Geographic Extent and Characteristics of the World's Arid Zones and Their Peoples

1

Mahesh K. Gaur and Victor R. Squires

1.1 Introduction

Arid zones are generally defined as regions where rate of evaporation is greater than precipitation. These are also characterized by persistent water scarcity, frequent drought, high climatic variability and high wind velocity and various forms of land degradation, including desertification and loss of biodiversity. As such, arid lands occupy 5.36 million km^2 or 41% area of the earth's land surface and are home to roughly more than a third of the world's population (Mortimore 2009). Large areas of arid zones are located in North and South America, North Africa, the Sahelian region, Africa South of the Equator, the Near East and the Asia and the Pacific regions between latitudes of 15 and 30° in both northern and southern hemispheres. Arid zones are home to roughly 2.5 billion people who rely directly on arid land ecosystem services for their livelihoods (UN EMG 2011) and support 50% of the world's livestock where 44% of the world's food is grown.

As per the *aridity index*, there are four categories of arid lands, hyperarid, arid, semiarid and dry subhumid regions. So, the main distinction could be made between deserts (hyperarid and arid) and semi-deserts (semiarid). Hyperarid zones cover 6.6% of earth's land surface, arid zones cover 10.6%, while semiarid zones are more extensive, occur in all continents and cover 15.2% whereas the dry subhumid category covers 8.7% of earth's land surface (UN 2010). Lack of water, limited foodstuffs and extremes of climatic phenomenon have generally made arid zones critical places for any kind of habitation. This desperate situation is predicted to worsen even further as a result of climate change and shifting weather patterns due to anthropogenic activities.

M.K. Gaur (✉)
ICAR-Central Arid Zone Research Institute, Jodhpur-342003, India
e-mail: maheshjeegaur@yahoo.com

V.R. Squires
Institute of Desertification Studies, Beijing, China
e-mail: dryland1812@internode.on.net

M.K. Gaur, V.R. Squires (eds.), *Climate Variability Impacts on Land Use and Livelihoods in Drylands*, DOI 10.1007/978-3-319-56681-8_1

From the climatic point, *aridity* is an overall moisture deficit (especially when resulting from a permanent absence of rainfall for a long period of time) under average climatic conditions. As such, the cause of aridity is significant within the context of various environmental and atmospheric factors (including global climate change), which contribute to the occurrence of aridity. In classification of aridity zones, the aridity index or the index of moisture deficit is generally taken into consideration. It is calculated by comparing the incoming moisture totals with potential moisture loss: the evapotranspiration/precipitation levels.

1.2 Definition of Arid Zones

Definitions and delimitations of arid environments and deserts abound, varying according to the purpose of the enquiry or the location of the area under consideration. Numerous literary, climatic and biological classifications have been proposed for arid lands (McGinnies 1988) and there seem to be two separate types of definition of arid zones: the one is series of *literary definitions* based on the changing meanings of '*desert*', and the other is a series of *scientific attempts* to establish a meaningful *boundary* to the arid zone. *Literary definitions*, thoroughly reviewed by Heathcote (1983), commonly employ terms such as 'inhospitable', 'barren', 'useless', 'unvegetated' or 'devegetated', and 'devoid of water'. The *scientific approaches* to the definition of the arid zones have varied according to the aims of the enquiry. Arid zones may be those areas of the world where evaporation exceeded precipitation. This boundary, or '*dry line*', is comparable in some ways to the 'snowline' in mountainous areas. *Scientific definitions* have been based on a number of criteria, including erosion processes (Penck 1894), drainage pattern (de Martonne and Aufrère 1927), climatic criteria based on plant growth (Köppen 1931) and vegetation types (Shantz 1956). A region is arid when it is characterized by a severe lack of available water, to the extent of hindering or preventing the growth and development of plant and animal life. Environments subject to arid climates tend to lack vegetation and are called *desertic*. As such, the word '*arid*' has been derived directly from Latin *aridus* meaning "dry, arid, parched," from *arere* "to be dry". Further, all schemes involve a consideration of moisture availability, at least indirectly, through the relationship between precipitation and evapotranspiration.

