Ecoulements et D'Erosion (DM2E)
The website of the Water Resource Systems Research Laboratory at Newcastle University
http://www.ncl.ac.uk/wrgi/wrsrl/projects/dm2e/dm2e.html

131. RTD Info 23 - **Desertification**: identifying the symptoms to administer ...
IMPORTANT LEGAL NOTICE - The information on this site is subject to a disclaimer and a copyright notice. Global change The rural exodus is emptying the villages and the abandoned land is no longer ...
http://europa.eu.int/comm/research/rtdinf23/en/change.html

132. Convention to Combat Desertificatin (CCD)
Statement to the Convention to Combat **Desertification** (CCD) COP 4 Bonn ?Germany Ian Johnson, Vice President, World Bank Mr. President, Mr. Executive Secretary, Distinguished Delegates, Colleagu...
http://www.cgiar.org/chairij/ccdbonn.htm

133. Environment News Service: Earth's Spreading Deserts Get World Attentio...
BONN, Germany, June 16, 2000 (ENS) - Public concerts, theater performances, seminars, workshops, special training sessions, visits to field projects, and media campaigns are some of the initiatives...
http://ens.lycos.com/ens/jun2000/2000L-06-16-04.html

134. UNCCD Convention Text
Text and Ratification Status of theConvention to Combat **Desertification** The Convention to Combat **Desertification**, text and explanations: Status of Ratification and Entry into Force
http://www.unccd.int/convention/menu.php

135. Untitled NEW DEVELOPMENTS Updated 06 March 2000 by Ruben E Philippines Ratifies U.N. Convention to Combat **Desertification** (16 February 2000, New York) The Philippines has ratified the United Nations Conv...
http://www.undp.org/missions/philippine/new-devt.htm

136. Eden Foundation
Eden Foundation is an international organisation working for the preservation of biodiversity and better ways for humans to live in harmony with their environment.
http://www.eden-foundation.org/
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Land Use > Desertification

137. DeMon - University Utrecht
- Welcome to the Utrecht Home Page of the EU-Project - - Satellite Based **Desertification** Monitoring in the Mediterranean Basin - By Dr. M. de Jong.
http://www.frw.ruu.nl/fg/demon.html
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Land Use > Desertification

138. RANGE DEGRADATION IN BOTSWANA: MYTH OR REALITY?
Livestock:Coping with Drought a OneWorld partner Paper 27a A Solution to **Desertification**: Holistic Resource Management Allan Savory It is clear from the failure of our efforts in many countries...
http://www.oneworld.org/odi/pdn/papers/paper27a.html

139. **Desertification** Web Quest Who has seen my cows? Who has seen my goats? These leafless trees And this dry land Must be why they left. Youssou N'Dour
http://education.nmsu.edu/webquest/wq/Deserti/Desertificatio...

140. Peace Corps | World Wise Schools | Lesson Plans | Teacher Guides | Sen...
Purpose: To practice basic map skills while reviewing the location and physical features of Africa and Senegal. Have students find the words in the puzzle.
http://www.peacecorps.gov/wws/guides/senegal/puzz.html

141. Untitled
AGENDA 21, CHAPTER 12. MANAGING FRAGILE ECOSYSTEMS: COMBATING **DESERTIFICATION** AND DROUGHT Fragile ecosystems are important ecosystems, with unique features and resources.
http://www.ksdn.or.kr/resource/treaty/treaty01/t010012-e.htm

142. Conservation : Habitat ED 1995 / 4
Concerted action on **desertification** in Africa A regional research programme has been established to address **desertification** in sub-Saharan Africa. In the new Desert Margins Initiative, six sub-Sah...
http://www.gn.apc.org/ecosystem/ch954.htm

143. FAO FactFile Factfile Archive Archive of News and Highlights This graphic in pdf FAO Media Database Comments?: Webmaster@fao.org
http://www.fao.org/NEWS/FACTFILE/FF9710-E.HTM

144. Untitled Document
This site has moved to www.unep.ch/conventions
http://www.unep.ch/iuc/
Directory: Lifestyle > Politics and Society > Environmentalism > Education > Publications

145. PART I The concept of **desertification** was defined by UNCOD in 1977 as follows: "**Desertification** is the diminution or destruction of the biological potential of land, and can lead ultimately to deser...
http://grid2.cr.usgs.gov/des/uncedp1.php3

146. PART II Starting from 1978 , the Governing Council of UNEP at each of its regular sessions and in accordance with the mandate given to it by the UN General Assembly, considered progress in the implementati...
http://grid2.cr.usgs.gov/des/uncedp2.php3

147. PART III The main goal of implementing the Plan of Action to Combat **Desertification** remains the same as it was formulated in 1977 by the United Nations Conference on **Desertification** and endorsed by the Unit...
http://grid2.cr.usgs.gov/des/uncedp3.php3

148. PART IV There is no methodology for an accurate estimation of total economic loss due to **desertification** as there are far too many unaccountable losses involved, particularly off-site and social losses.
http://grid2.cr.usgs.gov/des/uncedp4.php3

149. Europe's first hot desert
Problems of **desertification** in Kalmykia (within the Russian Federation, north-west of Caspian Sea). Water resources, salinity, overgrazing and the need for international help for the Kalmyk people.
http://www.geocities.com/RainForest/Vines/7534/

150. JPL 1997 Abstract
Monitoring potential **desertification** via airborn TIR data: Sediment transport in the Mojave Desert, California M S Ramsey (Dept. of Geology, Arizona State Univ., Box 871404, Tempe, AZ 85287-1404; ...
http://www.pitt.edu/~mramsey/papers/jpl97_abs.html

151. **Desertification**
Photo taken in Burkina Faso during the dry season shows free-roaming cattle, evergreen trees, and millet residues. Cattle graze on seedlings, reducing shrub and tree cover.
http://is.dal.ca/~dp/reports/hopfnerst.htm

152. StarNet archive
Sunday, 31 January 1999 Overgrazing is tied to border **desertification** METRO/REGION1B By Tim Steller THE ARIZONA DAILY STAR
http://www.azstarnet.com/clips/chewland.htm

153. DEDC/PAC WWW Home Page
> The UNEP DEDC/PAC web page is designed to be viewd using Frame-Capable browser. Your Browser dose not have this capbility. Click HERE to browse our page.
http://www.unep.org/unep/program/natres/land/home.htm

154. Vetiver Grass Technology
A Tool Against Environmental Degradation and **Desertification** in Iberia. Dr. Paul Truong Resource Sciences Centre Queensland Department of Natural Resources Brisbane, Australia.
http://www.inpeco.pt/eng/environment/vetiver/vetiver.html

155. Thesis Main Page
PATTERNS OF HETEROGENEITY DERIVED FROM REMOTE SENSING IMAGES Implications for the Environmental Assessment of **Desertification** at Southern Portugal Northern Mértola, July 1995
http://gasa.dcea.fct.unl.pt/julia/Thesis/thesis.htm

156. EROS Bibliography
Land Degradation and **Desertification** EROS Bibliography Archive DESERT-L, file erosbib.txt. Part 1/1, total size 588133 bytes: Land Degradation and **Desertification** Bibliography
http://www.wcmc.org.uk/dynamic/desert/res_bib.html

157. UNCCD Page
Text of the United Nations Convention to Combat **Desertification** This section contains the full text of the Convention to Combat **Desertification**, which was elaborated by the Intergovernmental Negoti...
http://www.unccd.int/convention/text/convention.php

158. ALN No. 40: The CCD in Africa and the Mediterranean
This article describes actions taken to date regarding implementation of the UN Convention to Combat **Desertification** in African and Mediterranean countries. Published in Arid Lands Newsletter No. 4...
http://ag.arizona.edu/OALS/ALN/aln40/CCDarticle.html

159. Contents Social and environmental aspects of **desertification** Edited by J.A. Mabbutt and Andrew W. Proceedings of an Inter-Congress Meeting of the International Geographical Union Working Group on Desertif...
http://www.unu.edu/unupress/unupbooks/80127e/80127E00.htm

160. Untitled **Desertification** may possibly have caused more human suffering than any other environmental issue facing our planet today. The Many Consequences of **Desertification**
http://home.ica.net/~drw/env/d-page~2.htm

161. EUR-Lex: 11.70.10 - General
Directory of Community legislation in force Analytical register 298A0319(01) United Nations Convention to combat **desertification** in those countries experiencing serious drought and/or desertificati...
http://europa.eu.int/eur-lex/en/lif/reg/en_register_117010.html

162. Agenda 21, Chapter 12
URL = http/www.igc.apc.org/habitat/agenda21/ch-12.html Managing Fragile Ecosystems: Combating **Desertification** And Drought 12.1 Fragile ecosystems are important ecosystems, with unique features ...
http://www.igc.org/habitat/agenda21/ch-12.html

163. Feature The new statistics are available on each agency□ website, including the World Bank□ at http/www.worldbank.org/data/jointdebt.html Today□ Feature
http://www.worldbank.org/html/today/html/feature.htm

164. MEDALUS III - Agri Basin web pages
This site contains information on research studies developed in the Agri basin target area (Southern Italy) under MEDALUS III EEC Project (Mediterranean **Desertification** and Land Use). The site ...
http://www.unibas.it/medalus/agrimed.htm

165. Other Intersting sites on the Internet
Other Intersting sites on the Internet **Desertification** and deserts MEDALUS II is an international research project to investigate the effects of **desertification** on land use in Mediterranean Europe.
http://www.wcmc.org.uk/~dynamic/desert/oth_main.html

166. Lenard Milich: Dissertation
This document is available on cd for U.S.$30, cheaper than ordering from UMI; furthermore, the cd shows all images in color, which neither the UMI paper medium nor its microfilm can do.
http://ag.arizona.edu/~lmilich/diss.html

167. Desert reaches Europe
EMMA GABUNSHINA describes how **desertification** has caused an environmentalcrisis in European Russia and the struggle, assisted by UNEP, to combat it The dark shadow of **desertification** has now fallen...
http://www.ourplanet.com/imgversn/85/gabun/

168. Untitled Olafur Arnalds Agricultural Research Institute, Keldnaholt, IS-112 Reykjavik, Iceland Tel: 354 577 1010; Fax: 354 577 1020; E-mail: ola@rala.is Steve ArcherDepartment of Rangeland Ecology & Man...
http://www.rala.is/rade/KLUWER/info.htm

169. Express 94-07 October 1994
INTERNATIONAL DEVELOPMENT INFORMATION CENTRE Are the world's arable lands being relentlessly consumed and degraded? Is this threat real and is it being adequately addressed in our agenda for the ...
http://www.acdi-cida.gc.ca/xpress/dex/dex9407.htm
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Land Use > Desertification

170. Software tools for harvesting, storage, and utilization of rainwater i...
IDRC is supporting a pilot project to help Jordan capture and make the most efficient use of rainwater for food and feed production. The project, which links scientists from the Middle East and Ca...
http://www.idrc.ca/books/reports/1997/21-01e.html

171. About UNCCD Secretariat
About the UNCCD SecretariatBonn, Germany The Secretariat for the Convention to Combat **Desertification** (UNCCD) was established by the United Nations General Assembly to assist the Intergovernmental ...
http://www.unccd.int/secretariat/secretariat.php

172. ENB:04:12
A BRIEF HISTORY OF THE INCD INTERSESSIONAL ACTIVITIES WORKSHOP ON **DESERTIFICATION** AND LAND USE IN THE MEDITERRANEAN BASIN EXPERTS MEETING ON **DESERTIFICATION** FROM LATIN AMERICA AND THE CARIBBEAN
http://www.iisd.ca/vol04/0412000e.html

173. Environmental Organization WebDirectory - Land Conservation:Deserts an...
Land Conservation:Deserts and Arid Lands **Desertification** Information Network - Data and links concerning **desertification** Desert Research Institute - DRI is the environmental research division of U...
http://www.webdirectory.com/Land_Conservation/Deserts_and_Ar...

