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Chapter 1

# Introduction to Climate Change and Land Degradation

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## ABSTRACT

The definition of land degradation in the United Nations Convention to Combat Desertification (UNCCD) gives explicit recognition to climatic variations as one of the major factors contributing to land degradation. In order to accurately assess sustainable land management practices, the climate resources and the risk of climate-related or induced natural disasters in a region must be known. Land surface is an important part of the climate system and changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes. Following deforestation, surface evapotranspiration and sensible heat flux are related to the dynamic structure of the low-level atmosphere and these changes could influence the regional, and potentially, global-scale atmospheric circulation. Surface parameters such as soil moisture, forest coverage, transpiration and surface roughness may affect the formation of convective clouds and rainfall through their effect on boundary-layer growth. Land use and land cover changes influence carbon fluxes and GHG emissions which directly alter atmospheric composition and radioactive forcing properties. Land degradation aggravates $CO_2$-induced climate change through the release of $CO_2$ from cleared and dead vegetation and through the reduction of the carbon sequestration potential of degraded land.

Climate exerts a strong influence over dry land vegetation type, biomass and diversity. Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favours nomadic lifestyle. The generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. The severity, frequency, and extent of erosion are likely to be altered by changes in rainfall amount and intensity and changes in wind. Impacts of extreme events such as droughts, sand and dust storms, floods, heat waves, wild fires etc., on land degradation are explained with suitable examples. Current advances in weather and climate science to deal more effectively with the impacts of different climatic parameters on land degradation are explained with suitable examples. Several activities promoted by WMO's programmes around the world help promote a better understanding of the interactions between climate and land degradation through dedicated observations of the climate system; improvements in the application of agro-meteorological methods and the proper assessment and management of water resources; advances in climate science and prediction; and promotion of capacity building in the application of meteorological and hydrological data and information in drought preparedness and management. The definition of land degradation adopted by UNCCD assigns a major importance to climatic factors contributing to land degradation, but there is no concerted effort at the global level to systematically monitor the impacts of different climatic factors on land degradation in different regions and for different classes of land degradation. Hence there is an urgent need to monitor the interactions between climate and land degradation. To better understand these interactions, it is also important to identify the sources and sinks of dryland carbon, aerosols and trace gases in drylands. This can be effectively done through regional climate monitoring networks. Such networks could also help enhance the application of seasonal climate forecasting for more effective dryland management.

## 1 INTRODUCTION

Desertification is now defined in the United Nations Convention to Combat Desertification (UNCCD) as "land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” (UNCCD 1999). Furthermore, UNCCD defines land degradation as a “reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.”

According to UNCCD, over 250 million people are directly affected by land degradation. In addition, some one billion people in over one hundred countries are at risk. These people include many of the world’s poorest, most marginalized, and politically weak citizens.

Land degradation issue for world food security and the quality of the environment assumes a major significance when one considers that only about 11% of the global land surface can be considered as prime or Class I land, and this must feed the 6.3 billion people today and the 8.2 billion expected in the year 2020 (Reich et al. 2001). Hence land degradation will remain high on the international agenda in the 21st century.

Sustainable land management practices are needed to avoid land degradation. Land degradation typically occurs by land management practices or human development that is not sustainable over a period of time. To accurately assess sustainable land management practices, the climate resources and the risk of climate-related or induced natural disasters in a region must be known. Only when climate resources are paired with potential management or development practices can the land degradation potential be assessed and appropriate mitigation technology considered. The use of climate information must be applied in developing sustainable practices as climatic variation is one of the major factors contributing or even a trigger to land degradation and there is a clear need to consider carefully how climate induces and influences land degradation.

## 2 EXTENT AND RATE OF LAND DEGRADATION

Global assessment of land degradation is not an easy task, and a wide range of methods are used, including expert judgement, remote sensing and modeling. Because of different definitions and terminology, there also exists a large variation in the available statistics on the extent and rate of land degradation. Further, most statistics refer to the risks of degradation or desertification (based on climatic factors and land use) rather than the actual (present) state of the land.

Different processes of land degradation also confound the available statistics on soil and/or land degradation. Principal processes of land degradation (Lal et al. 1989) include erosion by water and wind, chemical degradation (comprising acidification, salinization, fertility depletion, and decrease in cation retention capacity), physical degradation (comprising crusting, compaction, hard-setting etc.) and biological degradation (reduction in total and biomass carbon, and decline in land biodiversity). The latter comprises important concerns related to eutrophication of surface water, contamination of ground water, and emissions of trace gases ($CO_2$, $CH_4$, $N_2O$, $NO_x$) from terrestrial/aquatic ecosystems to the atmosphere. Soil structure is the important property that affects all degradative processes. Factors that determine the kind of degradative processes include land quality as affected by its intrinsic properties of climate, terrain and landscape position, climax vegetation and biodiversity, especially soil biodiversity.

In an assessment of population levels in the world's dry lands, the Office to Combat Desertification and Drought (UNSO) of the United Nations Development Programme (UNDP) showed that globally 54 million sq. km or 40% of the land area is occupied by dry lands (UNSO 1997). About 29.7% of this area falls in the arid region, 44.3% in the semi-arid region and 26% in the dry sub-humid region. A large majority of the dry lands are in Asia (34.4%) and Africa (24.1%), followed by the Americas (24%), Australia (15%) and Europe (2.5%).

Figure 1 indicates that the areas of the world vulnerable to land degradation cover about 33% of the global land surface. At the global level, it is estimated that the annual income foregone in the areas immediately affected by desertification amounts to approximately US$ 42 billion each year.

The semi-arid to weakly aridic areas of Africa are particularly vulnerable, as they have fragile soils, localized high population densities, and generally a low-input form of agriculture (Lal 1988). About 25% of land in Asian countries is vulnerable.

Long-term food productivity is threatened by soil degradation, which is now severe enough to reduce yields on approximately 16% of the agricultural land, especially cropland in Africa, Central America and pastures in Africa. Sub-Saharan Africa has the highest rate of land degradation. It is estimated that losses in productivity of cropping land in sub-Saharan Africa are in the order of 0.5–1% annually, suggesting productivity loss of at least 20% over the last 40 years (Scherr 1999).

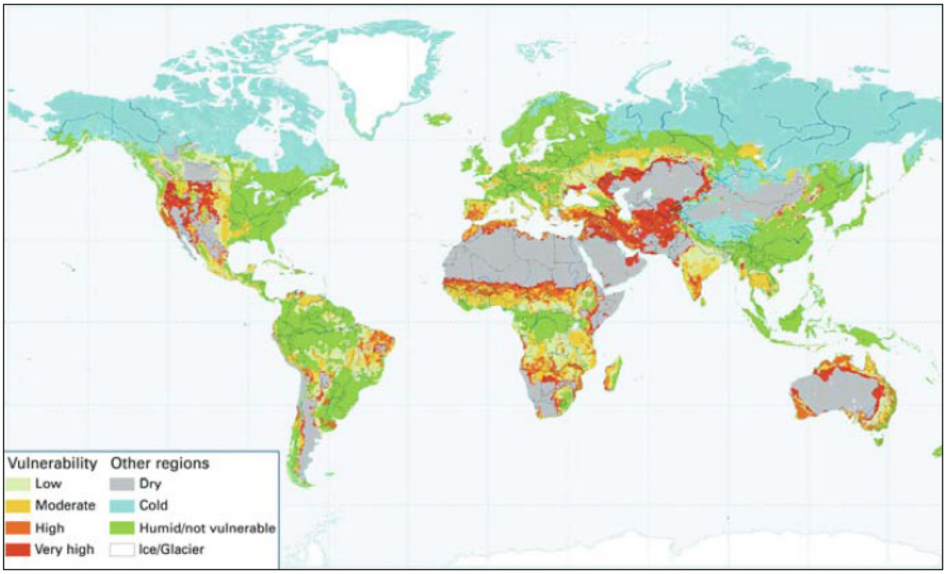

**Figure 1.** Soil degradation in the world's drylands, 1990s (Source: UNEP)

Africa is particularly threatened because the land degradation processes affect about 46% of Africa (Reich et al. 2001) The significance of this large area becomes evident when one considers that about 43% of the continent is characterized as extreme deserts (the desert margins represent the areas with very high vulnerability.) There is only about 11% of the land mass which is humid and which by definition is excluded from desertification processes. There is about 2.5 million km$^2$ of land under low risk, 3.6 million km$^2$ under moderate risk, 4.6 million km$^2$ under high risk, and 2.9 million km$^2$ under very high risk. The region that has the highest propensity is located along the desert margins and occupies about 5% of the landmass. It is estimated that about 22 million people (2.9% of total population) live in this area (Reich et al. 2001). The low, moderate and high vulnerability classes occupy 14, 16, and 11% respectively and together impact about 485 million people.