Meigs's (1953) classification of arid environments was produced on behalf of UNESCO. Being ultimately concerned with global food production, it is not surprising that arid areas too cold for plant growth (such as polar deserts) were excluded from the classification. Meigs based his scheme on Thornthwaite's (1948) indices of moisture availability (Im):

$$\mathrm{Im} = \frac{(100S - 60D)}{\mathrm{PE}}$$

where PE is potential evapotranspiration, calculated from meteorological data and *S* and *D* are, respectively, the moisture surplus and moisture deficit, aggregated on an annual basis from monthly data and taking stored soil moisture into account.

Table 1.1 The extent of the global arid zones (expressed as a percentage of the global land area)

Classification	Semiarid	Arid	Hyperarid	Total
Köppen (1931)	14.3	12.0	–	26.3
Thornthwaite's (1948)	15.3	15.3	–	30.6
Meigs (1953)	15.8	16.2	4.3	36.3
Shantz (1956)	5.2	24.8	4.7	34.7
UN (1977)	13.3	13.7	5.8	32.8

Source: Heathcote (1983)

Table 1.2 Arid land climates

		Mean temperature (°C)	
	% of arid lands	Coldest month	Warmest month
Hot	43	10–30	>30
Mild winter	18	10–20	10–30
Cool winter	15	0–10	10–30
Cold winter	24	<0	10–30

Source: Meigs (1952)

Meigs (1953) identified three types of arid environments: semiarid ($-40 \leq Im < -20$), arid ($-56 \leq Im < -40$) and extreme (or hyper–) arid ($\leq Im < -156$). Grove (1977) subsequently attached mean annual precipitation values to the first two categories (200–500 mm and 25–200 mm, respectively), though these are only approximate. Hyperarid areas have no seasonal precipitation regime and occur where 12 consecutive months without precipitation have been recorded (Meigs 1953). According to this scheme, these three environments cover about 36% of the global land area, differing only slightly from areas calculated according to this schemes (Table 1.1).

United Nations has declared 2010–2020 as *Decade for Deserts and the Fight Against Desertification*. According to it, the spread of the arid lands around the world is as follows:

Common name		Area (mill.km^2)	Percentage of total arid lands	Percentage of world land surface
Desert	Hyperarid	9.8	16.09	6.6
Semi-desert	Arid	15.7	25.78	10.6
Grassland	Semiarid	22.6	37.11	15.2
Rangelands	Dry subhumid	12.8	21.02	8.7
Total		60.9	100.00	41.3

Adapted from http://www.un.org/en/events/desertification_decade/whynow.shtml and modified

Meigs (1952) divided arid lands into those that are hot all year round and those with mild, cool and cold winters (Table 1.2). Variations in temperature affect the seasonal availability of moisture, by influencing evapotranspiration rates and affecting the form of precipitation in relatively high-latitude arid areas.

Table 1.3 Regional extent of arid zones

Region	Aridity zone							
	Arid		Semiarid		Dry subhumid		All arid lands	
	1000 km^2	%	1000 km^2	%	1000 km^2	%	1000 km^2	%
Asia (incl. Russia)	6164	13	7649	16	4588	9	18,401	39
Africa	5052	17	5073	17	2808	9	12,933	43
Oceania	3488	39	3532	39	996	11	8016	89
North America	379	2	3436	16	2081	10	5896	28
South America	401	2	2980	17	2223	13	5614	32
Central America and the Caribbean	421	18	696	30	242	10	1359	58
Europe	5	0	373	7	961	17	1359	24
World total	15,910	12	23,739	18	13,909	10	53,558	40

Source: FAO (2008)

Table 1.4 Global distribution for the types of arid lands

Arid land sub-habitat	Aridity index[a]	Share of global area (%)	Share of global population (%)	% rangeland	% cultivated	% other (incl. urban)
Hyperarid	<0.05	6.6	1.7	97	0.6	3
Arid	0.05–0.20	10.6	4.1	87	7	6
Semiarid	0.20–0.50	15.2	14.4	54	35	10
Subhumid	0.50–0.65	8.7	15.3	34	47	20
Total		41.3	35.5	65	25	10

Source: Safriel and Adeel (2005)

[a]The ratio of precipitation to potential evapotranspiration

There is no widely accepted definition of the term *arid zones*. Two of the most commonly accepted definitions are those of FAO and the United Nations Convention to Combat Desertification (UNCCD 2000). FAO has defined arid zones as those areas with a length of growing period (LGP) of 1–179 days (FAO 2000); this includes regions classified climatically as arid, semiarid and dry subhumid. The UNCCD classification employs a ratio of annual precipitation to potential evapotranspiration (P/PET). This value indicates the maximum quantity of water capable of being lost, as water vapour, in a given climate, by a continuous stretch of vegetation covering the whole ground and well supplied with water. Thus, it includes evaporation from the soil and transpiration from the vegetation from a specific region in a given time interval (WMO 1990). Under the UNCCD classification, arid zones are characterized by a P/PET of between 0.05 and 0.65.