174. Environment
Reference Sources: Multilateral Treaties Deposited with the Secretary-General: Status as at 30 April 1999 (ST/LEG/SER.E/17) Register of International Treaties and Other Agreements in the Field of ...
http://home.earthlink.net/~apronto/treaties/environ.htm

175. ENB Vol. 4 No. 137 (COP-3)
Earth Negotiations Bulletin A Reporting Service for Environment and Development Negotiations Vol. 4 No. 149 Tuesday, 26 December 2000 SUMMARY OF THE FOURTH CONFERENCE OF THE PARTIES TO THE CONVENTI...
http://www.iisd.ca/vol04/enb04149e.html

176. ENB: UNCCD COP-3, Recife, Brazil
IISD's Earth Negotiations Bulletin covers global decision-making surrounding sustainable development, and in doing so, provides an online multimedia resource for environment and development policy ...
http://www.iisd.ca/desert/cop3/

177. GIS Applications at NGDC using NOAA Data
National Geophysical Data Center / WDC-A for Solid Earth Geophysics Boulder, Colorado USA more detailed version of this study. A different approach to using AVHRR imagery to map deserts (and othe...
http://web.ngdc.noaa.gov/seg/globsys/gisdes.shtml

178. International Politics on the World Stage 8th Ed.
Deforestation and **Desertification** While those of us in the developed countries of the world tend to think of environmental deterioration as the consequence of our heavily industrialized economies, ...
http://www.dushkin.com/rourke/ch18/deforest.mhtml

179. National, Regional and Sub-Regional Reports submitted to the Conferenc...
National, Regional and Sub-Regional Reports submitted to the Conference of the

Parties The following is a listing of the reports submitted to the Conference of the Parties (COP).
http://www.unccd.int/cop/reports/menu.php

180. Arid Lands Newsletter No. 40: Table of contents
Table of contents for Arid Lands Newsletter No. 40, Fall/Winter 1996, 'The UN Convention to Combat **Desertification**, Part I: Africa and the Mediterranean.'
http://ag.arizona.edu/OALS/ALN/aln40/aln40toc.html

181. On the Line - the environment of Burkina Faso
On the Line - the environment of Burkina Faso
http://www.ontheline.org.uk/explore/journey/burkina/environ.htm

182. Contents
Perception of **desertification** Edited by R. Heathcote The United Nations University Research for the reports contained in this monograph was financed from the United Nations University (Japan) Pr...
http://www.unu.edu/unupress/unupbooks/

183. Expert Meeting, Biodiversity,...:Document 3
Expert Meeting on Synergies among the Conventions on Biodiversity, Climate Change, Combating **Desertification** and the Forest Principles Sede Boqer, Israel, 17-20 March 1997
http://www.bgu.ac.il/BIDR/events/synergy/datarep.html

184. Arid Lands Newsletter No. 41: Table of contents
Table of Contents for Arid Lands Newsletter No. 41, 'The Convention to Combat **Desertification**, Part II: Asia and the Americas.'
http://ag.arizona.edu/OALS/ALN/aln41/aln41toc.html

185. USGS Programs in Nebraska--Grassland Fire Danger Assessment
(from U.S. Geological Survey Fact Sheet FS-025-96) Grassland fires pose a serious threat to agricultural and urban areas when grasses become dry owing to hot, dry, and windy weather conditions.
http://ne20dnelnc.cr.usgs.gov/factsheet/factpart3.html

186. The Global Mechanism
The Global Mechanism (GM) of the United Nations Convention to Combat **Desertification** was established as an instrument to facilitate the rationalisation of resource allocation and the mobilisation o...
http://www.gm-unccd.org/

187. Untitled
In order for the effects of **desertification** to be stopped, the government has to be willing to try and combat the problem, and gain the participation of the population.
http://home.ica.net/~drw/env/d-page~3.htm

188. ICE Conflict Case NIGER
Fulani and Zarma tribes pushed into fights by **Desertification?** CASE NUMBER: 29 CASE MNEMONIC: NIGER CASE NAME: **Desertification** in Niger CASE AUTHOR: Andrew H.
http://www.american.edu/projects/mandala/TED/ice/Niger.htm

189. Climate Change Fact Sheet 103
Desertification is a widespread environmental problem that directly affects over 100 countries on all the inhabited continents. It occurs when productive land in arid, semi-arid, or sub-humid dryl...
http://www.unep.ch/iucc/fs103.htm

190. [08 Jun 1999] SG/SM/7021 OBV/98: SECRETARY-GENERAL STRESSES UNITED NAT...
SECRETARY-GENERAL STRESSES UNITED NATIONS SYSTEM WILL NOT LAG BEHIND IN SEARCH FOR CONCRETE SOLUTIONS TO **DESERTIFICATION** AND DROUGHT Following is the text of a message of Secretary-General Kofi An...
http://www.un.org/News/Press/docs/1999/19990608.sgsm7021.html

191. INFOTERRA: JUNE 1995: UNEP Dryland Awards
FOR INFORMATION FIRST "SAVING THE DRYLANDS" AWARDS HIGHLIGHT EIGHT OUTSTANDING CONTRIBUTIONS TO COMBATING **DESERTIFICATION** NAIROBI, 28 June 1995 -- Eight individuals or projects that mad...
http://www.www.ee/lists/infoterra/1995/06/0095.html

192. INFOTERRA: FEBRUARY 1995: Convention To Combat Desertifica
Announcement Of Publication: International Convention To Combat **Desertification** The Pacific Center For International Studies, a Madison, Wisconsin-based think tank focusing on international enviro...
http://www.www.ee/lists/infoterra/1995/02/0078.html

193. INFOTERRA: MAY 1995: INCD Chair at UNEP GC
FOR IMMEDIATE RELEASE THE CONVENTION ON **DESERTIFICATION**: A SYMBOL OF AFRICAN DYNAMISM NAIROBI, 24 May 1995 -- Ambassador Bo Kjellen, Chairman of the Intergovernmental Negotiating Committee for th...
http://www.www.ee/lists/infoterra/1995/05/0082.html

194. INFOTERRA: APRIL 1995: UNDP-UNEP Agreements on desert. & INFOTERRA
FOR IMMEDIATE RELEASE UNDP AND UNEP SIGN AGREEMENTS ON **DESERTIFICATION** AND ON COMPUTER NETWORKING PROGRAMMES FOR SUSTAINABLE DEVELOPMENT NEW YORK, 26 April 1995 -- Two important partnership agree...
http://www.www.ee/lists/infoterra/1995/04/0088.html

195. Information List for ENVIRONMENTAL ADMINISTRATION AND POLICY
DATA LIST ON ENVIRONMENTAL ADMINISTRATION AND POLICY (13 data) Send questions on contents, access, and use to www@nies.go.jp Information name: Towards Solving the Global **Desertification** Problem ...
http://www.nies.go.jp/english/eic-e/eiguide_e/linklist/i0000...

196. Departmental Research
Departmental Research, Newtech, Concerted Action on Mediterranean **Desertification**, HERB, Medalus
http://www.kcl.ac.uk/kis/schools/hums/geog/projects.htm

197. UNEP DEDC/PAC Web INCD Convention Page incdre00.htm
INTERGOVERNMENTAL NEGOTIATING COMMITTEE FOR THE ELABORATION OF AN INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION** IN THOSE COUNTRIES EXPERIENCING SERIOUS DROUGHT AND/OR **DESERTIFICATION**, PARTICUL...
http://www.unep.org/unep/program/natres/land/convfinl.htm

198. Water Conflict Prevention - Water Resources at Green Cross Internation...
Green Cross International Water and **desertification** program
http://web243.petrel.ch/GreenCrossPrograms/waterres/waterres...

199. BBC News | Asia-Pacific | Chinese call for action on deserts
The state-run China Daily newspaper has called for a new law to halt **desertification.**
http://news.bbc.co.uk/hi/english/world/asia-pacific/newsid_3...

200. Content Links: Science & Technology
Atmospheric Studies WebQuest:Students research weather, ozone, and acid rain. Journey into the Unknown Students research Black Holes. A **Desertification** WebQuestStudents will focus on the causes a...
http://www.pwcs.edu/i-tech/techint/middle/page3.html

201. EARS
Activities: Chlorophyll Fluorescence Meter, Thermogaphic Inspections, ,Coal Fire Monitoring, METEOSAT, NOAA and LANDSAT TM satellite image processing, Forest Monitoring, Cloud Detection, Crop Yi...
http://www.ears.nl/

202. The Jacob Blaustein Institute for Desert Research (BIDR)
Deserts and other drylands constitute more than 40% of the global land area. Global environmental changes such as global warming and further **desertification** of drylands threaten 900 million peop...
http://www.bgu.ac.il/BIDR/
Directory: Education > Science and Nature > Ecology > Biomes and Ecosystems > Deserts

203. Menu of Treaty Texts (subject index)
Note that some treaties are listed in more than one category. Click on the title of a treaty to see the full text of that treaty, plus links to status and summary files for that treaty. (Note: Date...
http://sedac.ciesin.org/pidb/texts-subject.html

204. Saharasia, and The Orgone Accumulator Handbook
Titles by James DeMeo. This Page Has Moved to a New Internet Address (Click

Below): Also Please Make Note of the New OBRL Web Address: Click above to transfer to the new web site
http://id.mind.net/community/orgonelab/xbjdemeo.htm

205. IALC: Related Information
index of hot links to other arid-lands-related resources
http://ag.arizona.edu/OALS/IALC/links/1stlevel.html

206. ENB: UNCCD COP-2, Dakar, Senegal
UNCCD COP-2 THE SECOND MEETING OF THE CONFERENCE OF THE PARTIES TO THE U.N. CONVENTION TO COMBAT **DESERTIFICATION** Hotel Meridien President, Dakar, Senegal 30 November - 11 December 1998
http://www.iisd.ca/desert/cop2/

207. Italy
Italian CHM-CCD UN Convention to Combat **Desertification** Local Search BioSeek Read Me Please Staff & Contacts
http://wwwamb.casaccia.enea.it/chm-cbd/

208. Other climate research facilities worldwide
UEA Maths dept. Oceanography information MEDALUS - Mediterranean **Desertification** and Land Use NCAR - US National Center for Atmospheric Research U.
http://www.cru.uea.ac.uk/cru/other.htm

209. towards earth summit two
http/www.igc.apc.org/habitat/csd-97/schedule.html towards earth summit two january to june 1997 dates and links for some key events **desertification** convention negotiations - 10th session (incd-...
http://www.igc.apc.org/habitat/csd-97/schedule.html

210. Soil Conservation
Consortium for Earth Sciences Information Network Guide: Land Degradation and **Desertification** Noah's Ark: Information on how to create and maintain healthy soil and how to grow crops organically.
http://classes.aces.uiuc.edu/EnvSt298/soil_conservation.html

211. Technogies to protect forests and the earth
Sumitomo Chemical's Technologies toProtect Forests and the Earth Diminution of tropical forest and accelerated **desertification** of dry lands are becoming a serious problem.
http://www.sumitomo-chem.co.jp/earth/daichie.html

212. UNEP - Environmental Issues
Access to Environmental Information Air Quality Biodiversity and Conservation Chemicals (PIC and POPs) Cleaner Production Climate Change **Desertification** and Drylands Disasters and Emergencies Econo...
http://www.unep.org/unep/issue.htm

213. Prion Deletion and Insertion Mutants
New CJD victim had Saturday job in butcher's September 4 1997 Times BY RUSSELL JENKINS A MAN who worked part-time in a butcher's shop a decade ago has become the latest victim of Creutzfeldt-Jakob...
http://www.mad-cow.org/~tom/sept_news.html

214. Untitled Image Significance: This false-color image depicts **desertification**; arid lands; drought; and if compared to similar images taken at other points in time, land-use change which are the subjects of a...
http://sedac.ciesin.org/pidb/rsimages/RSGallery.html

215. UMDL: Africa Resources
West Africa United Nations report on food supply in sub-Saharan Africa says 20 countries are facing exceptional food emergencies. **Desertification** facts in pdf files.
http://scnc.aaps.k12.mi.us/~huridb/Africa/

216. MidLink Magazine: Winter, 1995
MidLink Magazine wishes you all of the peace and joy of this season. Join our celebration of hope and peace as you view Electronic Peace Cards from kids all over the world.
http://www.cs.ucf.edu/~MidLink/dec.home.html

217. Desert regreening: GreenWinds
This page provides information about Greenwinds, a non-profit organization whose goals are to combat global warming, promote the use of alternative energy sources, and combat **desertification** by tur...
http://www.pege.org/greenwinds/index.htm

218. GeoLinks.htm
These listings are maintained by Professor Vic DiVenere Department of Earth and Environmental Science C.W. Post Campus - Long Island University Please let me know if any of these links fail to wo...
http://www.columbia.edu/~vjd1/geolinks.htm

219. DesertPage
What is a Desert? A desert is a region which receives an average annual rainfall of 10 inches or less and has sparse vegetation cover. Types of Deserts: The type of desert is in actuality a refer...
http://grove.ufl.edu/~skanfou/DesertPage.htm