Land degradation is also a serious problem in Australia with over 68% of the land estimated to have been degraded (Table 1).

According to UNCCD, the consequences of land degradation include undermining of food production, famines, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in land's resilience to natural climate variability and decreased soil productivity.

**Table 1.** Land degradation on cropland in Australia (Source: Woods, 1983; Mabbutt, 1992)

| Type | Area (1.000 km$^2$) |
|---|---|
| Total | 443 |
| Not degraded | 142 |
| Degraded | 301 |
| Water erosion | 206 |
| Wind erosion | 52 |
| Combined water and wind erosion | 42 |
| Salinity and water erosion | 0.9 |
| Others | 0.5 |

## 3 LAND DEGRADATION – CAUSES

Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system (Barrow 1994). Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes, which are not fully understood. Interactions between the two systems determine the success or failure of resource management programs. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability).

High population density is not necessarily related to land degradation. Rather, it is what a population does to the land that determines the extent of degradation. People can be a major asset in reversing a trend towards degradation. Indeed, mitigation of land degradation can only succeed if land users have control and commitment to maintain the quality of the resources. However, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty and illiteracy can be important causes of land and environmental degradation.

There are many, usually confounding, reasons why land users permit their land to degrade. Many of the reasons are related to societal perceptions of land and the values they place on land. The absence of land tenure and the resulting lack of stewardship is a major constraint in some countries to adequate care for the land. Degradation is also a slow imperceptible process and so many people are not aware that their land is degrading.

Loss of vegetation can propagate further land degradation via land surface-atmosphere feedback. This occurs when a decrease in vegetation reduces evaporation and increases the radiation reflected back to the atmosphere (albedo), consequently reducing cloud formation. Large-scale experiments in which numerical models of the general circulation have been run with artificially high albedo over dry lands have suggested that large increases in the albedo of subtropical areas should reduce rainfall.

# 4 CLIMATIC CONSEQUENCES OF LAND DEGRADATION

Land surface is an important part of the climate system. The interaction between land surface and the atmosphere involves multiple processes and feedbacks, all of which may vary simultaneously. It is frequently stressed (Henderson-Sellers et al. 1993; McGuffie et al. 1995; Sud et al. 1996) that the changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the largescale external moisture fluxes. Changes in surface energy budgets resulting from land surface change can have a profound influence on the earth’s climate.

Following deforestation, surface evapotranspiration and sensible heat flux are related to the dynamic structure of the low-level atmosphere. These changes in fluxes within the atmospheric column could influence the regional, and potentially, global-scale atmospheric circulation. For example, changes in forest cover in the Amazon basin affect the flux of moisture to the atmosphere, regional convection, and hence regional rainfall (Lean and Warrilow 1989). More recent work shows that these changes in forest cover have consequences far beyond the Amazon basin (Werth and Avissar 2002).

Fragmentation of landscape can affect convective flow regimes and rainfall patterns locally and globally. El Niño events and land surface change simulations with climate models suggest that in equatorial regions where towering thunderstorms are frequent, disturbing areas hundreds of kilometres on a side may yield global impacts.

Use of a numerical simulation model by Garrett (1982) to study the interactions between convective clouds, the convective boundary layer and a forested surface showed that surface parameters such as soil moisture, forest coverage, and transpiration and surface roughness may affect the formation of convective clouds and rainfall through their effect on boundary-layer growth.

An atmospheric general circulation model with realistic land-surface properties was employed (Dirmeyer and Shukla 1996) to investigate the climatic effect of doubling the extent of earth's deserts and most regions and it showed a notable correlation between decreases in evapotranspiration and resulting precipitation. It was shown that Northern Africa suffers a strong year-round drought while southern Africa has a somewhat weaker year-round drought. Some regions, particularly the Sahel, showed an increase in surface temperature caused by decreased soil moisture and latent-heat flux.

Land use and land cover changes influence carbon fluxes and GHG emissions (Houghton 1995; Braswell et al. 1997) which directly alter atmospheric composition and radiative forcing properties. They also change land-surface characteristics and, indirectly, climatic processes. Observations during the HAPEX-Sahel project suggested that a large-scale transformation of fallow savannah into arable crops like millet, may lead to a decrease in evaporation (Gash et al. 1997). Land use and land cover change is an important factor in determining the vulnerability of ecosystems and landscapes to environmental change.

Since the industrial revolution, global emissions of carbon (C) are estimated at 270±30 gigatons (Gt) due to fossil fuel combustion and 136±5 Gt due to land use change and soil cultivation. Emissions due to land use change include those by deforestation, biomass burning, conversion of natural to agricultural ecosystems, drainage of wetlands and soil cultivation. Depletion of soil organic C (SOC) pool has contributed 78±12 Gt of

C to the atmosphere, of which about one-third is attributed to soil degradation and accelerated erosion and two-thirds to mineralization (Lal 2004).

Land degradation aggravates CO2-induced climate change through the release of CO2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of degraded land.

# 5 CLIMATIC FACTORS IN LAND DEGRADATION

Climate exerts a strong influence over dry land vegetation type, biomass and diversity (Williams and Balling 1996). Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favours nomadic lifestyle. Vegetation cover becomes progressively thinner and less continuous with decreasing annual rainfall. Dry land plants and animals display a variety of physiological, anatomical and behavioural adaptations to moisture and temperature stresses brought about by large diurnal and seasonal variations in temperature, rainfall and soil moisture.

Williams and Balling (1996) provided a nice description of the nature of dryland soils and vegetation and the manner in which climate affects the soils and vegetation. The generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. For example, wind and water erosion is extensive in many parts of Africa. Excluding the current deserts, which occupy about 46% of the landmass, about 25% of the land is prone to water erosion and about 22%, to wind erosion.

Structural crusts/seals formed by raindrop impact which could decrease infiltration, increase runoff and generate overland flow and erosion. The severity, frequency, and extent of erosion are likely to be altered by changes in rainfall amount and intensity and changes in wind.

Land management will continue to be the principal determinant of the soil organic matter (SOM) content and susceptibility to erosion during the next few decades, but changes in vegetation cover resulting from short-term changes in weather and near-term changes in climate are likely to affect SOM dynamics and erosion, especially in semi-arid regions.

From the assessment of the land resource stresses and desertification in Africa which was carried out by the Natural Resources Conservation Service of the United States Department of Agriculture (Reich et al. 2001) utilizing information from the soil and climate resources of Africa, it can be concluded (Table 2) that, climatic stresses account for 62.5% of all the stresses on land degradation in Africa. These climatic stresses include high soil temperature, seasonal excess water; short duration low temperatures, seasonal moisture stress and extended moisture stress and affect 18.5 million km$^2$ of the land in Africa. This study clearly exemplifies the importance of the need to give a more careful consideration of climatic factors in land degradation.

