DRY LANDS AND DESERTIFICATION

Willy Verheye
National Science Foundation Flanders/Belgium, and Geography Department, University of Gent, Belgium

Keywords: Aerosols, aridity, crop adaptation, desertification, dust storms, fuel wood, irrigation, land degradation, over-grazing, rangeland, water harvesting, wildfires, and xerophytes

Contents

Summary

Dry lands are areas which have no water available to mesophytic plants. Aridity can have a climatic or a plant-physiological basis. Desertification is the process which leads to aridity, either because of a deteriorating rainfall regime or due to a degradation of the environment by human activities. Dry lands extend over approximately 35 % of the

global land surface. Based on climatic or non-climatic criteria a distinction can be made between hyper-arid, arid, semi-arid and dry sub-humid areas.

A number of characteristic features of desert environments are discussed. These include: temporal and spatial rainfall variability, daily temperature amplitude, wind erosion, transport and accumulation, vegetation and biological activity, soil properties including salinity, and human actions. The main causes for desertification are a low and irregular rainfall, over-grazing and over-cultivation, wildfires and un-responsible tree cutting and fuel wood consumption.

The management of dry land areas should primarily focus on the best and most economic use of available water, either from rainfall or from groundwater aquifers. This involves surface water management and water harvesting, groundwater exploitation and recharge, efficient irrigation and drainage, and crop adaptation. Rangelands constitute the biggest land resource of dry areas, but they remain vulnerable if not properly managed.

Though desertification is known since the earliest civilizations, it is only since the Rio Earth Summit in 1992 that it has received international attention. Actions to refrain and remedy the extension of deserts are currently coordinated at an international level by the UN Convention on Combating Desertification (UNCCD).

1. Introduction

Arid lands, dry lands or deserts are, by definition, areas which have no water available to mesophytic plants for long periods. The most prominent characteristic of deserts is **aridity** (from the Latin word *arere*, to be dry) and this implies deficiency of rainfall and absence of a shallow groundwater table. However, the amount of rainfall alone can not serve as an adequate measure of aridity unless this amount is related to its effectiveness. This can derive from two main situations:

- precipitation is low and irregular and, associated with a high evapotranspiration; hence, little moisture is left in the soil for plant growth and soil formation; or
- water is present in the soil but it is held by strong internal forces (created for example by the presence of salts) and therefore not available to plants.

The first situation refers to climatic aridity, the second to plant-physiological aridity. The connotation of dry lands is a general term which makes no distinction between these.

Desertification is the process that leads to aridity, initially because rainfall decreases, but additionally because the environment is so much degraded that plants can no more develop properly. In the first sense desertification leads to desert conditions and is geographically confined to regions with low rainfall or where the rainfall has significantly decreased in the course of time; in a broader context it is associated with land degradation in general and in this case it is not necessarily a feature of the arid zone.

The broadening of the climatic concept of desertification, its linkage with land degradation and with the human impact of the process, has led to great **confusion**. This has been enhanced by the UN Convention to Combat Desertification (UNCCD) where desertification was taken as "*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities, where land means the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system*" (Burke and Thornes, 1998). The result of this confusion is that some authors have given an over-emphasis to man-made land degradation, describing desertification even in high-rainfall areas of northern Europe (Arnalds, 2000).

A great deal of the confusion or deliberate obfuscation about desertification reflects a poorly defined or incorrect use of terms, a failure to identify the various combination of processes at different time and space scales and ignorance or lack of data, and this confusion may even be politically, economically, socially and scientifically motivated. Since the word desertification has been picked up by the mass media, its public perception has been rather variable. Some people have used the word to mean the de-population of marginal rural areas due to migration and land abandonment (which is indeed part of the problem), others and especially the news media, tend to be sensationalist, sometimes giving the idea that land is becoming irreversibly unproductive, and that the Sahara desert is going to "invade" the Mediterranean.