220. NGO Suggestions to the Proposed Outcome of the Special Session
towards earth summit ii NGO Suggestions to the Proposed Outcome of the Special Session These suggested amendments to the government text for negotiating at Earth Summit II (The UN Special Session ...
http://www.igc.apc.org/habitat/csd-97/ngosug.html

221. DDL: The Chihuahuan Desert
The Chihuahuan Desert is the easternmost, southernmost, and largest North American desert. Most of it is located in the states of Chihuahua and Coahuila in Mexico, but fingers of the Chihuahuan re...
http://www.horizon.nmsu.edu/ddl/database/chihuahua.html

222. Sound from AGBM-7
Bo Kjellen, Swedish delegate and Chair of the Intergovernmental Negotiating Committee on the Convention to Combat **Desertification** Ambassador Bo Kjellen of Sweden has participated in negotiations t...
http://www.iisd.ca/linkages/climate/7-97sound.html

223. World Overpopulation Awareness
Key Emerging Environmental Threats - from the UNEP - United Nations Environmental Program, Dec 8, 1998 Freshwater supply and quality both surface and groundwater, assessment of watersheds
http://www.overpopulation.org/impact.html

224. allAfrica.com: Niger - Top News
back<< NigerTop News May 18 The United Nations Food and Agriculture Organization (FAO) today announced an agreement with a regional African group designed to promote food security, rural deve...
http://allafrica.com/niger/

225. Fourth Session of the COP Bonn, Germany, 2000
Fourth Session of the COPBonn, Germany, 2000 The fourth session of the Conference of the Parties (COP) for the Convention to Combat **Desertification** was held in Bonn, Germany, from the 11th to the 2...
http://www.unccd.int/cop/cop4/menu.php

226. Natural Sciences for Students: Issues
Endangered Species Exotic Species Issues in State and Federal Conservation, California Native Plant Society Land Degradation and **Desertification**, CIESIN
http://ceres.ca.gov/education/issues.html

227. ines-africa-page: IDOC Africa Files 1.97
Agriculture - Land DARKOH, M. The human dimension of **desertification** in the drylands of Africa HUTTON, John Missing the target: for the South, CITES fails wildlife, frustrates communities
http://www.ines.org/africa/f0197.html

228. ENB:04:01
A SUMMARY OF THE PROCEEDINGS OF THE ORGANIZATIONAL SESSION OF THE INC FOR THE ELABORATION OF AN INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION** TUESDAY, 26 JANUARY 1993
http://www.iisd.ca/vol04/0401000e.html

229. Living on Earth Transcript: June 28, 1996
Archives of Living on Earth, NPR's environmental news and information show. Transcripts are available online in both text and RealAudio format.

http://www.loe.org/archives/960628.htm

230. ICOM II Abstract: Honrubia
HONRUBIA, MARIO & MORTE, ASUNCION. Dpto de Biología Vegetal, Fac. Biología, Univ. Murcia 30100, SPAIN. Erosion and **desertification** are two of the most important environmental pr...
http://www-icom2.slu.se/ABSTRACTS/Honrubia.html

231. GREEN CROSS INTERNATIONAL GENERAL PRESENTATION
Environmental Legacy of Wars Fighting **Desertification** GREEN CROSS INTERNATIONAL GENERAL PRESENTATION Give Humanity a Chance, Give the Earth a Future
http://www.gci.ch/GreenCrossFamily/presentation.html

232. ENB:04:95 SUMMARY OF THE NINTH SESSION OF THE INC FOR THE CONVENTION TO COMBAT **DESERTIFICATION**: 3-13 SEPTEMBER 1996 A BRIEF HISTORY OF THE INCD NEGOTIATION OF THE CONVENTION
http://www.iisd.ca/vol04/0495000e.html

233. Technologies to protect air
Sumitomo Chemical's Technologies to Protect Air It is pointed out that the increasing concentration of carbon dioxide in the air warms the earth and may cause serious environmental consequences suc...
http://www.sumitomo-chem.co.jp/earth/taikie.html

234. GTAV: Hotlinks
From here, you may also. . . Weather and Climate and Related Hazards Atmospheric and climatic The National Oceanic and Atmospheric Administration (NOAA) of the U.S Department of Commerce
http://www.netspace.com.au/~gtav/hotlinks/climatehazards.html

235. AIM Communications Service
Welcome to the AIM Communications Service Mozambique News Agency AIM Reports Issue No.127, 10th February 1998 The Southern African Development Community (SADC) "is the only vehicle that will t...
http://www.geocities.com/Paris/1661/aim56.html

236. IHDP Scientific Projects
Land-Use and Land-Cover Change (LUCC, co-sponsored by IGBP) LUCC's objectives are to obtain a better understanding of land-use and land-cover changes (e.g., degradation, **desertification**, biodivers...
http://www.uni-bonn.de/ihdp/projects.htm

237. ENB:04:22
SUMMARY OF THE SECOND SESSION OF THE INC FOR THE ELABORATION OF AN INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: 13-24 SEPTEMBER 1993 A BRIEF HISTORY OF THE INCD
http://www.iisd.ca/vol04/0422000e.html

238. ENB:04:76
INC FOR THE CONVENTION TO COMBAT **DESERTIFICATION**: YEAR-END UPDATE A BRIEF HISTORY OF THE INCD FIRST SESSION SECOND SESSION THIRD SESSION FOURTH SESSION
http://www.iisd.ca/vol04/0476000e.html

239. Renewable Energy: Africa & Asia
Using Renewable Energy in Africa: How should Africa and Asia co-operate? Youba Sokona, ENDA Energy Programme. I INTRODUCTION Significant disturbances have, during the last few decades, hit the ec...
http://www.enda.sn/energie/reafrica.htm

240. SEDAC Issues
The ENTRI service is intended to provide information resources relevant to nine global environmental issues: land use/land cover change and **desertification**
http://sedac.ciesin.org/pidb/issues.html

241. Emerging Environmental Issues: good news and bad about the environment...
UN System-Wide Earthwatch aims to collect and distribute environmental monitoring information from all branches of the UN
http://www.unep.ch/earthw/Emergin.htm

242. networks
enda energy [en fran□is] enda home page home energy in Africa climate change **desertification** renewable energy rabede networks online documents publications links staff contact us
http://www.enda.sn/energie/nets.htm

243. ENB:04:90
INCD-9 HIGHLIGHTS: FRIDAY, 6 SEPTEMBER 1996 WORKING GROUP I WORKING GROUP II PANEL ON WOMEN AND **DESERTIFICATION** IN THE CORRIDORS THINGS TO LOOK FOR TODAY
http://www.iisd.ca/vol04/0490000e.html

244. Untitled
Terrestrial Ecology of the Land (ENVTERRA) Any environment effect on land except nuclear and toxic chemicals. Also see these related libraries: ENVDAMS (Dams) ENVBIOD (Biodiversity) ENVFORST (Nor...
http://www.alternatives.com/libs/envterra.htm

245. Green Cross International Profile
INTERNATIONAL PROGRAMS Environmental Legacy of Wars Water and **Desertification** Energy and Resource Efficiency Earth Charter Environmental Education and Communication
http://www.gci.ch/GreenCrossPrograms/profile.html

246. Untitled Regionalization at the JRN Authors: James F. Reynolds and Ross A. Scientific Basis for Regionalization at the JRN LTER Site Jornada Basin LTER focuses on changes in the distribution of soil res...
http://atlantic.evsc.virginia.edu/regionalization/jrn.html

247. ENB:04:24 A BRIEF HISTORY OF THE INCD INTERSESSIONAL ACTIVITIES CONFERENCE ON HUMAN LIVELIHOODS IN DRYLANDS LEGAL SEMINAR ON THE CONVENTION INTERNATIONAL PANEL OF EXPERTS ON **DESERTIFICATION** (IPED)
http://www.iisd.ca/vol04/0424000e.html

248. ENDA and Renewable Energy
Enda is a member of the Renewable Energy Network Renewable energies provide the key to many of sub-Saharan Africa's energy related problems - in the long run they stand to provide the solution to ...
http://www.enda.sn/energie/ENR.htm

249. White Gold Mail List: Re: Spelling hecker
Dear Joe, > However, sometimes my notes fall below that of a dissertation, or in Arizona > we call it a desertation. I think it is called **desertification** in Arizona.
http://www.lyghtforce.com/WhiteGold/00000088.htm

250. Passive Microwave Remote Sensing
Cooperation in microwave remote sensing between the Hydrological Sciences Branch of NASA-GSFC and the Earth Sciences Faculty of the Amsterdam Vrije Universiteit started as part of the Botswana-Pro...
http://www.geo.vu.nl/users/microwave/back.html

251. Welcome to SEPADO - SOMALIA
SEPADO, Somali Environmental Protection and Anti **Desertification** Organisation is Non Profit / Non Governmental Organisation that combats with environmental devestations in war torn Somalia
http://members.tripod.com/sepado/

252. Glossary A B C D E F G H I J K L M N O P Q R S T U V W X Y Z A. bahamensis a species of Aedes mosquito A. triseriatus A species of Aedes mosquito that transmits La Crosse virus.
http://www.solutions-site.org/reference/glossary.htm

253. ET 4/95: Keen on kamut: handling food allergies
Solve overpopulation, infant mortality, chronic hunger, fossil fuel pollution, deforestation and **desertification** through a global electrical grid. Sound like a bold statement?
http://www.sdearthtimes.com/et0294/et0294s3.html

254. energy in Africa
enda energy [en fran□is] enda home page home energy in Africa climate change **desertification** renewable energy rabede networks online documents publications links staff contact us
http://www.enda.sn/energie/plaq-gb.htm

255. Training at Gobabeb
Training at Gobabeb Training at Gobabeb is broad-based and regional. The planned arid lands training and research centre at Gobabeb would lend specific support to the International Convention to C...
http://www.iwwn.com.na/drfn/Gobtrain.html

256. ENB:04:75 SUMMARY OF THE SEVENTH SESSION OF THE INC FOR THE: CONVENTION TO: COMBAT **DESERTIFICATION**: 7-17 AUGUST 1995 A BRIEF HISTORY OF THE INCD FIRST SESSION
http://www.iisd.ca/vol04/0475000e.html

257. Ricardo Trigo I am a Phd student at the Climatic Research Unit, under the supervision of Dr. Jean Palutikof. Part of my research has been funded by the EC project MEDALUS (MEditerranean **Desertification** And Lan...
http://www.cru.uea.ac.uk/~ricardo/

258. allAfrica.com: Environment Ministers Meet In Niamey
Environment Ministers Meet In Niamey Email This Page Print This Page January 11, 2001 Posted to the web January 11, 2001 Environment ministers from countries in the Community of Sahelo-Saharan St...
http://allafrica.com/stories/200101110285.html

259. Career opportunity at GTRC
Career Opportunity Gobabeb training and Research Centre Phase I Programme The Gobabeb Training and Research Centre is a joint venture between the Ministry of Environment and Tourism and the Desert ...
http://www.iwwn.com.na/drfn/GTRC_vacancy.html

260. ALN No. 40: Henning: The Jatropha Project of Mali
Article describing project to promote use of Jatropha curcas plants in Mali for erosion control, soil improvement, renewable energy, and empowerment of women. Published in Arid Lands Newsletter No....
http://ag.arizona.edu/OALS/ALN/aln40/jatropha.html

261. snowdeal.org > parallax
environmental news network salon wired 1.4.2001 Christian Science Monitor Natural capitalism "Around the world, there are stark reminders of the impact that economic decisions can have on the...
http://www.snowdeal.org/section/parallax/

262. World - CIA 1992 The following is the entry for the World from the CIA World Fact Book, 1992 edition. large areas subject to severe weather (tropical cyclones), natural disasters (earthquakes, landslides, tsunami...
http://www.anbg.gov.au/world/world.html

263. United Nations Official U.N.Home Page. Includes U.N. Journal, Daily Highlights, Press Releases, Selected Newly Released Documents, U.N. Peacekeeping Operations, Documents of General As...
http://www.law.ecel.uwa.edu.au/intlaw/united_nations.htm

264. FAO : SD Dimensions : Environment
FAO's Sustainable Development Department advises governments on integrated policy, planning, and management of natural resources. It coordinates the Organization's implementation of the 1992 Earth...
http://www.fao.org/sd/ENdef_en.htm

265. ENB:04:86
SUMMARY OF THE EIGHTH SESSION OF THE INC FOR THE: CONVENTION TO: COMBAT **DESERTIFICATION**: 5-15 FEBRUARY 1996 A BRIEF HISTORY OF THE INCD NEGOTIATION OF THE CONVENTION
http://www.iisd.ca/linkages/vol04/0486000e.html