**Table 2.** Major land resources stresses and land quality assessment of Africa (Source: Reich, P.F., S.T. Numben, R.A. Almaraz, and H. Eswaran. 2001. Land resource stresses and desertification in Africa. In: Eds. Bridges, E.M., I.D. Hannam, F.W.T. Penning de Vries, S.J. Scherr, and S. Sombatpanit. 2001. Response to Land Degradation. Sci. Publishers, Enfield, USA. 101-114)

| Land Stresses | | | Inherent Land Quality | | |
|---|---|---|---|---|---|
| Stress Class | Kinds of Stress Area | Area (1,000 km2) | Class | Area (1,000 km2) | Area (%) |
| 1 | Few constraints | 118.1 | I | 118.1 | 0.4 |
| 2 | High shrink/swell | 107.6 | II | 1,319.6 | 4.5 |
| 3 | Low organic matter | 310.9 | II | | |
| 4 | High soil temperatures | 901.0 | II | | |
| 5 | Seasonal excess water | 198.9 | III | 765.4 | 2.6 |
| 6 | Minor root restrictions | 566.5 | III | | |
| 7 | Short duration low temperatures | 0.014 | III | | |
| 8 | Low structural stability | 333.7 | IV | | |
| 9 | High anion exchange capacity | 43.8 | IV | | |

| | | | | | |
|---|---|---|---|---|---|
| 10 | Impeded drainage | 520.5 | IV | 898.0 | 3.1 |
| 11 | Seasonal moisture stress | 3,814.9 | V | | |
| 12 | High aluminum | 1,573.2 | V | | |
| 13 | Calcareous, gypseous | 434.2 | V | | |
| 14 | Nutrient leaching | 109.9 | V | 5,932.3 | 20.2 |
| 15 | Low nutrient holding capacity | 2,141.0 | VI | | |
| 16 | High P, N retention | 932.2 | VI | | |
| 17 | Acid sulfate | 16.6 | VI | | |
| 18 | Low moisture and nutrient status | 0 | VI | | |
| 19 | Low water holding capacity | 2,219.5 | VI | 5,309.3 | 18.1 |
| 20 | High organic matter | 17.0 | VII | | |
| 21 | Salinity/alkalinity | 360.7 | VII | | |
| 22 | Shallow soils | 1,016.9 | VII | 1,394.7 | 4.8 |
| 23 | Steep lands | 20.3 | VIII | | |
| 24 | Extended low temperatures | 0 | VIII | 20.3 | 0.1 |
| Land Area | | 29,309.1 | | | |
| Water Bodies | | 216.7 | | | |
| Total Area | | 29,525.8 | | | |

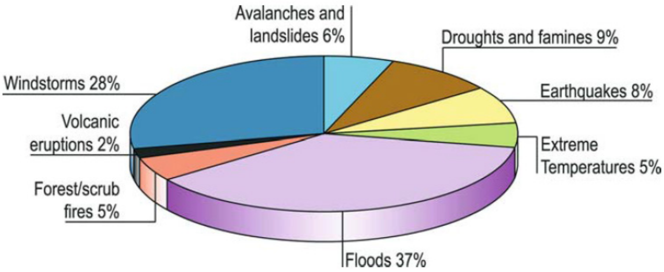

**Figure 2.** Global distribution of natural disasters (1993-2002)

According to the database of CRED, the Belgium Centre for Research on the Epidemiology of Disasters, weather- climate- and water-related hazards that occurred between 1993-2002, were responsible for 63 per cent of the US$ 654 billion damage caused by all natural disasters. These natural hazards are therefore the most frequent and extensively observed ones (Figure 2) and they all have a major impact on land degradation.

## 5.1 Rainfall

Rainfall is the most important climatic factor in determining areas at risk of land degradation and potential desertification. Rainfall plays a vital role in the development and distribution of plant life, but the variability and extremes of rainfall can lead to soil erosion and land degradation (Figure 3). If unchecked for a period of time, this land degradation can lead to desertification. The interaction of human activity on the distribution of vegetation though land management practices and seemingly benign rainfall events can make land more vulnerable to degradation. These vulnerabilities become more acute when the prospect of climate change is introduced.

Rainfall and temperature are the prime factors in determining the world’s climate and therefore the distribution of vegetation types. There is a strong correlation between rainfall and biomass since water is one of primary inputs to photosynthesis. Climatologists use an “aridity index” (the ratio of annual precipitation to potential evaporation) to help classify desert (arid) or semi-arid areas (UNEP 1992; Williams and Balling 1986; Gringof and Mersha 2006). Drylands exist because the annual water loss (evaporation) exceeds the annual rainfall; therefore these regions have a continual water deficit. Deserts are the ultimate example of a climate where annual evaporation far exceeds the annual rainfall. In cases where the annual water deficits are not so large, some plant life can take hold usually in the form of grasslands or steppes. However, it is these dry lands on the margins of the world’s deserts that are most susceptible to desertification, the most extreme example of land degradation. Examples of these regions include the Pampas of South Americas, the Great Russia Steppes, the Great Plains of North America, and the Savannas of Southern Africa and Sahel region of Northern Africa. With normal climatic variability, some years the water deficits can be larger than others but sometimes there can be a several year period of water deficit or long-term drought. During this period, one can see examples of land degradation in the Dust Bowl years of the 1930s in the Great Plains or the nearly two decade long drought in the Sahel in the 1970s and 1980s. It was this period of drought in the Sahel that created the current concern of desertification.

For over a century, soil erosion data has been collected and analyzed from soil scientists, agronomists, geologists, hydrologists, and engineers. From these investigations, scientists have developed a simple soil erosion relationship that incorporates the major soil erosion factors. The Universal Soil Loss Equation (USLE) was developed in the mid-1960s for understanding soil erosion for agricultural applications (Wischmeier and Smith 1978). In the mid-1980's, it was updated and renamed the Revised Universal Soil Loss Equation (RUSLE) to incorporate the large amount of information that had accumulated since the original and to address land use applications besides agriculture such as soil loss from mined lands, constructions sites, and reclaimed lands. The RUSLE is derived from the theory of soil erosion and from more than 10,000 plot-years of data from natural rainfall plots and numerous rainfall simulations.

*The RUSLE is defined as:*

$$A = R\ K\ L\ S\ C\ P$$

Where A is the soil loss per year (t/ha/year); R represents the rainfall-runoff erosivity factor; K is the soil erodibilty factor; L represents the slope length; S is the slope steepness; C represents the cover management, and P denotes the supporting practices factor (Renard et al. 1997). These factors illustrate the interaction of various climatic, geologic, and human factors and that smart land management practices can minimize soil erosion and hopefully land degradation.

The extremes of either too much or too little rainfall can produce soil erosion that can lead to land degradation. However, soil scientists consider rainfall the most important erosion factor among the many factors that cause soil erosion. Zachar (1982) provides an overview of soil erosion due to rainfall which can erode soil by the force of raindrops, surface and subsurface runoff, and river flooding. The velocity of rain hitting the soil surface produces a large amount of kinetic energy which can dislodge soil particles. Erosion at this micro-scale can also be caused by easily dissoluble soil material made water soluble by weak acids in the rainwater. The breaking apart and splashing of soil particles due to raindrops is only the first stage of the process, being followed by the washing away of soil particles and further erosion caused by flowing water. However, without surface runoff, the amount of soil erosion caused by rainfall is relatively small (Lal 2001).