In this paper desertification is understood as "*the process of degradation of the environment, being the result of either natural conditions (decrease or extreme variability of rainfall) or of adverse human interventions, but leading always to a critical shortage of water for the vegetation*". This means that the term is climate-linked and is geographically restricted to arid and semi-arid areas and their immediate fringes. Obviously, desertification is most prominent in semi-arid regions and on the edge with dry sub-humid areas where a further degradation of marginal natural conditions can become critical for the survival of flora and fauna.

2. Extension of Dry Lands

Dry lands are commonly associated with the arid zones of the world (in which arable crop production is not possible without irrigation) and their semi-arid and dry sub-humid fringes in which rainfall, though precarious, is only sufficient for crops requiring special management techniques. Except for some areas in Asia and North America most arid zones extend in the inter-tropical belt - in particular between 10 and 35° North and South immediately north and south of the tropical convergence zone - where rainfall is irregular and small, and where evaporation is so high that water is not active neither for plant uptake nor for weathering and soil formation.

Dry lands occupy approximately one third of the total terrestrial surface. The largest arid areas are located in Africa, the Middle East and Australia, with comparatively less dry lands in North and South America (Figure 1). A good description of dry land environments, their land use and production potential is given by Arnon (1972), Hare (1985), UNESCO (1990) and Simmers (2003).

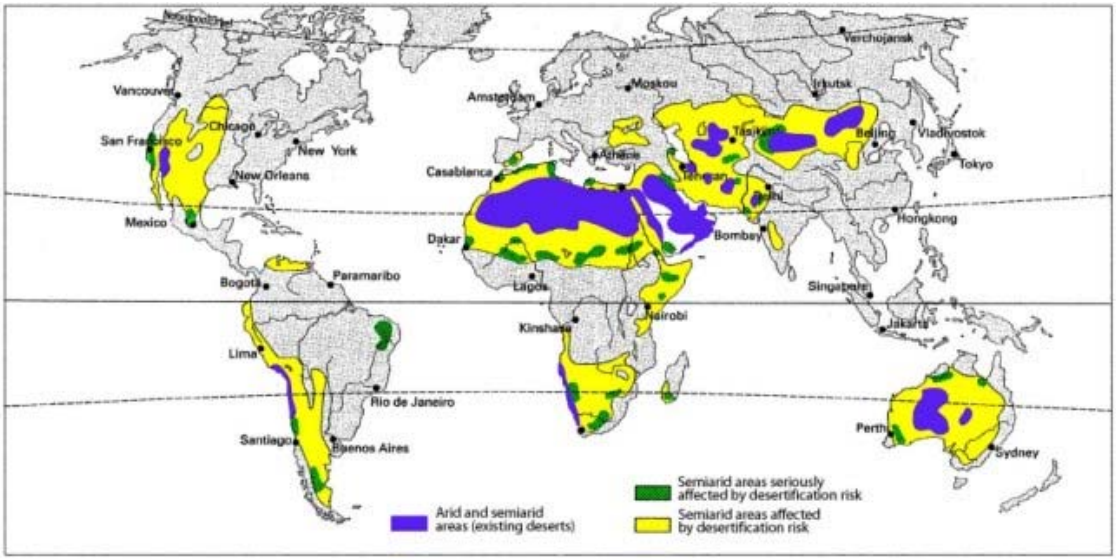

Figure 1: Geographical location and extension of arid areas in the world

Africa is by far the continent with most dry lands. The **Sahara** is the largest desert in the world. In reality it is only a part of a larger (sub)tropical area extending from the Atlantic Ocean across northern Africa, Arabia and western Asia, into north-western India and Pakistan. The Sahara includes a wide variety of landforms including barren land, shifting sands, stony surfaces, eroded hills and mountains.