266. ENB:04:44 SUMMARY OF THE FOURTH SESSION OF THE INC FOR THE: ELABORATION OF AN: INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: 21-31 MARCH 1994 A BRIEF HISTORY OF THE INCD
http://www.iisd.ca/linkages/vol04/0444000e.html

267. ENB:04:56 The representative said that Sudan has established a supreme council on environment and natural resources to implement the Convention. Widespread grassroots reforestation campaigns are currently u...
http://www.iisd.ca/linkages/vol04/0456034e.html

268. ENB:04:02 A BRIEF HISTORY OF THE INCD A SUMMARY OF THE ORGANIZATIONAL SESSION ACTIVITIES SINCE THE ORGANIZATIONAL SESSION THE INTERNATIONAL PANEL OF EXPERTS ON **DESERTIFICATION** (IPED)
http://www.iisd.ca/linkages/vol04/0402000e.html

269. ELAN: apr97 : No-timber Forest Resources Symposium
Wed, 23 Apr 1997 08:44:19 -0700 celerino montes (cmontes@cicese.mx) CALL FOR PAPERS □IMPOSIUM ON NON-TIMBER FOREST RESOURCES?and □ORKING SESSIONS FOR THE INTERNATIONAL CONVENTION TO COMBAT DES...
http://csf.colorado.edu/elan/apr97/0061.html

270. FAO FactFile Factfile Archive Archive of News and Highlights FAO Home page Search our site This graphic in pdf FAO Media Database Comments?: Webmaster@fao.org
http://www.fao.org/news/factfile/FF9711-E.HTM

271. USGS Programs in Nebraska
The USGS provides maps, reports, and information to help others meet their needs to manage, develop, and protect America's water, energy, mineral, and land resources.
http://water.usgs.gov/wid/html/ne.html

272. ENB:04:34 PREAMBLE: SUMMARY OF THE THIRD SESSION OF THE INC FOR THE ELABORATION OF AN INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: 17-28 JANUARY 1994
http://www.iisd.ca/linkages/vol04/0434000e.html

273. Environment conservation, sustainable agriculture, reforestation, appr...
Skylake is an environment conservation, low cost housing, sustainable agriculture, reforestation, appropriate technology, irrigation and rural development project in Chaiyaphum, Thailand dealing wi...
http://www.wrweb.com/skylake.htm

274. Sustainable Development Links INDEX
Sustainable Development Links -- Covering Specific Environmental Issues -- Atmosphere - General I Biological Diversity I Biotechnology I Climate Change I **Desertification** and Drought I Forests I Fr...
http://www.unac.org/links/SusDev/environment.html

275. Highlights of Research
Highlights of Research A New Methodology for Long-range Forecasting of the Nile Floods Deforestation, **Desertification**, and the Drought in West Africa
http://web.mit.edu/eltahir/www/highlights.html

276. CCD Resource Page
CCD RESOURCE PAGE Implementation of the Convention to Combat **Desertification** can take many and various forms, but all solutions begin with awareness of the problem.
http://www.enda.sn/energie/desertif/tools.htm

277. Sustainable Use of Desert Vegetation
Taklamakan Desert, **Desertification**, Sustainable Use of Vegetation, Tamarix, Alhagi, Calligonum, Populus Ecological Basis for a Sustainable Management of the Indigenous Vegetation in a Central Asia...
http://chemsrv0.pph.univie.ac.at/ska/desert/chinmain.html

278. Disaster Management Team
UNDP Programmes in Gujarat Harnessing women's collective strength for women's empowerment US $ 400,00 People participation in dealing with **desertification** US $ 799,000
http://www.un.org.in/dmt/guj/defaultguj.htm

279. homepage
Download Acrobat Reader to get PDF (Portable Document Format) pages CO-ORDINATION OF ENVIRONMENTAL PROGRAMMES What's new International Seminar on Combating **Desertification** Freshwater Resources and ...
http://www.unesco.org/environment/

280. Clim-Econ 96 disc by thread
This archive was generated by hypermail 1.02. Clim-Econ 96 disc by thread Most recent messages Other mail archives **Desertification** Occasional Papers GreenLife Society: North American Chapter
http://csf.colorado.edu/mail/clim-econ/96/

281. List of Journals Indexed in AGRICOLA 1997 : D
List of Journals Indexed in AGRICOLA 1997 : D Dairy, food and environmental sanitation Dairy food environ. sanit. NAL call no. - SF221.D342 ISSN 1043-3546 Des Moines, Iowa : International Associ...
http://www.nalusda.gov/indexing/lji97/ljid.htm

282. ArabNet -- UAE, Business, Agriculture
Lying in the heart of the world's arid zone, the UAE has little rainfall and one would expect it to be a barren place. Barren places there certainly are, but the process of **desertification** has ver...
http://www.arab.net/uae/business/ue_agriculture.html

283. Trees, soil and water: Journey to Forever - healthcare for mountains, ...
Trees, soil and water: Journey to Forever - healthcare for mountains, trees for deserts, trees for people, forest, forestry, deforestation, erosion, soil conservation, water conservation, desertifi...
http://journeytoforever.org/tree.html

284. ENB:04:65
FUNDING: SUMMARY OF THE SIXTH SESSION OF THE INC FOR THE: ELABORATION OF AN: INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: 9-18 JANUARY 1995
http://www.iisd.ca/linkages/vol04/0465000e.html

285. GDRS Ankara Research Institute
Rural Services Ankara Research Institute The Institute was established in 1962 with an area of 204.8 ha in order to search solutions against erosion problems which are major consideration of Turkey...
http://www.khgm.gov.tr/ankarae.htm

286. ENB:04:56
The representative said that subregional, regional and international collaboration is essential to mitigate the effects of drought. Countries in South Asia suffering from drought should have been ...
http://www.iisd.ca/linkages/vol04/0456035e.html

287. EPA Global Warming: Impacts - Deserts
The EPA Global Warming Site Desert Impacts. Scientists at NASA have suggested that in the long run, a worldwide expansion of deserts is likely.
http://www.epa.gov/globalwarming/impacts/deserts/

288. FAO PhotoFile
The world's soils, the most important resource for food production, are threatened by land degradation, deforestation, overgrazing, erosion or poor management of arable land.
http://www.fao.org/NEWS/FOTOFILE/PH9731-e.htm

289. Hot Topics OCLC NetFirst Hot Topics: Drought / **Desertification** Evolution and Creationism Racial Profiling Death Penalty Child Labor/Forced Labor September 1, 2000
http://www.westvalley.edu/wvc/pat/hottopics.html

290. ENB:04:55 INCD-6: SUMMARY OF THE FIFTH SESSION OF THE INC FOR THE: ELABORATION OF AN: INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: 6-17 JUNE 1994 A BRIEF HISTORY OF THE INCD
http://www.iisd.ca/linkages/vol04/0455000e.html

291. The Daily Star: General News
The Daily Star: The First Daily Newspaper on the Internet from Bangladesh
http://www.dailystarnews.com/199804/22/n8042210.htm

292. New Scientist Planet Science | Back to the woods
HOME · CONTENTS · JOBS In this week's letters Your letter Have a letter to the editor of your own? Send it in. Back to the woods ALLAN SAVORY claims there is increasing desertificati...
http://gmworld.newscientist.com/ns/19990410/letters10.html

293. datadubai.com: AGRICULTURE IN THE U.A.E.
Lying in the heart of the world's arid zone, the UAE has little rainfall, but the process of **desertification** has very largely been arrested in the country.
http://www.datadubai.com/agri.htm

294. EnvTecSoc sorted: CONFERENCE: Impact on biological carbon sinks
Sat, 3 Feb 1996 19:26:00 -0800 (PST) Claire Gilbert (blazing@crl.com) International conference Global change impacts on biological carbon sinks* How are ultraviolet radiation, climate change, wat...
http://csf.colorado.edu/Envtecsoc/96s/0034.html

295. Untitled The Independent, 25 August 1997. ADB team to study Ganges barrage The Asian Development Bank will send a mission to Bangladesh soon to study the feasibility of a barrage over the Ganges, the proje...
http://www.dainichi-consul.co.jp/english/arsenic/as30.txt

296. List of Journals Indexed in AGRICOLA 1996 : D
List of Journals Indexed in AGRICOLA 1996 : D Dairy research report - Louisiana Agricultural Experiment Station Dairy res. rep. NAL call no. - SF241.L8N6 ISSN 0459-8504 Homer, La. : The Station.
http://www.nal.usda.gov/indexing/lji96/ljid.htm

297. TENTH SESSION OF THE INC FOR THE: CONVENTION TO COMBAT **DESERTIFICATION**: 6-17 JANUARY 1997 A BRIEF HISTORY OF THE INCD NEGOTIATION OF THE CONVENTION
http://www.iisd.ca/linkages/vol04/0496000e.html

298. General Objectives China EU Project
EU Project: Sustainable management of Desert Vegetation General Objectives This project should make a contribution of measures with which an expansion of **desertification** can be prevented, using a...
http://chemsrv0.pph.univie.ac.at/ska/desert/genobj.html

299. Sustainable Biosphere Project: Mediterranean Basin-Southern Europe, N...
With a nearly landlocked sea surrounded by shrublands, farmlands, deserts, and forests, this region has a long history of intensive human use. Juxtaposition of industrialized and developing countr...
http://osu.orst.edu/groups/sbp/medit.html

300. New Scientist Planet Science | Eroding America
HOME · CONTENTS · JOBS In this week's letters Your letter Have a letter to the editor of your own? Send it in. Eroding America WORLDWIDE biodiversity loss and consequent desertificat...
http://www.newscientist.co.uk/ns/19990327/letters2.html

301. Desert regreening: GreenWinds
This page provides information about Greenwinds, a non-profit organization whose goals are to combat global warming, promote the use of alternative energy sources, and combat **desertification** by tur...
http://www.pege.org/greenwinds/
Directory: Lifestyle > Politics and Society > Environmentalism > Topics > Sustainable Devpt > Organizations > International

302. Lab. Hydrology & Erosion
The evaluation of the functions of forest on the hydrologic cycle and gas exchange processes □Forest influences on the hydrologic and carbon cycles, regulating the conversion of precipitation to r...
http://bluemoon.kais.kyoto-u.ac.jp/actvt-eg.html

303. ENB:03:06
Eighty-seven countries signed the Convention to Combat **Desertification** at a ceremony in Paris on 14-15 October 1994. After signing the Convention, Governments -- many represented by their Minister...
http://www.iisd.ca/linkages/vol03/0306004e.html

304. Deutsche Forstservice GmbH: Forestry related links
forestry related links
http://www.dfs-online.de/links.htm

305. Nation-Online.com: The New Nation Internet Edition
The New Nation: Providing the latest news from Bangladesh
http://www.nation-online.com/199901/30/n9013009.htm

306. ENB:04:56 Eighty-seven countries signed the Convention to Combat **Desertification** at a ceremony in Paris on 14-15 October 1994. (See box on page 6.) After signing the Convention, Governments " many repre...
http://www.iisd.ca/linkages/vol04/0456008e.html

307. Pollution? Conservation policies have had some success in the forests and wetlands of the Eastern U.S. - but globally the environmental picture looks bleak. **Desertification** is accelerating; rainforests are b...

http://www.henrygeorge.org/intpol.htm

308. ENB:04:66 The first session of the INCD was held in Nairobi, Kenya, from 24 May - 3 June 1993. The first week of the session focused on the sharing of technical information and assessments on various aspect...
http://www.iisd.ca/linkages/vol04/0466002e.html

309. List of Journals Indexed in AGRICOLA 1998 : D
List of Journals Indexed in AGRICOLA 1998 : D Dairy, food and environmental sanitation Dairy food environ. sanit. NAL call no. - SF221.D342 ISSN 1043-3546 Des Moines, Iowa : International Associ...
http://www.nalusda.gov/indexing/lji98/ljid.htm

310. Untitled UNITED NATIONS CONVENTION TO COMBAT **DESERTIFICATION** IN COUNTRIES EXPERIENCING DROUGHT, PARTICULARLY IN AFRICA, WITH ANNEXES (Senate - October 18, 2000)
http://www.sovereignty.net/p/land/treaty3-res.htm