According to both classifications, the hyperarid zones (LGP = 0 and P/PET <0.05), or true deserts, are not included in the arid zones and do not have potential for agricultural production, except where irrigation water is available. While about 47.2% of the world's total land area is considered to be arid zones (according to the UNCCD classification system), the extent of arid zones in various regions ranges from about 20% to 90% (Tables 1.3 and 1.4 and Fig. 1.1).

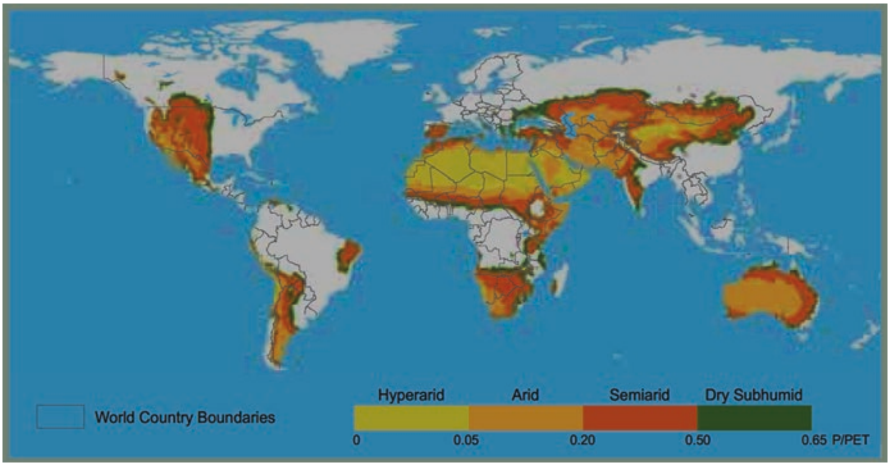

Fig. 1.1 Distribution of arid lands in the world (*Source*: IIASA/FAO 2003)

Actually, global arid zone is considered to include all elements of this threefold classification. There are several reasons for this:

1. The division between the three elements are somewhat arbitrary, often based on limited climatic data.
2. In arid lands, annual precipitation frequently varies substantially from year to year, so that in semiarid, arid and hyperarid areas, the only safe assumption is that any year could be extremely arid (Shantz 1956).
3. Distinct geomorphic thresholds in terms of processes and landforms have not been identified between the three elements of the scheme.
4. Climatic fluctuations and anthropogenic activities in the twentieth century have caused the expansion of arid physical conditions into some semiarid areas.
5. Semiarid areas are often called '*deserts*' by their inhabitants.

1.3 Characteristics of Arid Zones

Arid lands are a vital part of the earth's human and physical environments. They encompass grasslands, agricultural lands, forests and urban areas. The salient characteristics of hot arid zone are the following:

1. Aridity index is high (more than 70%).
2. High range of temperature and solar radiation, erratic and low rainfall, low atmospheric humidity and high wind velocity in summer.
3. Famine of food, fodder and water, i.e. '*Trikal*' is a permanent guest in every 3 or 5 years.
4. Soil is sandy with low water holding capacity, low organic content and deficit in nitrogen and phosphorus contents.

5. Vegetation is sparse, limited with low biomass production and xerophytic.
6. Heavy pressure of men and animals (cutting, felling, lopping, grazing, browsing, etc.) on vegetation.
7. Human population is thin except in the Indian arid zone, which is one of the most densely populated arid zones of the world.

Arid land ecosystems play a major role in global biophysical processes by reflecting and absorbing solar radiation and maintaining the balance of atmospheric constituents (Ffolliott et al. 2002). They provide much of the world's grain and livestock, forming the habitat that supports many vegetable species, fruit trees and micro-organisms. Sand covers 20% of the earth's surface. Over 50% of this area is deflated desert pavements.

Water scarcity is the predominant feature of arid lands. While heavy rains may occur, rainfall typically varies, sometimes dramatically, from season to season and from year to year. In hyperarid, arid and semiarid regions, water is scarce most of the time, and human settlements may cluster around rare sources of water such as rivers, springs, wells and oases. In such areas, traditional cultures have developed ways of finding, conserving and transporting water, including specialized land management techniques and structures to capture and retain precipitation or to encourage groundwater recharge.