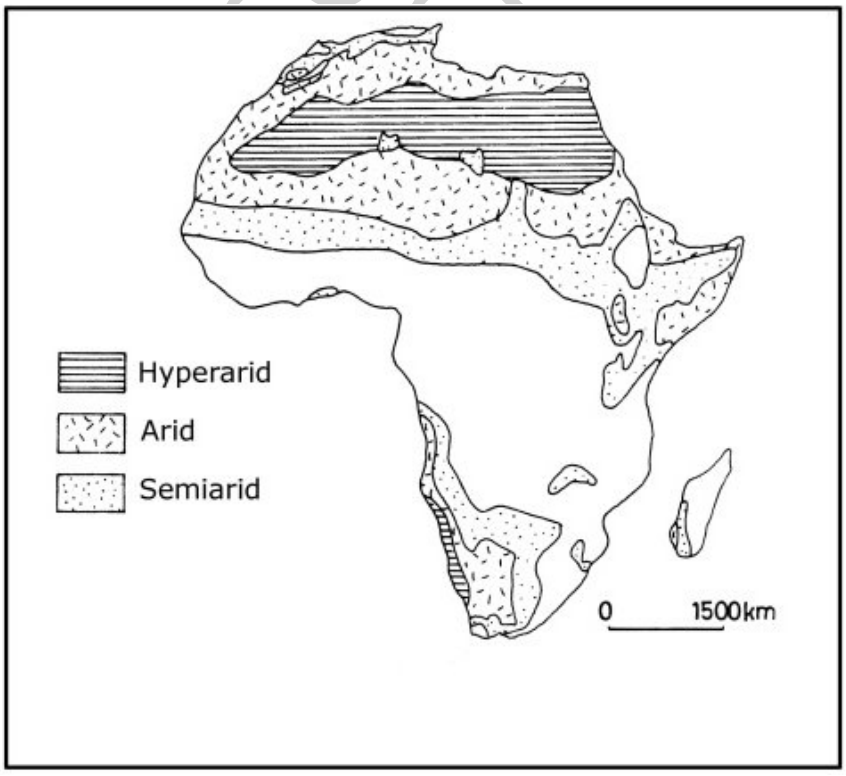

Figure 2: Extension of dry lands in Africa

The greater part of the Sahara receives less than 100 mm of annual rain, mostly occurring in heavy showers. Strong winds are common during the day, but the weather is calm at night. Dust storms are frequent. The northern fringe of the Sahara is bordered by a narrow strip of steppe between the desert and the coastline with a Mediterranean climate. South is a warm steppe region with summer rains. This Sudanese Sahel includes portions of Senegal, Mali, Burkina Faso, Mauritania, Ghana, Niger, Togo, Benin, Nigeria, Cameroun, Chad and Sudan (Figure 2).

In **southern Africa** desert conditions prevail along the west coast from Angola to the Cape Province. Precipitation falls as summer rains in the north, and throughout the year in the south. This region comprises the extremely arid Namibian Desert, and the less dry Kalahari and Karroo semi-deserts, covering in total some 550,000 km². Two thirds of the Republic of South Africa have an arid or semi-arid climate.

South west Asia has dry lands extending from Arabia to western India. Most of the Arabian Desert is hot and barren, covering approximately 2.5 million km². The low and erratic rainfall is mainly concentrated in the winter months. The northern part is a stony or sandy desert producing some pasturage; in the center are mountains and chains with alluvial, cultivated valleys; the southern part is located in the rain-shadow of these mountains and is of little use for agriculture or grazing.

The arid zone of **India and Pakistan** covers nearly 750,000 km², and includes Sind, Baluchistan, all Rajasthan west of the Aravalli Mountains, the south western tip of Punjab and most of the North West Frontier Province. Cultivable land is restricted to the Indus plains, irrigated by the Indus River and its tributaries. Winters are cool and summers are hot with temperatures above 50°C. Precipitation is concentrated in winter and is therefore not very effective.

Mid-latitude dry lands extend over more than 2 million km² and cover northern Iraq, Afghanistan and Baluchistan, the former Soviet Union, Manchuria and China. They concern desert and steppe regions with drifting sand. Winters are cold and summers are hot with scanty precipitation. The climate becomes more severe from the west to the east, with winters becoming colder and longer; summers are too cool in the west and too short in the east to justify intensive irrigation. The main characteristic of the greater part of these regions is the very cold winter with minimum temperatures as low as -25 to -30°C resulting in soil freezing to various depths. Winters are milder in the south-western part (Caucasus and southern Ukraine).