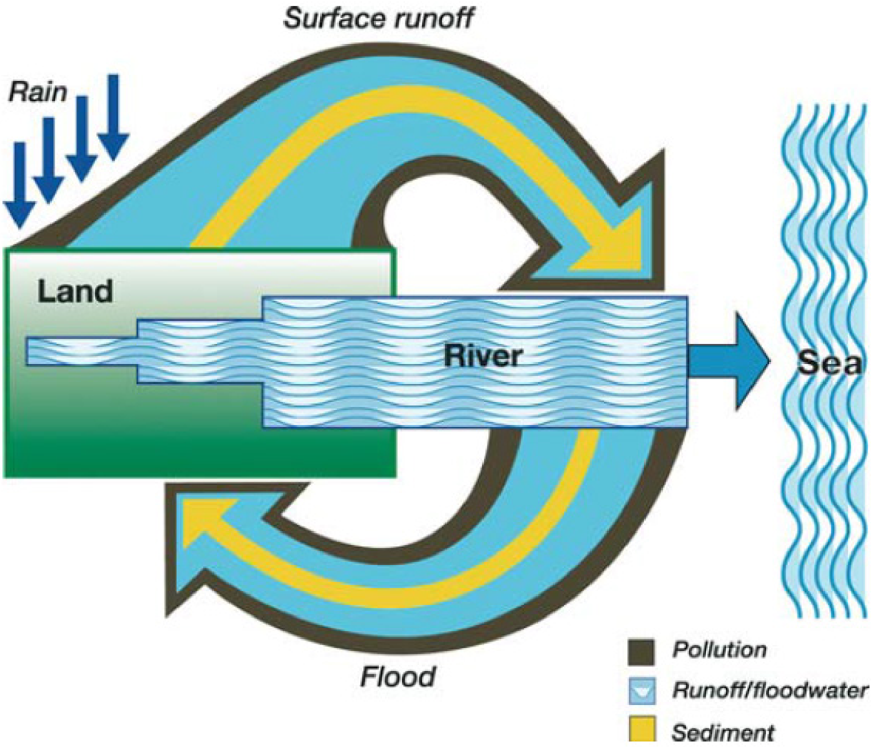

**Figure 3.** Schematic diagram of rain-fall-induced processes involved in land degradation

Once the soil particles have dislodged they become susceptible to runoff. In general, the higher intensity of the rainfall, the greater is the quantity of soil available in runoff water. In the case of a light rain for a long duration, most of the soil dislodgement takes place in the underwater environment and the soil particles are mostly fine. The greater the intensity of rainfall and subsequent surface runoff, the larger the soil particles that are carried away. A critical factor that determines soil erosion by rainfall is the permeability of the soil, which indirectly influences the total amount of soil loss and the pattern of erosion on slopes. One unfortunate by-product of runoff is the corresponding transport of agricultural chemicals and the leaching of these chemicals into the groundwater.

Rainfall intensity is the most important factor governing soil erosion caused by rain (Zachar 1982). Dry land precipitation is inherently variable in amounts and intensities and so is the subsequent runoff. Surface runoff is often higher in dry lands than in more humid regions due to the tendency of dry land soils to form impermeable crusts under the impact of intense thunderstorms and in the absence of significant plant cover or litter. In these cases, soil transport may be an order of magnitude greater per unit momentum of falling raindrops than when the soil surface is well vegetated. The sparser the plant cover, the more vulnerable the topsoil is to dislodgement and removal by raindrop impact and surface runoff. Also, the timing the rainfall can play crucial role in soil erosion leading to land degradation. An erratic start to the rainy season along with heavy rain will have a greater impact since the seasonal vegetation will not be available to intercept the rainfall or stabilize the soil with its root structure.

An on-going effort of scientists is to try to integrate all these factors into models that can be used to predict soil erosion. The Water Erosion Prediction Project (WEPP) model is a process-based, distributed parameter, continuous simulation, erosion prediction model for use on personal computers and can be applied at the field scale to simulate hillslope erosion or more complex watershed scale erosion (USDA 2006). It mimics the natural processes that are important in soil erosion. It updates the soil and crop conditions every day that affect soil erosion. When rainfall occurs, the plant and soil characteristics are used to determine if surface runoff will occur. The WEPP model includes a number of conceptual components that include: climate and weather (rainfall, temperature, solar radiation, wind, freeze – thaw, snow accumulation and melting), irrigation (stationary sprinkler, furrow), hydrology – (infiltration, depressional storage, runoff), water balance (evapotranspiration, percolation, drainage), soils (types and properties) , crop growth – (cropland, rangeland, forestland), residue management and decomposition, tillage impacts on infiltration and erodibility, erosion – (interrill, rill, channel), deposition (rills, channels, and impoundments), sediment delivery, particle sorting and enrichment.

Of special note is the impact of other forms of precipitation on soil erosion (Zachar 1982). Hail has a severe effect on the soil surface because its kinetic energy is several times that of rain resulting in much more soil surface being destroyed and a greater amount of material being washed away. And if hailstorms are accompanying with heavy rain, as is the case with some thunderstorms, large amounts of soil can be eroded especially on agricultural land before the crops can stabilize the soil surface. Snow thaw erosion occurs when the soil freezes during the cold period and the freezing process dislodges the soil, so that when the spring thaw occurs, fine soil particles are released in the runoff. This kind of erosion can often produce greater erosion losses than by rain. Also, when the soil freezes the infiltration rate is greatly reduced so that when the thaw arrives, relatively intense soil erosion can take place even though the amount of snow thaw is small. In this situation, the erosive processes can be multiplied by a combination of a heavy rain event and sudden influx of warm air. Leeward portions of mountainous areas are susceptible to this since they are typically drier and have less vegetation and are prone to katabatic winds (rapidly descending air from a mountain range warms very quickly).

## 5.2 Floods

Dryland rivers have extremely variable flows and river discharge and the amount of suspended sediments are highly sensitive to fluctuations in rainfall as well as any changes in the vegetation cover in the basins. The loss of vegetation in the headwaters of dryland rivers can increase sediment load and can lead to dramatic change in the character of the river to a less stable, more seasonal river characterised by a rapidly shifting series of channels. However, rainfall can lead to land degradation in other climates, including sub-humid ones. Excessive rainfall events either produced by thunderstorms, hurricanes and typhoons, or mid-latitude low-pressure systems can produce a large amount of water in a short period of time across local areas. This excess of water overwhelms the local watershed and produces river flooding. Of course, this is a natural phenomenon that has occurred for millions of years and continuously shapes the earth. River flooding occurs in all climates, but it is in dryland areas where the problem is most acute.

Flood forecasting is complex process that must take into account many different factors at the same time, depending on the type and nature of the phenomenon that triggers the flooding. For example, widespread flash floods are often started off by heavy rain falling in one area within a larger area of lighter rain, a confusing situation that makes it difficult to forecast where the worst flood will occur. Forecasting floods caused by the heavy rain or storm surges that can sweep inland as part of a tropical cyclone can also be a complex job, as predictions have to include where they will land, the stage of their evolution and the physical characteristics of the coast.

To make predictions as accurate as possible, National Hydrological Services (NHSs) and National Meteorological Services (NMSs) under the auspices of the WMO undertake flood forecasting based on quantitative precipitation forecasts (QPFs), which have become more accurate in recent years, especially for light and moderate amounts of precipitation, although high amounts and rare events are still difficult to predict. So setting up forecasting systems that integrate predictions for weather with those for water-related events is becoming more of a possibility every day, paving the way for a truly integrated approach.

Forecasting also needs to be a cooperative and multidisciplinary effort. With the many issues and the complexity of factors surrounding floods, flood managers have to join forces with meteorologists, hydrologists, town planners, and civil defense authorities using available integrated models. Determining the socioeconomic impacts of floods will mean taking a close look at construction or other activities in and around river channels. Up-to-date and accurate information is essential, through all the available channels: surface observation, remote sensing and satellite technology as well as computer models.