311. ENB:04:23 INC FOR THE ELABORATION OF AN INTERNATIONAL CONVENTION TO COMBAT **DESERTIFICATION**: YEAR-END UPDATE PREPARATION OF THE NEGOTIATING TEXT CONFERENCE ON HUMAN LIVELIHOODS IN DRYLANDS
http://www.iisd.ca/linkages/vol04/0423000e.html

312. Error Page not found
ErrorPage not found The URL "/desertification.htm" was not found on this server. This website has been restructured, thus old bookmarks probably won't work anymore.
http://www.unccd.int/desertification.htm

313. Committee on Science and Technology (CST)
Committee on Science and Technology (CST) The Committee on Science and Technology (CST): In accordance with article 24 of the Convention, the Committee of Science and Technology (CST) was establish...
http://www.unccd.int/cop/cst/menu.php

314. The Daily Star: International News
The Daily Star: The First Daily Newspaper on the Internet from Bangladesh
http://www.dailystarnews.com/200002/14/n0021413.htm

315. Circle Cities - sustainable development oceans ocean river rivers la...
PUTTING THE ENVIRONMENTAL MOVEMENT ON THE MOVE ... TGP's Circle City Project As we approach the 21st century environmental problems such as overpopulation, global warming, **desertification**, pollu...
http://pages.prodigy.com/technogreen/pg10cc.htm

316. Third World Development - Journals and Newspapers
Third World Development / Journals and Newspapers E JOURNALS The Circular on **Desertification** Common Path- from the Commonwealth Foundation Development Update- by the United Nations Multinational Mo...
http://www.nene.ac.uk/lrs/Subjects/ThirdWorld/journals.html

317. Untitled Document
This information has been provided by M. Bateman and P. Last updated: 19 Apr 1999 The SCIDR Home Page has moved! Please update your bookmark. Click here to go to the new address.
http://www.shef.ac.uk/uni/academic/I-M/idry/

318. CSE-GEF Climate Change Page
SOUTH ASIAN NGO FOCAL POINT MARCH 28 - APRIL 3 International Waters The Ozone Layer CLIMATE CHANGE A Mirage of Money **Desertification**, almost exclusively a Southern problem, finds low priority wit...
http://www.oneworld.org/cse/html/gef/gef_cc.htm

319. English Site Map
- Biodiversity - Climate Change - **Desertification** - CITES - RAMSAR Treaty Documents Other Documents Site Map General Info Steering Committee Experts Meeting: Participants
http://www.nrcan-rncan.gc.ca/cfs/crc/english/sitmap_e.htm

320. MidLink Magazine
Welcome to MidLink Magazine , the electronic magazine for kids in the middle grades--generally ages 10 to 15. Browse through our interactive space to enjoy art and writing that will link middle sc...
http://www.cs.ucf.edu/~MidLink/index.fall.95.html

321. PUBPOL-L Archive: Re: The slavery of the 20th century
Richard Measell (rmeasell%SAINTMARYS.EDU@vm1.spcs.umn.edu) Wed, 13 Sep 1995 19:59:11 -0500 On Tue, 12 Sep 1995, Jay Hanson wrote: > > Evidence for unststainability, IPSO FACTO, is everywhere...
http://www.hhh.umn.edu/pubpol/pubpol-d/199509/0032.html

322. IDRC Reports Archive: A Market for Drylands and Deserts? (July 1994)
A Market for Drylands and Deserts? by Lucy Oriang in Kenya The depth of economic and environmental stress in eastern African nations is leading researchers to examine closely a sensitive topic: th...
http://www.idrc.ca/books/reports/V222/market.html

323. Expert Meeting, Biodiversity,...:Document 4DRAFT, 8 MARCH 1997
Expert Meeting on Synergies among the Conventions on Biodiversity, Climate Change, Combating **Desertification** and the Forest Principles Sede Boqer, Israel, 17-20 March 1997
http://www.bgu.ac.il/BIDR/events/synergy/instit.html

324. Positive Futures VS: Re: Big Foot/Sahara
David Appell wrote: > What originally got me going when Richard wrote: > > "It [the Sahara] seems to me to be a better example of modern > "wildernesses" being the result...
http://csf.colorado.edu/mail/pfvs/may98/0220.html

325. Ch20 Edouard G. For Sub-Saharan Africa as a whole, consisting of 45 countries, gross national product per person in constant dollars fell by 20 per cent between 1977 and 1986.
http://www.unu.edu/unupress/unupbooks/80918e/80918E0l.htm

326. Information Exchange Workshop in Africa - Nairobi, Kenya - On-going I...
On-Going Regional and International Information Exchange Initiatives Environmental Liaison Centre International Two projects were presented: 1) capacity building for information exchange mechanis...
http://www.ncsdnetwork.org/afrmidea/reports/infoexch97/initi...

327. DPA- newsfront for UNDP
Tuesday, 18 January, 2000 The NetAid webcast and Artists videos require RealPlayer. Human Development Report 1999 The Government of Finland agreed yesterday to provide US$1.6 million to the UNDP...
http://www.undp.org/dpa/frontpagearchive/january00/18jan00/i...

328. International Issues
The emergence of problems which are manifest on a global scale has been a defining feature of the environmental agenda over the past decade. The 1992 Rio agreements on climate change and biodivers...
http://www.sussex.ac.uk/Units/gec/topics/internat.htm

329. CSIRO Corporate Media Release 97/249
CSIRO MEDIA RELEASE 97/249 12 December 1997 FOODBOWL REGION "RISKS BECOMING DESERT" Large areas of northern NSW face the threat of **desertification** within the next decades, say CSIRO rese...
http://www.csiro.au/communication/mediarel/mr1997/mr97249.htm

330. Positive Futures VS: Re: Big foot/Sahara
> The "desertification" of the Sahara in the past and today may be a > "natural" process at least in part, but it has certainly been heavily > impacted and speeded up b...
http://csf.colorado.edu/mail/pfvs/may98/0177.html

331. Positive Futures VS: Re: Big foot/Sahara
Fri, 8 May 1998 18:40:06 +0900 (JST) Neil Johnson (neiljo@huis.hiroshima-u.ac.jp) > political power structures - I understand that the **desertification** was partly a > result of capitalist whe...
http://csf.colorado.edu/mail/pfvs/may98/0130.html

332. BENE Feb96 discussion: CONFERENCE: Impact on biological carbon sinks
Sat, 3 Feb 1996 22:25:20 +0600 Claire Gilbert (blazing@crl.com) International conference Global change impacts on biological carbon sinks* How are ultraviolet radiation, climate change, water and...
http://csf.colorado.edu/bene/1996/feb96/0005.html

333. Official Documents of the Fourth Session of the COP
Official Documents of the Fourth Session of the COP This provides the

provisional list of documents for the fourth session of the Conference of the Parties to the Convention to Combat Desertificati...
http://www.unccd.int/cop/officialdocs/cop4/doclist.php

334. ALN No. 44: Charrier: Water...in the Middle East
This article describes NGO Green Cross International's Water and **Desertification** Program in terms of their recent and planned future actions in the Middle East-North Africa (MENA) region. Published...
http://ag.arizona.edu/OALS/ALN/aln44/charrier.html

335. PUBPOL-L Archive: UNSUSTAINABLE (was The Slavery ...)
Jay Hanson (jhanson%ILHAWAII.NET@vm1.spcs.umn.edu) Thu, 14 Sep 1995 07:03:19 -1000 At 07:59 PM 9/13/95 -0500, Richard Measell wrote: >On Tue, 12 Sep 1995, Jay Hanson wrote: >> >> Ev...
http://www.hhh.umn.edu/pubpol/pubpol-d/199509/0035.html

336. Activities of GRID-Tsukuba and Data dissemination system in Database s...
Keiji Nunoi GRID-Tsukuba (GRID : Global Resource Information Database) Database Section of CGER(Center for Global Environmental Research) NIES(National Institute for Environmental Studies)
http://webtech.jrc.it/eogeo99/Papers/Nunoi/paper.html

337. Clim-Econ 96 disc by date
This archive was generated by hypermail 1.02. Clim-Econ 96 disc by date Most recent messages Other mail archives **Desertification** Occasional Papers GreenLife Society: North American Chapter
http://csf.colorado.edu/mail/clim-econ/96/date.html

338. ISU Publications_MSS TP reports
These projects are available directly from ISU. Please use the order form. Name of Report Code / Year Space Assisted Network Against **Desertification** (SAND)
http://isu.isunet.edu/IS/Library/Publications/TP.html

339. Catastrophism, Lost Civilizations, Forgotten Technologies, and Missed ...
Lost worlds, lost civilizations, forgotten technologies, strange evolutionary changes, and other mysteries of humanity's past and origins.
http://members.aol.com/jrspacer/lostcv4.html

340. Aoelian sediment transport
Aeolian sediment transport Objectives Aeolian dynamics involve studies of wind erosion, sediment transport, dune dynamics and growth of active desert areas **(desertification).**
http://www.geo.aau.dk/english/research/surface/aeolian/index...

341. Regional Consultation for North Africa and the...
Rio + 5 The Regional Consultation for North Africa and the Middle East Five years after the Earth Summit Final Report 18 -23 November 1996 - Beirut - Lebanon
http://www.ecouncil.ac.cr/rio/regional/africa/nafrica.htm

342. ALN No. 41: Sievers & Tsaruk: The CCD, Central Asian NGO perspecti...
This article describes some of the factors working against acceptance of the Convention to Combat **Desertification** in Central Asia and describes involvement of NGOs in the process. Published in ALN ...
http://ag.arizona.edu/OALS/ALN/aln41/sievers.html

343. Whither the Spirit of Rio?
Whither the Spirit of Rio? Prepared for the Earth Council by: Johannah Bernstein and Pamela Chasek Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Co...
http://www.ecouncil.ac.cr/about/contrib/spirtrio/whither.htm

344. Afghanistan
Desertification, in which human intervention causes good land to turn into desert, is far advanced in Afghanistan (see Desert). Because many Afghans are poor, they collect dung, uproot shrubs, and...
http://www.comptons.com/encyclopedia/ARTICLES/0000/00032000_...

345. Expert Meeting, Biodiversity, Climate Change ...: Documents
Expert Meeting on Synergies among the Conventions on Biodiversity, Climate Change, Combating **Desertification** and the Forest Principles Sede Boqer, Israel, 17-20 March 1997
http://www.bgu.ac.il/BIDR/events/synergy/documents.html

346. Glossary of Terms: D
Death Rate Rate at which deaths are occurring in a population. Can be measured as the number of individuals expiring per unit time or as percentage of the population dying per unit time.
http://www.geog.ouc.bc.ca/conted/onlinecourses/enviroglos/d....

347. Proposed Outcome of the Special Session
http/www.igc.apc.org/habitat/csd-97/prop-out.html This document was posted online by the United Nations Department for Policy Coordination and Sustainable Development (DPCSD) and has been formatt...
http://www.igc.org/habitat/csdngo/1997/prop-out.html

348. Poverty alleviation and land degradation in the drylands
Poverty alleviation and land degradation in the drylands: Issues and action areas for the international convention on **desertification** Paper produced by the United Nations Sudano-Sahelian Office in...
http://www.undp.org/seed/unso/pub-htm/pov-eng.htm

349. cwp3 Agricultural Reform: feeding China in a sustainable method By Ashley Hanks Two of the most talked about topics regarding China development are its food supply and its environment.
http://www.gwu.edu/~econ169/ashleyhanks-econ169.htm

350. The wasted land
The wasted land Ann Eveleth The apartheid-era homeland system and rural "betterment schemes" were the worst causes of land degradation, according to a rapid appraisal of land resources c...
http://web.sn.apc.org/wmail/issues/980619/NEWS31.html

351. BUDDHA DENDO TENDAI BUDDHIST OPEN TEACHINGS
DANA ESSHIN SOZO BRAINSTORMING SHIKAN MEDITATION THE CURRENT SANGHA GYO: ASCETIC PRACTICES NOW IS A FORTUNATE TIME PEOPLE GOING ON PILGRIMAGE SOME WORDS OF DENGYO DAISHI ONE VIEW OF TENDAI BUDDHISM...
http://www.quietmountain.com/dharmacenters/buddhadendo/tenda...