In **North America** the dry land areas lie almost exclusively west of the 100° meridian. There are two distinct rainfall regimes, with winter rains prevailing in the west and summer rains in the east. Three dry land regions can be distinguished: the Pacific Valleys, the Inter-mountain Region, and the Great Plains.

The *Pacific Valley* area includes the Central Valley of California, ranging from semi-arid in Sacramento Valley to arid in the southern San Joaquin Valley, as well as the Imperial and Death Valleys of southern California, and the Salt and Gila Valleys in Arizona. Still further south is the coastal desert of the Mexican Peninsula of Baja California, with hot summers and near tropical winters.

The *Inter-mountain region* lies in the rain-shadow of the Sierra Nevada. Summer temperatures are high; winters whilst generally cold have temperatures that are somewhat milder than might be expected at this latitude. A dominant climatic feature is the bi-annual rainfall variation with one maximum in winter and a second in the warm season; it is especially well marked in central Arizona.

The Inter-mountain region is divided into two main sectors: a northern cool-desert or *sagebrush zone* including the high-altitude Columbia Basin plateau in the north and the Great Basin rangelands in the south, and a southern warm-desert or *creosote-bush zone*; the latter includes the Mohave and Sonora Deserts, with mild winters and hot summers and a frost-free growing period of 300 days.

The *Great Plains* form the largest continuous grassland area of North America and extend from 22° to 54° North, e.g. up to Alberta and Saskatchewan Provinces in Canada. Winter temperatures vary from 10-20°C in the south to below 0°C in the north. Precipitation which is greatest along the eastern margin of the Southern Plains occurs mainly in summer, but high evapotranspiration rates reduce their effectiveness.

In **South America** the arid zone forms a long narrow strip along the western coast between the sea and the Andes Range. The Atacama Desert extends from northern Peru (5° South) to north Chile (26° South) and is very dry, though rather foggy, with no rainfall for several tens of years.

Inland to the East and located in the rain-shadow of the Andes is the Gran Chaco pampa plain with mild winters and moderate winter rainfall, extending to the south west in Patagonia, Argentina (approximately 500,000 km²). Winters are cool, and rainfall occurs throughout the year. The Patagonian desert is not barren, but produces pastures for extensive sheep grazing.

In **Australia** some 40 % of the country (3,2 million km²) is occupied by the central desert, characterized by mild to hot winters. Average annual rainfall is around 125 mm and is concentrated in the summer in the north and in the winter in the south. A semi-arid belt with erratic summer rainfall and tropical temperatures separates the central desert from the more humid climates on the margin of the continent.

-
-
-

Bibliography

Angström, A. (1936). *A Coefficient of Humidity of General Applicability*. Geografiska Annaler, 18: 245-254 [Paper introducing a new index for measuring the degree of aridity].

Arnalds, A. (2000). *Mitigation Actions in Desertified Areas of Northern Europe*. In: Enne, G., Zanolla, Ch. and Peter, D., eds.: Desertification in Europe: Mitigation, Strategies, Land Use Planning. Proceed. Advanced Study Course, Alghero, Sardinia, DG XII: Research, European Communities, Brussels-Luxemburg EUR 19390, 209-220 [Paper describing environmental degradation and loss of woodlands and natural vegetation cover in Iceland, and associating this phenomenon with desertification].

Arnon, I. (1972). *Crop Production in Dry Regions. 1: Background and Principles*. A Plant Science Monograph, Leonard Hill Publ., London, 650p. [An excellent monograph on the desert environment and its production potential].

Barberis, A. (2000). *The Impact of Summer Fires on Vegetation in Sardinia*. In: Enne G., Zanolla, Ch. and Peter, D., eds.: Desertification in Europe: Mitigation, Strategies, Land Use Planning. Proceed. Advanced Study Course, Alghero, Sardinia, EC/DG XII: Research European Communities, Brussels/Luxemburg EUR 19390, 276-281 [Describes the causes and effects of wildfires in Sardinia].