Unsustainable land and water use and the impacts of climate change are driving the degradation of arid lands. Approximately 6 million km^2 (about 10%) of arid lands bear a legacy of land degradation. Such degradation – sometimes also referred to as 'desertification' – can take the form of soil erosion, nutrient depletion, water scarcity, altered salinity or the disruption of biological cycles (UNEP 2007). It has been estimated that about 1–6% of arid land human populations live in desertified areas, but a much larger percentage is under threat from further desertification (MEA 2005).

System productivity is greatly limited by inherently poor soil and/or human-induced soil degradation. On poorly managed land, the share of water that is available to plants can be as low as 40–50% of rainfall. On severely degraded land, as little as 5% of total rainfall may be used productively. '*Agricultural droughts*' can emerge even when water itself is not scarce within the landscape: when low soil fertility, poor crop and soil management and the use of poorly adapted varieties combine, the result is rainfall that is not being fully utilized for plant growth and grain filling (Humphreys et al. 2008).

In the wetter semiarid and subhumid regions, total seasonal rainfall often exceeds crop water needs. In fact, as long as appropriate levels of inputs are used, there is typically enough rainfall to double, and sometimes even quadruple, yields. In these areas, low soil fertility and a lack of inputs (particularly nitrogen) are major constraints to increasing yield and rainwater productivity – for example, most poor, smallholder farmers in sub-Saharan Africa do not apply fertilizer (Hilhorst and Muchena 2000; Morris et al. 2007; Twomlow et al. 2008). Nevertheless, there is evidence of positive trends in productivity in long-term data for certain African arid land countries.

Even in dry, semiarid temperate areas, such as Central West Asia and North Africa, seasonal rainfall of only 300–400 mm is enough to produce as much as 4 tonnes per hectare (t/ha) of wheat grain because precipitation falls during the cool winter growing season and because the growing season is longer. However, yields are typically less than half of this.

High variabilities in both rainfall amounts and intensities are characteristics of arid land regions, as are the occurrence of prolonged periods of drought. A drought is defined as a departure from the average or normal conditions, sufficiently prolonged (1–2 years – FAO 2004) as to affect the hydrological balance and adversely affect ecosystem functioning and the resident populations. There are actually four different ways that drought can be defined (National Weather Service 2004). Meteorological drought is a measure of the departure of precipitation from normal. Due to climatic differences, a drought in one location may not be a drought in another location. Agricultural drought refers to situations where the amount of soil water is no longer sufficient to meet the needs of a particular crop. Hydrological drought occurs when surface and subsurface water supplies are below normal. Socioeconomic drought describes the situation that occurs when physical water shortages begin to affect people.

The terms drought and aridity are sometimes used interchangeably, but they are different.

1.4 Causes of Aridity

Aridity is basically a comparison between water supply and water demand. Water supply in general is the amount of water received from precipitation, while water demand is measured in terms of evapotranspiration. Potential evaporation may be estimated by use of commonly observed climatological data. Aridity may be considered as an expression in a qualitative or quantitative manner of the dryness of an area. Aridity results from climatic, topographic and oceanographic factors which prevent moisture-bearing weather systems reaching an area of the land surface. Broadly, aridity arises from general causes acting individually or in combination of various other factors.

1.4.1 Continentality or Distance

Distance from the oceans prevents the penetration of rain-bearing winds into the center of large continents by topography or by distance. Precipitation and evapotranspiration are both usually lower than in arid areas owing their origins to atmospheric stability, while cold winters are common. Relatively small arid areas are surrounded by an extensive zone of semiaridity. Part of the desert area of the United States and the Monte-Patagonian Desert to the leeward of the Andes in South America is a result of the acidifying effect major mountain barriers have on air masses which move over them. One of the causes of the Takla Makan, Turkestan and Gobi deserts of Central Asia is the great distance from major moisture sources.

1.4.2 Atmospheric Stability

A general cause of aridity is the formation of dry, stable air masses that resist convective currents. The Somali-Chalbi desert probably owes its existence to a stable environment produced by large-scale atmospheric motions. Deserts dominated by the eastern portions of subtropical high-pressure cells originate in part from the stability produced by these pressure and wind systems. Tropical and subtropical deserts cover about 20% of the global land area (Glennie 1987). These are concentrated in zones of descending, sable air, the tropical high-pressure belts. In these areas, large arid zones are composed of central arid areas surrounded by relatively small, marginal, semiarid belts.