352. Agenda 21 - Natural Resource Issues
Agenda 21 - Natural Resource Issues For a list of countries that have reported on each of the twelve natural resource issues addressed in Agenda 21, select an issue.
http://www.un.org/esa/agenda21/natlinfo/agenda21/natur.htm

353. Web - The Network for social change
Fee-Based Services Telnet WEB.APC.ORG or 192.139.37.1 Enter your username and password Problems such as ozone depletion, the greenhouse effect, nuclear threats, **desertification**, deforestation, hun...
http://galaxy.einet.net/hytelnet/FEE027.html

354. BBC Online - BBC World, Saturday, 16 January 1999
All times in GMT BBC World News; Weather World Living: Earth Report **Desertification** Environmental series presented by David Attenborough. This programme looks at the spread of desert land in Ka...
http://search.bbc.co.uk/schedules/1999/01/16/world.html

355. Rio+5 Summary Report- Togo
Consultation organized by the Togoles Federation of NGOs and attended by representatives of government and civil society. Though there is no national council or committee for sustainable developme...
http://www.ecouncil.ac.cr/rio/natreg/afrmidea/english/tog.htm

356. INFOTERRA: JANUARY 1995: DESERT MARGINS WORKSHOP
UNEP Information (ipaunep@gn.apc.org) Sun, 8 Jan 1995 13:12:06 +0100 FOR IMMEDIATE RELEASE INTERNATIONAL, REGIONAL, NATIONAL AND NON-GOVERNMENTAL ORGANIZATIONS JOIN LANDMARK WORKSHOP ON DESERTIFI...
http://www.www.ee/lists/infoterra/1995/01/0025.html

357. Land Land Land resources, particularly soil, provide the foundation for nearly all of our food and forest resources. Yet, they are experiencing widespread degradation all over the world, through proces...
http://www.sdgateway.net/topics/100.htm

358. UN/DPCSD Newsletter Kiosk, Vol. 3, No. 4 (August/September 1996)
Kiosk Online Volume 2, Issue 5 - October/November 1995 Kiosk Online is an insider's look at the United Nations in the coordination of economic and social development policies.

http://www.un.org/esa/kiosk34.htm

359. Danger Signs Danger Signs Climate change, war, poverty, **desertification**, and pollution are all signs of deeper problems within our societies. They act as canaries in the coal mine - warning us when the system ...
http://www.sdgateway.net/topics/42.htm

360. INFOTERRA: SEPTEMBER 1997: INFOTERRA: Global Water Resources
Scientists agree global water resources need international cooperation August 1997 Water News Online ALBUQUERQUE -- An international conference on the growing problem of global **desertification** h...
http://www.www.ee/lists/infoterra/1997/09/0001.html

361. INFOTERRA: AUGUST 1995: UNEP TEXT AT INCD-7
Douglas Kahn (dkahn@nywork2.undp.org) Thu, 10 Aug 1995 16:01:59 +0200 Forwarded: Statement by Elizabeth Dowdeswell, Executive Director of UNEP, at the Seventh Session of the Intergovernmental Neg...
http://www.www.ee/lists/infoterra/1995/08/0017.html

362. WRI Article: Guesselbodi National Forest, Niger
Prepared with assistance from Kirk Talbott, World Resources Institute The Forestry Land Use Planning Project (FLUP) was launched in Niger in 1980 to help control desertification--one of deforestat...
http://www.wri.org/biodiv/intl-05.html

363. IIASA - Publications Catalog - Working Papers
The Failure of Scientific Expertise to Influence the **Desertification** Negotiations. Models for Growth of Pine Stands in Territories of Northern Eurasia.
http://www.iiasa.ac.at/docs/Admin/PUB/Catalog/PUB_TYPE_WP.html

364. Sahara and Arabia deserts once green - 7/12/1999 - ENN News - Environm...
Slight changes in Earth's orbit and the tilt of its axis thousands of years ago kicked off a series of events in the sub tropics that led to the **desertification** of the Saharan and Arabian regions o...
http://www.enn.com/enn-news-archive/1999/07/071299/sahara_42...

365. FAO - COMMITTEE ON AGRICULTURE
The World Food Summit underscored the critical role of land and water in food production, food security and sustainable development. It called for the highest priority to be given to programmes ai...
http://www.fao.org/UNFAO/Bodies/COAG/COAG15/X0326E.htm

366. INFOTERRA: FEBRUARY 1997: INFOTERRA: NGOs and desrtification
Oleg Tsaruk (tashkent@glasnet.ru) Fri, 28 Feb 1997 20:23:31 +0300 (WSU) Tashkent, Feb. 27, 1997 To: infoterra@cedar.univie.ac.at Subject: **desertification** and NGOs
http://www.www.ee/lists/infoterra/1997/02/0090.html

367. BBC Online - BBC World, Monday, 18 January 1999
All times in GMT BBC World News; Weather World Living: Earth Report **Desertification** Environmental series presented by David Attenborough. This programme looks at the spread of desert land in Ka...
http://search.bbc.co.uk/schedules/1999/01/18/world.html

368. *FRONTLINE*: ISSUE 48, February 2, 1999
On 1/29/99 Forest Guardians, Defenders of Wildlife, the Sierra Club, National Audubon Society and the Southwest Environmental Center filed a notice of intent to sue the Bureau of Reclamation and th...
http://www.fguardians.org/frontline/ofront48.htm

369. INFOTERRA: AUGUST 1995: UNEP TEXT AT DESERT. MTG
Statement by Elizabeth Dowdeswell, Executive Director of UNEP, at the Seventh Session of the Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Combat Des...
http://www.www.ee/lists/infoterra/1995/08/0019.html

370. Homepage of the African Conservation Tillage Network (A.C.T.)
Welcome to the African Conservation Tillage Network - ACT The aim of the network is to promote the adoption of conservation tillage practices on the African continent in order to assure a more sus...
http://www.fao.org/act-network/home1.htm

371. INFOTERRA: AUGUST 1995 by subject
(no subject) --Particulates Kill --Rainfall Moving North? 08/95 El Planeta Platica: Eco Travels in Latin America 7th PREPARATORY SESSION FOR **DESERTIFICATION** CONVENTION
http://www.www.ee/lists/infoterra/1995/08/subject.html

372. Biomass News - N? Jan. 1998
News from the members - Is the use of bioenergy going to decrease in Finland ? - Biomass production from leguminosae forestry species to encounter **desertification** in Central-Southern Europe. - Aust...
http://www.ecop.ucl.ac.be/aebiom/biomassnews/Biomass6.htm

373. Man and Environment
All abstracts are compiled by the Editor, DIG. The addresses of contributors were not included in this issue. Denudation by Indian Rivers. Subramanian and R.A.
http://www.picatype.com/dig/dm1/dm1aa29.htm

374. Insitute of Development Studies Research Environment
Environment - IDS 2000 INITIATIVE - Programme 3 Transforming Environmental Policy and Practice 1.SUMMARY 2.INTRODUCTION 3.PROGRAMME GOAL 4.THE RESEARCH AGENDA 4.1.BACKGROUND 4.2.AREAS OF FOCUS 4.2....
http://www.ids.ac.uk/ids/env/envmis3.html

375. German Solar Cooker
German Solar Cooker Around 1.5 billion people world-wide use wood for cooking. Firewood, however, has become scarce, extensive cutting down of trees had often resulted in **desertification** and soil ...
http://www.germanembassy-india.org/

376. Agenda 21 - Natural Resource Issues
Agenda 21 - Natural Resource Issues For a list of countries that have reported on each of the twelve natural resource issues addressed in Agenda 21, select an issue.
http://www.un.org/esa/agenda21/natlinfo/agenda21/issue/natur...

377. Mozambique News Agency - AIM Reports
Mozambique News Agency AIM Reports brings news from Southern African country of Mozambique
http://www.poptel.org.uk/mozambique-news/newsletter/aim127.html

378. Agenda 21 - Georgia
No information is available. Legislation, regulations and policy instruments The United Nations Framework Convention on Climate Change was ratified on 29 July 1994 and entered into force on 27 Oct...
http://www.un.org/esa/agenda21/natlinfo/countr/georgia/natur...

379. Scientists agree global water resources need international cooperation...
Scientists agree global water resources need international cooperation August 1997 Water News Online ALBUQUERQUE, N.M. -- An international conference on the growing problem of global desertificat...
http://www.uswaternews.com/archives/arcpolicy/7sciagr8.html

380. Agenda 21 - Germany
Click here to go to these sections: In Germany, the Federal Ministry of Food, Agriculture and Forestry is responsible for sustainable agriculture and is a member of the National Coordination Mecha...
http://www.un.org/esa/agenda21/natlinfo/countr/germany/natur...

381. United Nations Sustainable Development, Agenda21
Agenda 21 - Chapter 12 MANAGING FRAGILE ECOSYSTEMS: COMBATING **DESERTIFICATION** AND DROUGHT Fragile ecosystems are important ecosystems, with unique features and resources.
http://www.un.org/esa/sustdev/agenda21chapter12.htm

382. BBC News | ASIA-PACIFIC | China battles against sand invasion
China is calling for drastic measures to stop **desertification** after Beijing and other northern Chinese locations are hit by a series of sandstorms
http://news.bbc.co.uk/hi/english/world/asia-pacific/newsid_7...

383. Agenda 21 - Yugoslavia
No information available. No information available. No information available. No information available. No information available. No information available.
http://www.un.org/esa/agenda21/natlinfo/countr/yugosl/natur.htm

384. Operational Strategy
This operational strategy has been developed to guide the Global Environmental Facility (GEF) in the preparation of country-driven initiatives in the GEF's four

focal areas: biodiversity, climate c...
http://www.gefweb.org/public/opstrat/ch1.htm

385. Agenda 21 - Ginea Bissau
Click here to go to these sections: Status The major factors which contribute to the high poverty rate include a growing population, increasing **desertification** from the advance of the Sahel into p...
http://www.un.org/esa/agenda21/natlinfo/countr/guineab/socia...

386. Ethical Implications of Carrying Capacity, by Garrett Hardin (1977)
human overpopulation, **desertification**, the tragedy of the commons, situational ethics, famine, carrying capacity, Garrett Hardin, science, ecology, economics, environment, politics
http://www.dieoff.com/page96.htm

387. Agenda 21 - Belarus
Click here to go to these sections: No information is available No information is available No information is available No information is available No information is available
http://www.un.org/esa/agenda21/natlinfo/countr/belarus/natur...

388. agriculture application 2
HOME PROFILE PRODUCTS CONTACT LINKS SEARCH NEWS Land evaluation and planning Monitoring changes in land use and environmental condition Land disease identification and management e.g. erosion, sal...
http://202.139.249.206/agricult.htm

389. Catastrophism, Lost Civilizations, Forgotten Technologies, and Missed ...
Lost worlds, lost civilizations, forgotten technologies, strange evolutionary changes, and other mysteries of humanity's past and origins.
http://kurellian.tripod.com/lostcv4.html

390. NOAA GVI Eight Year
Originating GRID Center : GRID-Nairobi Access : Free Access NOAA/GVI Eight-Year (1983-1990) The NOAA/GVI (Global Vegetation Index) Eight-Year Mean Maximum data set was created by GRID-Nairobi as a ...
http://www-cger.nies.go.jp/grid-e/gridtxt/gvi10.html

391. SOURCE Bulletin No.15, February 2001
SOURCE Bulletin gives more in-depth news on water supply, resources, sanitation, and related fields. It is a joint endeavour of the Water Supply and Sanitation Collaborative Council (WSSCC) and IRC...
http://www.wsscc.org/source/bulletin/sb15.html

392. Agenda 21 - Ghana
Click here to go to these sections: No information is available Decision-Making: Coordinating Bodies Environment Protection Agency and the Ministry of Environment, Science and Technology are the ...
http://www.un.org/esa/agenda21/natlinfo/countr/ghana/natur.htm

393. Agenda 21 - Kyrgyzstan
Click here to go to these sections: No information is available No information is available No information is available No information is available No information is available
http://www.un.org/esa/agenda21/natlinfo/countr/kyrgyz/natur.htm

394. Agenda 21 - Swaziland Click here to go to these sections: No information is available. No information is available. No information is available. No information is available.
http://www.un.org/esa/agenda21/natlinfo/countr/swazil/natur.htm

395. COLA Report 11 This is an investigation of the impact of and mechanisms for biosphere feedback in the northeast Asian grassland on the East Asian summer monsoon.
http://grads.iges.org/reps/rep11/colarep11.html

396. Environment News: World's Wettest Spot Drying Up
BOMBAY, India, November 13, 1998 (ENS) - The world's wettest spot, a tiny hamlet in northeast India, is hit by an acute drinking water shortage and is also showing signs of **desertification.**
http://ens.lycos.com/ens/nov98/1998L-11-13-01.html

397. International Water Resources Association (IWRA)
INTERNATIONAL WATER RESOURCES ASSOCIATION ASSOC. INTERNACIONAL DE RECURSOS HIDRICOS ASSOC. INTERNATIONALE DES RESSOURCES EN EAU IWRAnews Archive for December, 1998
http://www.iwra.siu.edu/listserver/iwranews/199812.html

398. RE: Grasshopper control.
Somebody (?) wrote: >I am familiar with your area and was involved with the grasshopper issue. > The unstable nature of the grasshopper population issue is related to >**desertification.**
http://csf.colorado.edu/perma/lists/nov97/msg01925.html

399. I stand corrected
Subject: I stand corrected >The wording of the 1988-1989 topic _did_ include the phrase "one or more." >It had to, otherwise I couldn't have "reforested" the whole place, ...
http://www.cs.jhu.edu/~jonathan/debate/ceda-l/archive/CEDA-L...