Burke, S. and Thornes, J.B. (1998). *Actions taken by Governmental and Non-Governmental Organizations to Mitigate Desertification in the Mediterranean*. Dir. Gen. Science, Research and Development, European Community, Concerted Action Report 10, Office of the Official Publications of the European Communities, Luxemburg, 349p. [Discusses the problem of confusion in terminology and gives an overview of actions taken in the past 10 years in Greece, Italy, Morocco and Tunisia].

Cameron, R.E. (1960*). Cold Desert Characteristics and Problems relevant to Other Arid Lands.* In: Mc Ginnies, W.G. and Goldman, B.J., eds.: Arid Lands in Perspective. Amer. Assoc. Advanc. Science, Washington, D.C., 167-205 [Comparative study of the occurrence of microorganisms in different desert locations in the world, with an emphasis on North American conditions].

De Martonne, E. (1962). *Une Nouvelle Fonction Climatologique: L'Indice d'Aridité*. La Météorologie Nouvelle, 2: 449-458 [Reference paper explaining the concept of a climatic aridity index based on rainfall and temperature criteria].

Diop, O. (2001). *Conflits Fonciers entre Agriculteurs et Eleveurs dans la Zone Sylvi-pastorale au Sénégal: Le Cas de la Communauté Rurale de Dealy*. The Land, 5(2): 137-148. [Paper describing the origin and causes of the ethnic conflicts on land between herdsmen and farmers in the Groundnut Basin in North Senegal].

Evenari, M., Shanan L. and Tadmor, N. (1971). *The Negev: The Challenge of a Desert*. Harvard Univ. Press, Cambridge, Mass., 345p. [A monograph on the geography, past civilizations and agricultural practices in the Negev, including references to the use of dew as a water source].

Goudie, A.S. (1974). *Further Experimental Investigations of Rock Weathering by Salt Crystallization and Other Mechanical Processes*. Spezialband Zeitschr. Geomorf., 21: 1-12 [Paper illustrating the volumetric expansion of salts and their effect on rock weathering and physical breakdown].

Hare, F.K. (1985). *Climate Variations, Droughts and Desertification*. WMO Publ. 653, World Meteor. Org., Geneva, 35p. [A good overview of dry land properties, extension and classification].

Kidron, G.J., Yaïr, A. and Danin, A. (2000*). Dew Variability within a Small Arid Drainage Basin in the Negev Highlands*. Quart. J. Royal Meteor. Soc., 126: 63-80. [Report on dew measurements in an arid environment and its use as a water source at present and in the past].

Koç, A., Oztas, T. and Tahtaçioglu, N. (2000*). Rangeland-Livestock Interaction in Our Near History: Problems and Recommendations.* In: Munsuz, N. *et al*., eds.: Proceed. Intern. Symposium on Desertification, June 2000, Konya, Turkey, Soil Sci. Soc. of Turkey and Selçuk Univ., 293-298 [Gives a good overview of rangeland mismanagement in Turkey, and its impact on progressing desertification in the country].

Köppen, W. and Geiger, R. (1936). *Handbuch der Klimatologie*. Gebr. Bornttraeger, Berlin. [A standard work in climatology, presenting the classification of world climates based on temperature and rainfall criteria].

Krumbein, W. (1969). *Uber dein Einfluss der Mikroflora auf die Exogene Dynamik (Verwitterung und Küstenbildung).* Geol. Rundschau, 58: 333-363 [Paper reporting on investigations on microbial activity on rock weathering].

Lang, R. (1920). *Verwitterung und Bodenbildung als Einführung in die Bodenkunde*. Petermans Mitteil., 13: 107-123 [Paper introducing a climatic factor for differentiating arid areas].

Newhall, N. (s.d.). *Calculation of Soil Moisture Regimes from the Climatic Record*. Soil Survey Investigation Report, Soil Conserv. Services, USDA, Washington D.C., 17p.[Paper explaining the concept of using a water balance model for defining pedo-climate].