Flood risk assessment and management have been around for decades but recently there has been a shift to Integrated Flood Management. The defining characteristic of Integrated Flood Management is integration, expressed simultaneously in different forms: an appropriate mix of strategies, points of interventions, types of interventions (i.e. structural or non-structural), short or long-term, and a participatory and transparent approach to decision making – particularly in terms of institutional integration and how decisions are made and implemented within the given institutional structure.

Land use planning and water management have to be combined in one synthesized plan through co-ordination between land management and water management authorities to achieve consistency in planning. The rationale for this integration is that the use of land has impacts upon both water quantity and quality. The three main elements of river basin management – water quantity, water quality, and the processes of erosion and deposition – are inherently linked.

Therefore, an integrated flood management plan should address the following five key elements (APFM 2004):

- Manage the water cycle as a whole;

- Integrate land and water management;
- Adopt a best mix of strategies;
- Ensure a participatory approach;
- Adopt integrated hazard management approaches.

## 5.3 Droughts

Drought is a natural hazard originating from a deficiency of precipitation that results in a water shortage for some activities or some groups. It is the consequence of a reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors – such as high temperatures, high winds and low relative humidity – that can aggravate the severity of the event. For example, the 2002-03 El Niño related Australian drought (Coughlan et al. 2003), which lasted from March 2002 to January 2003, was arguably one of, if not the, worst short term droughts in Australia's recorded meteorological history (Nicholls 2004). Analysis of rainfall records for this 11-month period showed that 90% of the country received rainfall below that of the long-term median, with 56% of the country receiving rainfall in the lowest 10% (i.e., decile-1) of recorded totals (Australia-wide rainfall records commenced in 1900). During the 2002-03 droughts Australia experienced widespread bushfires, severe dust storms and agricultural impacts that resulted in a drop in Australia's Gross Domestic Product of over 1% (Watkins 2005). The first 5 months of 2005 were exceptionally dry for much of Australia, leading many to label this period a truly exception drought.

Extended droughts in certain arid lands have initiated or exacerbated land degradation. Records show that extensive droughts have afflicted Africa, with serious episodes in 1965–1966, 1972–1974, 1981–1984, 1986–1987, 1991–1992, and 1994–1995. The aggregate impact of drought on the economies of Africa can be large: 8–9 per cent of GDP in Zimbabwe and Zambia in 1992, and 4–6 per cent of GDP in Nigeria and Niger in 1984. In the past 25 years, the Sahel has experienced the most substantial and sustained decline in rainfall recorded anywhere in the world within the period of instrumental measurements. The Sahelian droughts in the early 70s were most unique in their severity and were characterized as "the quintessence of a major environmental emergency" and their long term impacts are now becoming clearer (Figure 4).

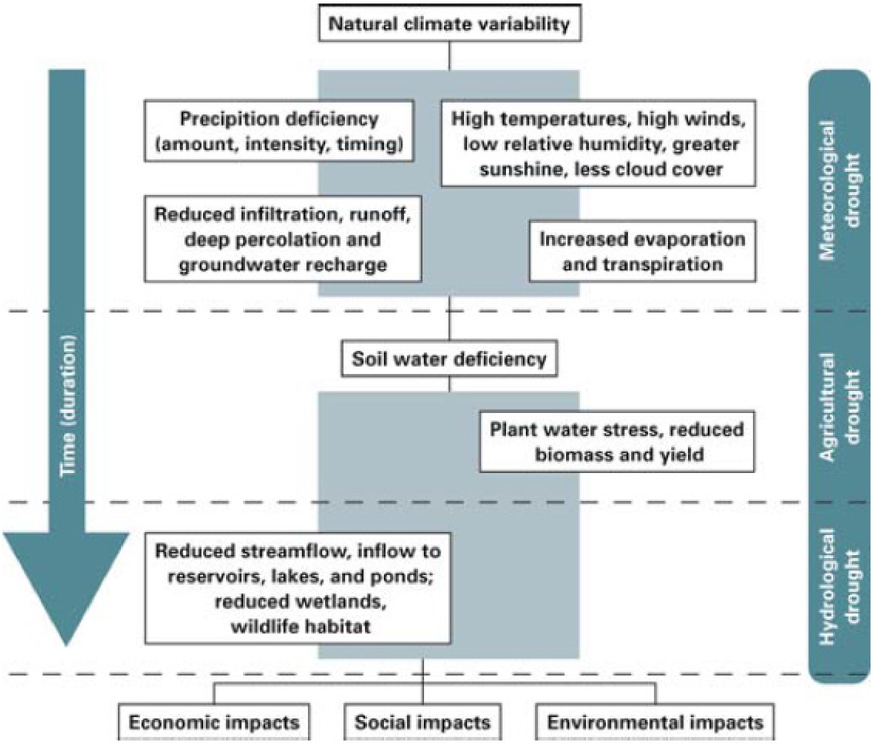

**Figure 4.** Types and impacts of draught

Sea surface temperature (SST) anomalies, often related to the El Niño Southern Oscillation (ENSO) or North Atlantic Oscillation (NAO), contribute to rainfall variability in the Sahel. Droughts in West Africa correlate with warm SST in the tropical south Atlantic. Examination of the oceanographic and meteorological data from the period 1901-1985 showed that persistent wet and dry periods in the Sahel were related to contrasting patterns of SST anomalies on a near-global scale (Sivakumar 2006). From 1982 to 1990, ENSO-cycle SST anomalies and vegetative production in Africa were found to be correlated. Warmer eastern equatorial Pacific waters during ENSO episodes correlated with rainfall of <1,000 mm yr$^{-1}$ over certain African regions.

A coupled surface-atmosphere model indicates that – whether anthropogenic factors or changes in SST initiated the Sahel drought of 1968-1973 – permanent loss of Sahel savannah vegetation would permit drought conditions to persist. The effect of drought, reducing soil moisture and thus evaporation and cloud cover, and increasing surface albedo as plant cover is destroyed, is generally to increase ground and near-surface air temperatures while reducing the surface radiation balance and exacerbating the deficit in the radiation balance of the local surface-atmosphere system (Williams and Balling 1996). This entails increased atmospheric subsidence and consequently further reduced precipitation.

Early warning systems can reduce impacts by providing timely information about the onset of drought (Wilhite et al. 2000) Conventional surface observation stations within National Meteorological Services are one link in the chain, providing essential benchmark data and time series necessary for improved monitoring of the climate and hydrologic system. Tracking certain indicators such as stream flow or soil moisture can help in formulating drought index values – typically single numbers, far more useful than raw data for decision-making.

Drought plans should contain three basic components: monitoring and early warning, risk assessment, and mitigation and response (Wilhite and Svoboda 2000) . Because of the slow onset characteristics of droughts, monitoring and early warning systems provide the foundation for an effective drought mitigation plan. A plan must rely on accurate and timely assessments to trigger mitigation and emergency response programs.

Various WMO programmes monitor extreme climate events associated with drought, while four monitoring centres – two in Africa, one in China and the Global Information and Early Warning System – provide weather advisories and one and three-month climate summaries. Among other African early warning systems, the Southern Africa Development Community (SADC) monitors the crop and food situation in the region and issues alerts during periods of impending crisis. Such networks can be the backbone of drought contingency planning, coordinated plans for dealing with drought when it comes.