400. RE: Grasshopper control.
I am familiar with your area and was involved with the grasshopper issue. The unstable nature of the grasshopper population issue is related to **desertification.**
http://csf.colorado.edu/perma/lists/nov97/msg01923.html

401. ALN No. 41: CCD current status, Asia and LAC
This article by the Interim Secretariat of the CCD describes the CCD's status as of mid-1997 in Asia, Latin America and the Caribbean. Published in Arid Lands Newsletter No. 41, Spring/Summer 1997.
http://ag.arizona.edu/OALS/ALN/aln41/ccd41.html

402. World Biomes: Savanna Biome
World Biomes At the completion of this module you will be able to: Describe the characteristics of savanna vegetation and its associated climate. Describe the main causes of **desertification** and it...
http://www.uwsp.edu/geo/faculty/ritter/geog101/modules/biosp...
Directory: Education > Science and Nature > Ecology > Biomes and Ecosystems > Savanna

403. AGRIPEDIA - **Desertification**
Desertification is the land degradation in arid, semiarid and dry subhumid areas that results from adverse human impact such as over-cultivating or overgrazing.
http://frost.ca.uky.edu/Agripedia/glossary/desertf.htm

404. **desertification** in Africa
Environment and development in coastal regions and in small islands Combating **desertification** in coastal Africa: a campaign to alert the local population
http://www.unesco.org/csi/region/desert.htm

405. Econews Webpage: Information is Empowering
EcoNews Africa THE UGANDAN NATIONAL NGO CONSULTATIVE FORUM By Mary Rwakaikara Silver, Timothy Byakora and Naftali Onchere Background The Government of Uganda signed and ratified the Convention t...
http://www.web.net/~econews/CCD/ugandaccd.html

406. **DESERTIFICATION**
Means of implementation Means of implementation (a) Financing and cost evaluation 12.22 The Conference secretariat has estimated the average total annual cost (1993-2000) of implementing the act...
http://ches.ing.ula.ve/GAIA/AG21/programme_areas/A21_12B_mi....

407. THE HINDU ONLINE : Meet to focus on **desertification**
Cl: Environment From Our Special Correspondent NEW DELHI, Aug. 21. A three-day Asian region conference which opened here today will focus on one of the major environmental problems _ desertificati...
http://www.webpage.com/hindu/960824/11/2216a.html

408. **desertification** in the sahel coutries
Last changed: May 19, 1999 Solutions Site Discussion - **Desertification desertification** in the sahel coutries
http://solutions-site.org/_sd_des/00000003.htm

409. ARAL SEA GIS The Aral Sea GIS: Map of the Aral Sea The Aral Sea GIS is under development since 1993. It covers the Aral Sea, AmuDarya delta, dry bottom and deserts, as well as SyrDarya delta both in Uzbekist...
http://giserv.karelia.ru/aral/index.htm

410. ENB:04:65 During this session, the Committee identified the issues that must be discussed in order to ensure a productive first meeting of the Conference of the Parties.
http://www.iisd.ca/linkages/vol04/0465034e.html

411. The New American - America's Conservative Magazine
A conservative, bi-weekly publication that defends Constitutional principles and traditional values
http://www.thenewamerican.com/
Directory: Education > Arts and Humanities > Communications > Alternative Media > Conservative

412. Diskors **Desertification** processes, not only cause environmental problems, but in the long term cause important socio-economic problems too. The progressive loss of the soil's biological productivity throu...
http://www.magnet.mt/press_releases/1998/june/nf0306.htm

413. CATLOW SHIPEK Some propaganda to chew on briefly... □ have no doubt that it is a part of the destiny of the human race in its gradual improvement to leave off eating animals.?-- Henry David Thoreau
http://katlo.freeservers.com/

414. ENB:04:13 The second session of the Intergovernmental Negotiating Committee for the elaboration of an international convention to combat **desertification** in those countries experiencing serious drought and/or...
http://www.iisd.ca./linkages/vol04/0413001e.html

415. BIODIV-TALK Archive: Virtual Global Biodiversity Forum - GBF12-CCD
Join the Virtual Global Biodiversity Forum 27 Nov - 21 Dec 1998 Please add your voice to the inaugural run of Virtual Global Biodiversity Forum (VGBF).
http://nccnsw.org.au/member/cbn/biodiv-talk/0013.html

416. ENB:04:38 The Plenary met briefly at 12:30 pm so that the Spanish Minister of Public Works, Transport and Environment, Jos, Borrel Fontelles, could formally introduce the Declaration of Almer□, the pro...
http://www.iisd.ca./linkages/vol04/0438001e.html

417. ENB:04:90 A panel discussion on Women and **Desertification** met during the afternoon. Presentations were made on women and access to credit, women, land tenure and ownership, and pilot projects to inform rura...
http://www.iisd.ca/linkages/vol04/0490005e.html

418. Hilites Archive: HILITES> 9-12: Desert and **Desertification** Project 1995-1996
---------- Forwarded message ---------- Date: Thu, 17 Aug 1995 07:37:17 -0700 From: boker@zeus.datasrv.co.il Subject: Desert and **Desertification** Project 1995-1996
http://archives.gsn.org/hilites/1995/0036.html

419. ALN No. 43: Riethmacher and Hassan: The CCD after COP-1
This special report describes the accomplishments of COP-1, with emphasis on creating synergies among implementation activities for the CCD and other international conventions such as the UN Framew...
http://ag.arizona.edu/OALS/ALN/aln43/ccd.html

420. ENB:04:86 Discussion on this subject was based on two resolutions adopted with the Convention at INCD-5: the resolutions on urgent action for Africa and on interim action in other regions.
http://www.iisd.ca/linkages/vol04/0486007e.html

421. Untitled Environmental Issues Links: WARNING: Many of the articles in these links have a particular bias. Try to read several articles, look for the facts and then think about your own opinion on these mat...
http://www.user.globalnet.co.uk/~drayner/environmentg.htm

422. **DESERTIFICATION** of EARTH and FERAL HUMANS
DESERTIFICATION OF EARTH AND FERAL HUMANS
http://www.quietmountain.com/dharmacenters/buddhadendo/DESER...

423. Untitled EARTH NEGOTIATIONS BULLETIN PUBLISHED BY THE INTERNATIONAL INSTITUTE FOR SUSTAINABLE DEVELOPMENT (IISD) WRITTEN AND EDITED BY: Elisabeth Corell Wagaki Mwangi Lynn Wagner Nabiha Megateli Managing Ed...
http://www.iisd.ca/download/asc/enb04103e.txt

424. EcoNews Africa" 960112: **Desertification** Convention Updates
Compiled by Wangu Mwangi Probably no other Convention negotiated at the United Nations level has had as much a focus on Africa as the Convention to Combat **Desertification**, CCD.
http://www.web.net/~econews/ena5-1d.html

425. Len Milich: Anthropogenic **Desertification** vs □atural?Climate Trends
While physical processes were responsible for the formation of China's deserts, human activities are believed to have contributed to their enlargement (Fullen and Mitchell, 1991).
http://ag.arizona.edu/~lmilich/desclim.html

426. Scientific Reviews on Arid Zone Research, Volume 10, 1999 : Man in the Desert/L.P. Barara: Book No. 14635
Scientific Reviews on Arid Zone Research, Volume 10, 1999 : Man in the Desert/L.P. Barara. 1999, xiv, 394 p., tables, illustrations, $36 (net. Inclusive of registered airmail postage and packing).
http://www.vedamsbooks.com/no14635.htm

427. ENB:04:79 Italy, on behalf of the European Union<M> noted that four more EU countries have ratified and several others are in the process of doing so. Costa Rica, on behalf of G-77 and China, said the...
http://www.iisd.ca/vol04/0479002e.html

428. Week's Interview - Yemen Times
Issue 11- March 16th thru March 22nd 1998, Vol VIII Mohammed Al-Tamiri: "When we decide to plant a particular area with trees, ownership claims start to pour in." Mr.
http://www.yementimes.com/98/iss11/intrview.htm

429. ENB:04:55 Perhaps the most important accomplishment of the INCD process is the international attention that has been mobilized around the problem of **desertification.**
http://www.iisd.ca/linkages/vol04/0455060e.html

430. Soil Conservation
Consortium for Earth Sciences Information Network Guide: Land Degradation and **Desertification** Noah's Ark: Information on how to create and maintain healthy soil and how to grow crops organically.
http://classes.aces.uiuc.edu/EnvSt298/soil_conservation.html

431. GLOBE Europe News Issue 1, 1999 - GOVERNMENTS MEET ON **DESERTIFICATION**
GOVERNMENTS MEET ON **DESERTIFICATION** Desert encroachment does not only happen in developing countries. It is also a European and mediterranean problem, and to highlight this in advance of the Confe...
http://globeint.org/html-europe/news-1-99/desert.htm

432. Dr. Tucker's Seminar
Home Courses GG 841 Seminar Schedule On Jan-29-1999 EXPANSION & CONTRACTION OF THE SAHARA FROM 1980 TO 1997 Compton J. Tucker Laboratory for Terrestrial Physics NASA Goddard Space Flight Center
http://cybele.bu.edu/courses/gg841/tucker.html

433. Erosion at the Valjean Site
Erosion, Erosion Recoverability, and **Desertification** Rates at the Valjean Site, Mojave Ecosystem Project by J. Calzia, B. Troxel, and C. EROSION RECOVERABILITY D.
http://www-wmc.wr.usgs.gov/home-esic/exhibit/erosion.html

434. ENB:04:01 The second meeting of the INC-D opened with a statement from Colombia, on behalf of the G-77, which requested that all official documents issued on this topic reflect the full title of the Committe...
http://www.iisd.ca/linkages/vol04/0401006e.html

435. Ch05 Study Group on Climate and **Desertification** Leader: Professor P.D. The members of this study group are: Dr. University of the Witwatersrand, Johannesburg, South Africa.
http://www.unu.edu/unupress/unupbooks/80127e/80127E05.htm

436. CSE-GEF Climate Change Page
SOUTH ASIAN NGO FOCAL POINT MARCH 28 - APRIL 3 International Waters The Ozone Layer CLIMATE CHANGE A Mirage of Money **Desertification**, almost exclusively a Southern problem, finds low priority wit...
http://www.oneworld.org/cse/html/gef/gef_cc.htm

437. ENB:04:56 The representative said that the Chinese Government has put enormous human and material resources to combating **desertification** and hopes that the international community will help them combat deser...
http://www.iisd.ca/linkages/vol04/0456038e.html

438. prechgeo Originating GRID Center : GRID-Geneva Access : Free Access Change in Mean Annual Precipitation Data Set ID : GNV175 Background : The World Atlas of **Desertification** was published by UNEP in 1992 ...
http://www-cger.nies.go.jp/grid-e/gridtxt/prechgeo.html

439. Trees for the Future
Trees for the Future, a non-profit, helps people and the environment. Tree planting and agroforestry projects protect forests & villagers.
http://www.treesftf.org/index.html

440. **DESERTIFICATION** CONVENTION AGREED
THE FINAL TEXT of the **desertification** treaty was agreed at the fifth session of the Intergovernmental Negotiating Committee for the **Desertification** Convention (INCD) in Paris in June 1994.
http://www.cru.uea.ac.uk/cru/tiempo/issue12/desconv.htm

441. Econews Webpage: Information is Empowering
EcoNews Africa JANGWA BI-MONTHLY Overall Goal To provide information that will enable the increased implementation of the United Nations Convention to Combat **Desertification** (CCD) in the Eastern...
http://www.web.apc.org/~econews/CCD/index.html

442. International Environmental Law and Policy - Chapter Fifteen. Protection of Habitat
casebook supplement providing full text to legal documents, articles, links, and background information on environmental law and policy
http://www.wcl.american.edu/pub/iel/fifteen.htm