Papanastasis, V.P. (2000). *Land Degradation caused by Over-grazing and Wildfires and Management Strategies to Prevent and Mitigate their Effects*. In: Enne, G., Zanolla, Ch. and Peter, D., eds.: Desertification in Europe: Mitigation, Strategies, Land Use Planning. Proceed. Advanced Study Course, Alghero, Sardinia, EC/DG XII: Research European Communities, Brussels/Luxemburg EUR 19390, 187-198 [Excellent paper explaining the role and impact of over-grazing and wildfires in Mediterranean areas, with a case study from Crete].

Shantz, H.L. (1956). *History and Problems of Arid Lands Development*. In: White, G.F., ed.: The Future of Arid Lands. Amer. Ass. Adv. Sci., Publ. 43, Washington DC, 3-25 [Paper giving amongst other things a classification of arid lands on the basis of vegetation and land use criteria].

Simmers, I. (2003). *Understanding Water in a Dry Environment: Hydrological Processes in Arid and Semi-Arid Zones*. Intern. Assoc. Hydrogeologists/A.A. Balkema Publ., Lisse, The Netherlands, 341p. [A reference book on the effect of rainfall, runoff and water flow processes, as well as of human impact on management issues in arid and semi-arid zones].

Seth, S.M. (2003). *Human Impact and Management Issues in Arid and Semi-Arid Regions*. In: Simmers, I., ed: Understanding Water in a Dry Environment: Hydrological Processes in Arid and Semi-Arid Zones. Intern. Assoc. Hydrogeologists/A.A. Balkema Publ., Lisse, The Netherlands, 280-341. [Describes planning, developing and managing water resources in arid and semi-arid areas, including water quality and quantity aspects and technologies, and dealing with rainwater harvesting, groundwater recharge and waste water reuse].

Thornthwaite, C.W. (1948). *An Approach toward a Rational Classification of Climate*. Geogr. Review, 38(1): 55-94. [Reference paper explaining the classification of climates based on rainfall and evapotranspiration criteria].

UNEP (1997). *World Atlas of Desertification*. London, UK [This atlas presents in graphical and written form UNEP's most recent quantification of the global extent and severity of desertification].

UNESCO (1979). *Map of the World Distribution of Arid Regions*. [Explanatory Note. MAB Technical Notes, Nairobi.]

UNESCO (1990). *The Sahel Forum*. Proceedings of a Seminar on the State-of-the-Art of Hydrology and Hydrogeology in Arid and Semi-Arid Areas of Africa, Ouaguadougou, Burkina Faso. UNESCO Techn. Doc. in Hydrology, 31p. [A compilation of communications describing the geography of the Sahel region].

USDA (1975). *Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. US Dept. Agric., Soil Cons. Serv., Agric. Handbook 436, 754p. [Reference book on the classification of soils in the world].

Verheye, W. (1976). *Nature and Impact of Temperature and Moisture in Arid Weathering and Soil Forming Processes - A Review*. Pedologie, 26(3): 205-224 [Paper investigating the efficiency of rain and dew on arid weathering processes].

Wheater, H.S. (2002). *Hydrological Processes in Arid and Semi-Arid Areas*. In: Wheater, H.S. and Al-Weshah, R.A., eds.: Hydrology of Wadi Systems. UNESCO IHP-V Techn. Doc. in Hydrology, 55, 5-22 [Gives a good overview of environmental characteristics and processes in arid and semi-arid areas].

Zangvil, A. (1996). *Six Years of Dew Observations in the Negev, Israel*. J. Arid. Env., 32: 361-371. [Report on dew measurements in the Negev].

Biographical Sketch

Willy Verheye is an Emeritus Research Director at the National Science Foundation, Flanders, and a former Professor in the Geography Department, University of Ghent, Belgium. He holds an MSc. in Physical Geography (1961), a PhD. in soil science (1970) and a Post-Doctoral Degree in soil science and land use planning (1980).

He has been active for more than thirty-five years, both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international (UNDP, FAO, World Bank, African and Asian Development Banks, etc.) and national agencies, as well as for development companies and NGOs active in inter-tropical regions.