## 5.4 Solar radiation, temperature and evaporation

The only source of energy for the earth is the sun but our world intercepts only a tiny amount of this energy (less than a tenth of 1 percent) to provide the energy for the various biological (photosynthesis) and geophysical (weather and climate) processes for life depends on. The earth system, based on fundamental rules of physics, must emit the same amount of radiation as it receives. Therefore, the complex transfer of energy to satisfy this requirement is the basis for our weather and climate. Solar radiation is highly correlated with cloudiness, and in most dryland climates there are little or no clouds, the solar radiation can be quite intense. In fact, some of the highest known values of solar radiation can be found in places like the Sahara desert. Solar heating of the land surface is the main contribution to the air temperature.

Along with rainfall, temperature is the main factor determining climate and therefore the distribution of vegetation and soil formation. Soil formation is the product of many factors that include: the parent material (rock), topography, climate, biological activity, and time. Temperature and rainfall cause different patterns of weathering and leaching in soils. Seasonal and daily changes in temperature can affect the soil moisture, biological activity, rates of chemical reactions, and the types of vegetation. Important chemical reactions in the soil include the nitrogen and carbon cycles.

In the tropics, surface soil temperatures can exceed 55ºC and this intense heat contributes to the cracking of highly-clay soils that expose not only the soil surface but the soil subsurface to water or wind erosion. Of course, these high temperatures will also increase soil evaporation and further reduce available soil moisture for plant growth.

In temperate dry lands, the freeze-thaw cycle can have a direct effect on the composition of the soil by the movement of rocks and stones from various depths to the surface. In high elevations, the freeze-thaw is one factor degrading rock structures, causing cracks and fissures which could lead to landslides and rock avalanches.

Evaporation is the conversion of water from the liquid or solid state into vapour, and its diffusion into the atmosphere. A vapour pressure gradient between the evaporating surface and the atmosphere and a source of energy are necessary for evaporation. Solar radiation is the dominant source of energy and sets the broad limits of evaporation. Solar radiation values in the tropics are high, modified by the cloud cover, which leads to a high evaporative demand of the atmosphere. In the arid and semi-arid regions, considerable energy may be advected from the surrounding dry areas over irrigated zones. Rosenberg et al. (1983) lists several studies that have demostrated the "oasis effect" which is the transfer of energy across an evaporating surface and can cause large evaporative losses in a short period of time.

Climatic factors induce an evaporative demand of the atmosphere, but the actual evaporation resulting will be influenced by the nature of the evaporating surfaces as well as the availability of water. On a degraded land, the land surface itself influences the evaporative demand by the albedo and surface roughness, the latter affecting turbulence. In the arid and semi-arid regions, the high evaporation which greatly exceeds precipitation leads to accumulation of salts on soil surface. Soils with natric horizon are easily dispersed and the low moisture levels lead to limited biological activity.

## 5.5 Wind

The dry lands of the world are affected by moderate to severe land degradation from wind erosion and there is evidence that the frequency of sand storms/dust storms in increasing. It has been estimated that in the arid and semi-arid zones of the world, 24% of the cultivated land and 41% of the pasture land are affected by moderate to severe land degradation from wind erosion (Rozanov 1990).

The world-wide total annual production of dust by deflation of soils and sediments was estimated to be 61 to 366 million tonnes (Middleton 1986). Losses of desert soil due to wind erosion are globally significant. The upper limit for global estimates of the long-range transport of desert dust is approximately 1 x 1016 g year $^{-1}$.

For Africa, it is estimated that more than 100 million tonnes of dust per annum is blown westward over the Atlantic. The amount of dust arising from the Sahel zone has been reported to be around or above 270 million tons per year which corresponds to a loss of 30 mm per m2 per year or a layer of 20 mm over the entire area (Stahr et al. 1996).

Every year desert encroachment caused by wind erosion buries 210,000 hectares of productive land in China (PRC 1994). It was shown that the annual changes of the frequency of strong and extremely strong sandstorms in China are as follows: 5 times in the 1950s, 8 times in the 1960s, 13 times in the 1970s, 14 times in the 1980s, and 20 times in the 1990s (Ci 1998).

Sand and dust storms are hazardous weather and cause major agricultural and environmental problems in many parts of the world. There is a high on-site as well as off-site cost due to the sand and dust storms. They can move forward like an overwhelming tide and strong winds take along drifting sands to bury farmlands, blow out top soil, denude steppe, hurt animals, attack human settlements, reduce the temperature, fill up irrigation canals and road ditches with sediments, cover the railroads and roads, cause household dust damages, affect the quality of water in rivers and streams, affect air quality, pollute the atmosphere and destroy mining and communication facilities. They accelerate the process of land degradation and cause serious environment pollution and huge destruction to ecology and living environment (Wang Shigong et al. 2001). Atmospheric loading of dust caused by wind erosion also affects human health and environmental air quality.

Wind erosion-induced damage includes direct damage to crops through the loss of plant tissue and reduced photosynthetic activity as a result of sandblasting, burial of seedlings under sand deposits, and loss of topsoil (Fryrear 1971; Amburst 1984; Fryrear 1990). The last process is particularly worrying since it potentially affects the soil resource base and hence crop productivity on a long-term basis, by removing the layer of soil that is inherently rich in nutrients and organic matter. Wind erosion on light sandy soils can provoke severe land degradation and sand deposits on young seedlings can affect crop establishment.

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 et al. 1994). Thus dust entrainment during dust events leads to long-term soil degradation, which is essentially irreversible. The cost to productivity is difficult to measure but is likely to be quite substantial.

### 5.5.1 Causes of wind erosion

The occurrence of wind erosion at any place is a function of weather events interacting with soil and land management through its effects on soil structure, tilth and vegetation cover. In regions where long dry periods associated with strong seasonal winds occur regularly, the vegetative cover of the land does not sufficiently protect the soil, and the soil surface is disturbed due to inappropriate management practices, wind erosion usually is a serious problem.

At the southern fringe of the Sahara Desert, a special dry and hot wind, locally termed Harmattan, occurs. These NE or E winds normally occur in the winter season under a high atmospheric pressure system. When the wind force of Harmattan is beyond the threshold value, sand particles and dust particles will be blown away from the land surface and transported for several hundred kilometres to the Atlantic Ocean.

In the Northwest region of India, the convection sand-dust storm that occurs in the season preceding the monsoon is named Andhi (Joseph et al. 1980). It is called Haboob in Africa and Arabic countries. It is titled "phantom" or "devil" in some regions.

In general, two indicators, wind velocity and visibility, are adopted to classify the grade of intensity of sand-dust storms. For instance, the sand-dust storms occurring in the Northwest part of India are classified into three grades. 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 sanddust 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).

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 Organization (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.

Wind erosivity is the main factor controlling the broad pattern of wind erosion. It has been defined as "that property of the wind which determines its ability to entrain and move bare, dry soil in fine tilth" (Painter 1978). It can be estimated from daily or hourly records of wind speed above a threshold related to the lowest speed at which soil particles are entrained (Skidmore and Woodruff 1968). Chepil and Woodruff (1963) developed an index of wind erosion capacity (C) defined as:

$$C = \frac{V^3}{2.9(P-E_2)}$$

where V = wind speed at standard observing levels (~ 10 m), m s-1; P = precipitation (mm); and Ep is potential evapotranspiration (mm). Table 3 gives a classification of the wind erosion capacity as per the different values of the index of wind erosion capacity.

**Table 3.** Wind erosion capacity

| Index value | Wind erosion capacity |
|---|---|
| 0-20 | Insignificant or zero |
| 20-50 | Moderate |
| 50-150 | High |
| >150 | Very high |

When soil movement is sustained, the quantity of soil that can be transported by the wind varies as the cube of the velocity. Models demonstrate that wind erosion increases sharply above a threshold wind speed. In the U.S. corn belt, a 20% increase in mean wind speed greatly increases the frequency with which the threshold is exceeded and thus the frequency of erosion events.