443. ABC Country Book of Libya - geography Flag, Map, Economy, Geography, Climate, Natural Resources, Current Issues, International Agreements, Population, Social Statistics, Political System
Libya Interactive Factbook: GEOGRAPHY, Flag, Map,Geography, People, Government, Economy, Transportation, Communications
http://www.theodora.com/wfb/libya_geography.html

444. ANNEX A: OPERATIONAL GUIDELINES
The Asian Regional Network for **Desertification** Monitoring and Assessment (TPN1) is a network comprised of institutions or agencies that participate on a voluntary basis.
http://www.din.net.cn/din/asian_din/TPN1_ANNEX-A.html

445. gvigeo Originating GRID Center : GRID-Geneva Access : Free Access Data Set ID : GNV179 NOAA/GVI Eight-Year (1983-1990) Mean Maximum Background : The World Atlas of **Desertification** was published by UNEP ...
http://www-cger.nies.go.jp/grid-e/gridtxt/gvigeo.html

446. From Hope to Harvest - Building on Tradition combating **Desertification**- IFAD's 20th Anniversary
Building on Tradition Combating **Desertification** Explore it on your own. What is **Desertification? Desertification** is the degradation of land in arid, semi-arid and sub humid zones of the world, lea...
http://www.ifad.org/anniv/btcd.htm

447. puzzle A **Desertification** Puzzle Listed below are 17 terms which are related to the process of **desertification.** Find each of these terms in the puzzle frame.
http://education.nmsu.edu/webquest/wq/Deserti/puzzle.htm

448. Tiempo issue 9: INCD negotiating process begins
THE FIRST MEETING of the Intergovernmental Negotiating Committee for a Convention to Combat **Desertification** in Countries Experiencing Serious Drought and/or **Desertification**, Particularly in Africa ...
http://www.cru.uea.ac.uk/cru/tiempo/issue09/incd.htm

449. ENB:04:12 The Intergovernmental Negotiating Committee for the elaboration of an international convention to combat **desertification** in those countries experiencing serious drought and/or **desertification**, part...
http://www.iisd.ca/vol04/0412001e.html

450. De Rio à Rome via Dakar
Version Française RIO TO ROME VIA DAKAR African Regional Conference of NGOs on the Implementation of the Convention to Combat **Desertification.** 8-12 September 1997.
http://www.enda.sn/energie/autres/confeng.htm

451. ENB:04:22 At the conclusion of the first session of the INCD in Nairobi, delegates were unable to reach consensus on the negotiation of regional instruments, while ensuring priority for Africa.
http://www.iisd.ca./linkages/vol04/0422032e.html

452. gvigeo Originating GRID Center : GRID-Geneva Access : Free Access Data Set ID : GNV179 NOAA/GVI Eight-Year (1983-1990) Mean Maximum Background : The World Atlas of **Desertification** was published by UNEP ...
http://www-cger.nies.go.jp/grid-j/gridtxt/gvigeo.html

453. Water Resources
- Overview of the Project - Draft Agenda - Registration Information HTML Index of the whole document PDF format (1.1 MB) Symposium in Los Angeles on 17 October 1997
http://www4.gve.ch/gci/GreenCrossPrograms/waterres/waterreso...

454. **Desertification** policy
Desertification Policy Institute of development Studies, Brighton, 1998 This paper was prepared as a class exercise within the IDS MPhil Programme. The task was to prepare a briefing paper for a h...
http://nt1.ids.ac.uk/eldis/deser/despap.htm

455. Qinxue Wang' Resume
<- My Home SENSITIVITY OF **DESERTIFICATION** EFFECT ON LAND-SURFACE WATER DEFICIT IN ARID AND SEMI-ARID REGION: A CASE STUDY OF THE LOESS PLATEAU, CHINA Qinxue Wang and Hidenori Takahashi Graduate...
http://wwwgeo.ees.hokudai.ac.jp/memberhome/~qxw/igbp-p.htm

456. PRC **Desertification**: Mud Rain Rarer Now
Although The April mud rain attracted much attention mud rains are actually less frequent in north China cities than they were during the 1980s. The northern barrier forests planted over the past 2...
http://www.usembassy-china.org.cn/english/sandt/mudrain.htm

457. prechgeo Originating GRID Center : GRID-Geneva Access : Free Access Data Set ID : GNV175 Change in Mean Annual Precipitation Background : The World Atlas of **Desertification** was published by UNEP in 1992 as...
http://www-cger.nies.go.jp/grid-j/gridtxt/prechgeo.html

458. ENB:04:65 According to its multi-year thematic programme of work, the Commission on Sustainable Development"s (CSD) third session in April 1995, will review the implementation of all the Agenda 21 chapt...
http://www.iisd.ca/vol04/0465021e.html

459. 30.06.98 Govt launches project to combat SA's growing **desertification**
Govt launches project to combat SA's growing **desertification** from Prodder A project intended to combat South Africa's growing **desertification** was launched by government ministers last week.
http://www.woza.co.za/news/deserto.htm

460. ENB:13:12 The draft Co-chair's text recognizes, regarding **desertification**: relevance to both northern boreal forests and arid and semi-arid areas; action to address underlying causes; prevention over re...
http://www.iisd.ca/linkages/vol13/1312004e.html

461. Untitled Desert Research Society GISAF Aims: exploring irrigation with solar energy water-pumps trials with biological fertilizers mineralogical prospecting in the hamada
http://www.isoc.vienna.org/sahara/gisafenglish.html

462. UNITED NATIONS CONVENTION TO COMBAT **DESERTIFICATION** (UNCCD)
Finland considers the Convention to Combat **Desertification** an important element of the global agenda for sustainable development and human security.
http://www.vyh.fi/eng/intcoop/global/desert.htm

463. ENB:04:56
Amb. Mohamed A. Azwai said that **desertification** is one of the most important problems facing Africa. The need to combat **desertification** is now widely recognized and Libya hopes that the Conventi...

http://www.iisd.ca/linkages/vol04/0456025e.html

464. Budget Row Stalls Brazil Global Environment Talks
Budget Row Stalls Brazil Global Environment Talks 11/27/99
****************************** RELAYED TEXT STARTS HERE:
Title: Budget Row Stalls Brazil Global Environment Talks Source: Reuters
Status:...
http://forests.org/archive/brazil/budrowst.htm

465. Basic idea Eden Project Basic Idea
http://www.eden-foundation.org/project/basidea.html

466. The Initiative to Combatting **Desertification**
Initiative for Collaboration to Control Natural Resource Degradation **(Desertification)** of Arid Lands in the Middle East Gully erosion in the Central Negev
http://www.bgu.ac.il/desert_agriculture/initiative/Index.html

467. ENB:04:44 The issue of categories of countries, particularly the references to "other countries in a position to provide assistance" and "affected [developing] countries [needing assistance],&...
http://www.iisd.ca/linkages/vol04/0444052e.html

468. Other Information (BIDR's homepage)
Midreshet Ben-Gurion, Electronic Journals, The International Network of Green Planners (INGP) ...
http://www.bgu.ac.il/BIDR/otherinfo.html

469. Untitled EARTH NEGOTIATIONS BULLETIN PUBLISHED BY THE INTERNATIONAL INSTITUTE FOR SUSTAINABLE DEVELOPMENT (IISD) WRITTEN AND EDITED BY: Elisabeth Corell Wagaki Mwangi Steve Wise .
http://www.iisd.ca/linkages/download/asc/enb0469e.txt

470. ENB:04:17 Working Group II continued the previous day's discussion on the topic of institutions. The Chair, Anne de Lattre, reported that after consultations with the INCD Chair, Bo Kjell,n, discussion...
http://www.iisd.ca/linkages/vol04/0417002e.html

471. ENB:04:10 IGADD: The Executive Secretary presented the history, mandate and activities of IGADD in combatting **desertification. He said there is no need for** more definitions but the salient factors that link...
http://www.iisd.ca./linkages/vol04/0410001e.html

472. Bo B Melanders - Homepage, About me, Skrivarboa på Fotö Sweden
in english
http://www.sboa.se/melander-eng.htm

473. Global Conferences
UNITED NATIONS GLOBAL INITIATIVES United Nations Summits and Conferences Global Conference on Sustainable Development of Small Island Developing States.
http://www.undp.org.fj/global_conf/globconf.htm

474. ENB:04:86 The Intergovernmental Negotiating Committee of the Convention to Combat **Desertification** (INCD) met for its eighth session in Geneva, Switzerland, from 5-15 February 1996.
http://www.iisd.ca/vol04/0486001e.html

475. COMESA Angolan Natural Resources
BASIC AGRICULTURAL INFORMATION Land use: arable land: 2% permanent crops: 0% meadows and pastures: 23% forest and woodland: 43% other: 32% Irrigated land: Not known
http://www.comesa.int/states/angola/qangnatr.htm

476. ENB:04:44 The problem of definitions dates back to INCD-2. There were three problems. The first related to the definition of **desertification** and the recognition of the problem as a global issue whose effec...
http://www.iisd.ca/linkages/vol04/0444009e.html

477. The Convention Secretariats
The Convention Secretariats Climate Change UN Framework Convention on Climate Change UN Convention on Biological Diversity UN Convention to Combat **Desertification**
http://www.soc.titech.ac.jp/uem/trialogue/secretariat.html

478. Third World Foundation -- Global Climate Change
Third World Foundation Global Climate Change Global Climate Change - Professor Mohamed Kassas, University of Cairo. Dust bowls in developing countries hurl fine particles of dust into the atmosp...
http://www.thirdworld.org/global.html

479. ENB:04:76 In 1995 the Intergovernmental Negotiating Committee for the Convention to Combat **Desertification** (INCD) began a new phase in its negotiating process.
http://www.iisd.ca/vol04/0476001e.html

480. Iceland wins the Nordic Council's Environmental Prize : Newsletter 5, 98
NEWSLETTER No. 5, 1998 Earth erosion, **desertification** and loss of arable land are long-term environmental problems at the Nordic as well as international level.
http://www.norden.org/top/9805/n.htm

481. ENB:04:07 PLENARY: The focus of discussion shifts today as general debate begins on Agenda Item 4, "Elaboration of an international convention to combat **desertification** in countries experiencing serious...
http://www.iisd.ca/linkages/vol04/0407003e.html

482. COMESA Kenyan Natural Resources
BASIC AGRICULTURAL INFORMATION Land use: arable land: 3% permanent crops: 1% meadows and pastures: 7% forest and woodland: 4% other: 85% Irrigated land: 520 sq km (1989)
http://www.comesa.int/states/kenya/qkennatr.htm

483. ENB:04:55 This process has also stimulated key changes in the attitudes within the donor community. First, there has been an important change in the attitude of policy-makers regarding the socio-economic di...
http://www.iisd.ca/linkages/vol04/0455063e.html

484. Volcanic Hazards IS 302: Knapp MSSC Sping 99
International Studies 302 **Desertification**, Drought and Wildfires! This page made possible by TalleyTechnologies, Inc. World Environmental Issues Brush Fires in Australia
http://www.talleytech.com/~physics/i302/desert.html

485. Ongoing Projects: Desert and **Desertification** Project 1995-1996
Desert and **Desertification** Project 1995-1996 > > DESERT AND **DESERTIFICATION** PROJECT > 1995-1996 School Year > > During the 1994-1995 school year, we conducted a year-long > intern...
http://archives.gsn.org/pr/ongoing/1995/0006.html

486. **Desertification** and water-soil erosion expanding in China
In other subjects: Land Resources: Soil Erosion Land Resources: **Desertification** Close This Window Sorry, the English abstract of this article is not available now.
http://www.enviroinfo.org.cn/Land_Resources/Soil_Erosion/c46...

487. Consulting Firms / **Desertification** Control
Desertification Control CENTRAL CONSULTANT,Inc. □ CONSTRUCTION PROJECT CONSULTANTS,Inc. □ CTI ENGINEERING Co.,Ltd. □ FUKKEN CO.,LTD.(Consulting Engineers)
http://www.iijnet.or.jp/idi/cf7.htm [more from this site]

499. **Desertification** - a threat to the Sahel
Article discussing the causes and effects of **desertification** in the Sahel.
http://www.eden-foundation.org/project/desertif.html [more from this site]

500. aral sea **desertification**
Aral sea is going to disappear by an unsustainable land use. This is a report from the view point of landscape ecology. , and Ili delta. Note the two major farms of rice paddies are in a trade of...
http://rosa.envi.osakafu-u.ac.jp/~yuki/aral.html [more from this site]