There have been several efforts to integrate all these wind erosion factors into a computer model. One such effort is the Wind Erosion Prediction System (WEPS) which is a process-based, daily time-step model that predicts soil erosion by simulation of the fundamental processes controlling wind erosion (Wagner 1996). The WEPS model is able to calculate soil movement, estimate plant damage, and predict PM-10 emissions when wind speeds exceed the erosion threshold. It also provides users with spatial information regarding soil flux, deposition, and loss from specific regions of a field over time. The structure of WEPS is modular and consists of seven submodels and four databases. Most of the WEPS submodels use daily weather as the natural driving force for the physical processes that change field conditions. The other submodels focus on hydrology including the changes in temperature and water status of the soil; soil properties; growth of crop plants; crop plant decomposition; typical management practices such as tillage, planting, harvesting, and irrigation; finally the power of the wind on a subhourly basis.

### 5.5.2 Climatic implications of dust storms

The very fine fraction of soil-derived dust has significant forcing effects on the radiative budget. 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. 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). 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. Climatic changes in turn can modify the location and strength of dust sources.

# 6 WILD FIRES, LAND DEGRADATION AND ATMOSPHERIC EMISSIONS

Uncontrolled wildfires occur in all vegetation zones of the world. It is estimated that fires annually affect 1015 million hectares (m ha) of boreal and temperate forest and other lands, 2040 m ha of tropical rain forests due to forest conversion activities and escaped agricultural fires, and up to 500 m ha of tropical and subtropical savannas, woodlands, and open forests. The extent of the soil organic carbon pool doubles that present in the atmosphere and is about two to three times greater than that accumulated in living organisms in all Earth's terrestrial ecosystems. In such a scenario, one of the several ecological and environmental impacts of fires is that they are a significant source of greenhouse gases responsible for global warming.

Globally, biomass burning, which includes wild fires, is estimated to produce 40 percent of the carbon dioxide, 32 percent of the carbon monoxide, 20 percent of the particulates, and 50 percent of the highly carcinogenic poly-aromatic hydrocarbons produced by all sources (Levine 1990). Current approaches for estimating global emissions are limited by accurate information on area burned and fuel available for burning.

Emissions from fires are considerable and contribute significantly to gross global emissions of trace gases and particulates from all sources to atmosphere. Natural emissions are responsible for a major portion of the compounds, including non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and nitric oxide (NO), which determine tropospheric oxidant concentrations. The total NMVOC flux is estimated to be about 84×1012 g of carbon (Tg C) which is comprised primarily of isoprene (35%), 19 other terpenoid compounds (25%) and 17 non-terpenoid compounds (40%).

The influence of fire on soil characteristics (soil-water content, soil compaction, soil temperature, infiltration ability, soil properties especially organic matter, pH, exchangeable Ca, Mg, K, Na and extractable P) of a semi-arid southern African rangeland was quantified over two growing seasons (2000/01–2001/02) following an accidental fire (Snyman 2003). The decrease in basal cover due to fire (head fires) exposed the soil more to the natural elements and therefore to higher soil temperatures and soil compaction in turn leading to lower soil-water content and a decline in soil infiltrability.

# 7 CLIMATE CHANGE AND LAND DEGRADATION

Human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the 20th century and are expected to contribute to further changes in climate in the 21st century and beyond. These changes in atmospheric composition are likely to alter temperatures, precipitation patterns, sea level, extreme events, and other aspects of climate on which the natural environment and human systems depend.

According to IPCC (2003), established by WMO and UNEP, ecosystems are subject to many pressures (e.g., land-use change, resource demands, population changes); their extent and pattern of distribution is changing, and landscapes are becoming more fragmented. Climate change constitutes an additional pressure that could change or endanger ecosystems and the many goods and services they provide. Soil properties and processes – including organic matter decomposition, leaching, and soil water regimes – will be influenced by temperature increase. Soil erosion and degradation are likely to aggravate the detrimental effects of a rise in air temperature on crop yields. Climate change may increase erosion in some regions, through heavy rainfall and through increased wind speed.

$CO_2$-induced climate change and land degradation remain inextricably linked because of feedbacks between land degradation and precipitation. Climate change might exacerbate land degradation through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation, and winds. Several climate models suggest that future global warming may reduce soil moisture over large areas of semiarid grassland in North America and Asia (Manabe and Wetherald 1986). This climate change is likely to exacerbate the degradation of semiarid lands that will be caused by rapidly expanding human populations during the next decade. Emmanuel (1987) predicted that there will be a 17% increase in the world area of desert land due to the climate change expected with a doubling of atmospheric $CO_2$ content.

Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development (Riebsame et al. 1995). Climate change – especially changes in climate variability through droughts and flooding – will make addressing these problems more complex.

The greatest impact will continue to be felt by the poor, who have the most limited access to water resources. The impact of changes in precipitation and enhanced evaporation could have profound effects in some lakes and reservoirs. Studies show that, in the paleoclimate of Africa and in the present climate, lakes and reservoirs respond to climate variability via pronounced changes in storage, leading to complete drying up in many cases. Furthermore, these studies also show that under the present climate regime several large lakes and wetlands show a delicate balance between inflow and outflow, such that evaporative increases of 40%, for example, could result in much reduced outflow.

The frequency of episodic transport by wind and water from arid lands is also likely to increase in response to anticipated changes in global climate (Manabe and Wetherlad 1986). Lower soil moisture and sparser vegetative cover would leave soil more susceptible to wind erosion. Reduction of organic matter inputs and increased oxidation of SOM could reduce the long-term water-retention capacity of soil, exacerbating desertification. Moreover, increased wind erosion increases wind-blown mineral dust, which may increase absorption of radiation in the atmosphere (Nicholson and Kim 1997).

## 7.1 Carbon sequestration to mitigate climate change and combat land degradation

The soil organic carbon (SOC) pool to 1-m depth ranges from 30 tons ha$^{-1}$ in the arid climates to 800 tons ha$^{-1}$ in organic soils in cold regions (Lal 2007). Conversion of natural to agricultural ecosystems causes depletion of SOC pool by as much as 60% in soils of temperate regions and 75% or more in the cultivated soils of the tropics. The depletion is exacerbated when the output of carbon (C) exceeds the input and when soil degradation is severe.

Carbon sequestration implies transferring atmospheric $CO_2$ into long-lived pools and storing it securely so it is not immediately reemitted. Thus, soil C sequestration means increasing SOC and soil inorganic carbon stocks through judicious land use and recommended management practices. Some of these practices include mulch farming, conservation tillage, agroforestry and diverse cropping systems, cover crops and integrated nutrient management, including the use of manure, compost, biosolids, improved grazing, and forest management.

The potential carbon sink capacity of managed ecosystems approximately equals the cumulative historic C loss estimated at 55 to 78 gigatons (Gt). Offsetting fossilfuel emissions by achievable SOC potential provides multiple biophysical and societal benefits. An increase of 1 ton of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 kg $ha^{-1}$ for wheat, 10 to 20 kg $ha^{-1}$ for maize, and 0.5 to 1 kg $ha^{-1}$ for cowpeas and could enhance world food security (Lal 2007).

## 8 UNDERSTANDING THE INTERACTIONS BETWEEN CLIMATE AND LAND DEGRADATION – ROLE OF WMO

WMO is the United Nations specialized agency responsible for meteorology and operational hydrology. WMO provides support to the National Meteorological and Hydrological Services (NMHSs) of its 188 Member States and Territories in their respective missions of observing and understanding weather and climate and providing meteorological and related services in support of national needs. These needs especially relate to protection of life and property, safeguarding the environment and contributing to sustainable development.

The scientific programmes of WMO have been vital in expanding knowledge of the climate system. The systematic observations carried out using standardized methods have provided worldwide data for analysis, research and modelling of the atmosphere and its changing patterns of weather systems. WMO coordinates a global network for the acquisition and exchange of observational data under the Global Observing System of its World Weather Watch Programme. The system comprises some 10 000 stations on land, 1 000 upper-air stations, 7 000 ships, some 3 000 aircraft providing over 150 000 observations daily and a constellation of 16 meteorological, environmental, operational and research satellites. WMO also coordinates a network of three World Meteorological Centres, 35 Regional Specialized Meteorological Centres and 187 National Meteorological Centres. Specialized programmes of observations, including those for chemical constituents of the atmosphere and characteristics of the oceans and their circulations, have led to a better understanding of interactions between the domains of the climate system (the atmosphere, the oceans, the land surface and the cryosphere) and of climate variability and change.

Specifically, WMO contributes to understanding the interactions between climate and land degradation through dedicated observations of the climate system; improvements in the application of agrometeorological methods and the proper assessment and management of water resources; advances in climate science and prediction; and promotion of capacity building in the application of meteorological and hydrological data and information in drought preparedness and management. In this context, WMO will continue to address the issue of land degradation through its Agricultural Meteorology Programme, Hydrology and Water Resources Programme, and other scientific and technical programmes by:

## 8.1 Advocating for enhanced observing systems at national, regional and international levels

WMO is committed to work with the Parties to the UNCCD to improve the observing systems for weather, climate and water resources in order to meet the needs of the Convention, and to assist developing countries to strengthen their participation in the collection and use of these observations to meet their commitments to the Convention. In this regard, it is quite relevant to examine the Decisions of the Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) which address the issue of climate observing systems, and the regional workshop programme that has been developed and is being implemented in different parts of the world by the Global Climate Observing System (GCOS) Secretariat co-sponsored by WMO.

## 8.2 Promoting effective early warning systems

Early warning systems serve as an essential and important alert mechanism for combating land degradation. As meteorological and hydrological hazards are linked with climate variability, regular assessments and authoritative statements on the interpretation and applicability of observational data are needed for the study of climate variability and the implementation of a climate alert system to allow NMHSs to make early warnings on pending significant climate anomalies. Warnings of climate-related disasters are becoming feasible from weeks to seasons in advance. WMO's World Climate Programme will continue to issue routine statements on the state of El Niño or La Niña, which, through the NMHSs, can alert Governments to ensure preparedness against the impacts of El Niño-related anomalies, which can trigger various disasters. WMO played an active role in the activities of the ad hoc Panel on early warning systems established by the Committee on Science and Technology (CST) of the UNCCD. High on the recommendations of the Panel is the need to undertake a critical analysis of the performance of early warning, monitoring and assessment systems; the improvement of methods for and approaches to the prediction of drought and monitoring of desertification; and the development of mechanisms to facilitate an exchange of information focusing in particular on national and subregional networks. WMO's new major programme on Natural Disaster Prevention and Mitigation will provide the focus for the consolidation of its efforts in the area of early warnings and for taking new initiatives in this area in collaboration with other organizations.

## 8.3 Further enhancing climate prediction capability

Climate prediction capabilities are being enhanced through the Climate Variability (CLIVAR) project of the World Climate Research Programme (WCRP). The prediction of El Niño and the associated impacts are becoming possible, with reasonable skill, up to few seasons in advance. Related to this, WMO is broadening the implementation of the WMO Climate Information and Prediction Services (CLIPS) project, which is designed to promote the use of climate information and prediction services, capacity building, multi-disciplinary research and the development of new applications. Consensus long-range forecasts on droughts, which were issued at several Regional Climate Outlook Fora, organized in different parts of the world with active support from WMO, provide good early warning information to national authorities.

## 8.4 Assessing vulnerability and analyzing hazards

It is important to analyze vulnerability at the local, national and regional levels which is an important factor in evaluating the adequacy of early warnings. A good tool to assess those different vulnerabilities is the linkage between weather, climate and disaster databases to the different type of meteorological or hydrological disasters. In this regard, a pilot project is ongoing in Chile linking climate with flood disaster databases with the support of WMO through the World Climate Programme, as part of the activities of the Inter-Agency Task Force for Disaster Reduction (IATF's) Working Groups on Climate and Disasters and on Risk Vulnerability and Impact Assessment. This is an important tool for risk communication among policy makers and communities. WMO will continue to assist in developing and managing the relevant climate databases through data rescue and climate database management projects.

## 8.5 Implementing risk management applications

Risk management approaches need to be employed in combatting droughts and mitigating floods. In this context, hazard mapping, suitable agroclimatic zoning and the establishment of partnerships are essential tools for land use and preparedness planning. Several expert teams established by the Commission for Agricultural Meteorology (CAgM) of WMO are examining these issues critically and are issuing guidance reports for the users. In the area of flood forecasting and management, WMO's Hydrology and Water Resources Programme is implementing the Associated Programme for Flood Management (APFM) in collaboration with the Global Water Partnership, in the context of integrated water resources management. Several related projects are being developed in different parts of the world inorder to provide guidance on the development of support systems for sustainable land management and agroclimatic zoning.

## 8.6 Contributing actively to the implementation of the UN system' s International Strategy for Disaster Reduction (ISDR)

It is to be noted that society's ability to cope with and adapt to, climate change will depend heavily on its ability to assess how and where weather and climate patterns are likely to change, to predict the continuous fluctuations in risk and vulnerability to communities, and to develop adaptive strategies that will increase the community's resilience when the next potential disaster strikes. WMO leads the ISDR Working Group on Climate and Disasters.

## 8.7 Supporting the strengthening of the capabilities of the Parties and regional institutions with drought-related programmes

The capabilities of Parties and regional institutions with drought-related programmes will be strengthened and collaboration will be promoted with other institutions in drought- and desertification-prone regions, with emphasis on Africa, Asia, Latin

America and the Caribbean, and the northern Mediterranean region, which are all referred to in the Regional Annexes to the Convention. Examples of such institutions in Africa are the AGRHYMET Centre and the African Centre of Meteorological Applications for Development (ACMAD), both located in Niamey, Niger, the IGAD Climate Prediction and Applications Centre in Nairobi, Kenya and the SADC Drought Monitoring Centre in Gaborone, Botswana. In order to enhance capacity building in the development of National Action Plans within the framework of the Convention, WMO organized Roving Seminars on the Application of Climatic Data for Desertification Control, Drought Preparedness and Management of Sustainable Agriculture in Beijing, China in May 2001 and in Antigua and Barbuda in April 2004.

## 9 FUTURE PERSPECTIVES

The definition of land degradation adopted by UNCCD assigns a major importance to climatic factors contributing to land degradation, but there is no concerted effort at the global level to systematically monitor the impacts of different climatic factors on land degradation in different regions and for different classes of land degradation. Hence there is an urgent need to monitor the interactions between climate and land degradation. To better understand these interactions, it is also important to identify the sources and sinks of dryland carbon, aerosols and trace gases in drylands. This can be effectively done through regional climate monitoring networks. Such networks could also help enhance the application of seasonal climate forecasting for more effective dryland management.

There are serious gaps in the basic meteorological network and observational facilities in many areas, some of them in regions with severe land degradation problems. The most serious single and geographically widespread shortcoming is the lack of information on rainfall intensity. WMO is taking steps to facilitate the development of early warning systems by organizing the development of suitable instruments and statistical processing. Furthermore, WMO is coordinating efforts on the part of its Members to further investigations of using data from meteorological satellites to supplement knowledge of meteorological conditions influencing land degradation, especially over areas inadequately covered by ground-level observations. WMO, through its 188 Members, is pleased to be part of the effort to better understand the role of climate in land degradation and work with various national, regional and international organizations and the civil society in combating and arresting land degradation.

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