Also, aridity can also result from the lack of storm systems where precipitation is very unreliable and the mechanisms that cause convergence, create unstable environments, and provide the upward movement of air which is necessary for precipitation. The paths, frequencies and degrees of development of midlatitude cyclones or tropical cyclones are crucial factors in the production of rainfall.

The deserts of the subtropical latitudes are particularly sensitive to the climatology of cyclones. The Arabian and Australian deserts and the Sahara are examples of regions positioned between major wind belts with their associated storm systems.

1.4.3 Rain

Widespread rains are almost unknown over large parts of the hot deserts, most of the precipitation coming in violent convectional showers that do not cover extensive areas. The *wadis*, entirely without water during most of the year, may become torrents of muddy water filled with much debris after one of these flooding rains.

Because of the violence of tropical desert rains and the sparseness of the vegetation cover, temporary local runoff is excessive, and consequently less of the total fall becomes effective for vegetation or for the crops of the oasis farmer. Much of the precipitation that reaches the earth is quickly evaporated by the hot, dry desert air. Rainfall is always meagre.

In inter-ascending air, motion is associated primarily with extratropical wave cyclones, large-scale low pressure systems carried by the winds blowing from the west. This polar jet stream brings abundant precipitation to middle latitudes (40° and 60°), particularly along the west coasts of the continents.

In addition, it is extremely variable from year to year. The dependability of precipitation usually decreases with decreasing amount. No part of the earth is known for certain to be absolutely rainless, although in northern Chile, the rainfall over a period of 17 years was only 0.5 mm. During the whole 17 years, there were only three showers heavy enough to be measured.

1.4.4 Temperature

Skies are normally clear in the low latitude deserts so that sunshine is abundant. Annual ranges of temperature in the low latitude deserts are larger than in any other type of climate within the tropics. It is the excessive summer heat, rather than the winter cold, that leads to the marked differences between the seasons.

During the high-sun period, scorching, desiccating heat prevails. Midday readings of 40–45 °C are common at this season. During the period of low sun, the days still are warm, with the daily maxima usually averaging 15–20 °C and occasionally reaching 25 °C. Nights are distinctly chilly with the average minima in the neighborhood of 10 °C.

Most marked causes, however, are the large daily ranges, clear cloudless skies and relatively low humidity which permit an abundance of solar energy to reach the earth by day but also allow a rapid loss of energy at night. Large diurnal ranges in deserts are also associated with the meager vegetation cover, which permits the barren surface to become intensely heated by day.

1.4.5 Cold Ocean Currents

Cold ocean current affects the western coastal margins of South America and Southern Africa. This reinforces climatic conditions, causing low sea surface evaporation, high atmospheric humidity, low precipitation (very low rainfall, with precipitation mainly in the form of fog and dew) and a low temperature range. Aridity may result if air is cooled, and then rewarmed, prior to reaching the region, when:

(a) Cool air holds less moisture than warm air.
(b) When warm, moist air is cooled, excess water condenses and falls as precipitation. If it is subsequently rewarmed, it will be drier than it was previously.
(c) Winds that blow onshore tend to do so across cold currents produced by movement of water from high latitudes (poles) to low latitudes (equator) and associated with the upwelling of cold waters from the ocean's depth.
(d) Cold or cool winds have relatively small moisture-bearing capacity and, when warmed during their passage over the land, they become stable and, thereby, reinforce the stability produced by the global stability of these latitudes. (subtropical highs).
(e) This also occurs along coastal areas where there are cold coastal seas (*Baja* California) and in rain shadows (adiabatic heating and cooling).
(f) Sometimes, air moving across the frigid currents is cooled to a low temperature; thus, the air holds little moisture when it arrives over land, where it may provide fog or mist but rarely rain (Namib and Atacama).

1.5 Types of Aridity

Aridity refers to the average conditions of limited rainfall and water supplies not to the departures from the norm, which define a drought. All the characteristics of arid regions must be recognized in the planning and management of natural and agricultural resources (Jackson 1989). Because the soils of arid environments often cannot absorb all of the rain that falls in large storms, water is often lost as runoff (Brooks et al. 1997). At other times, water from a rainfall of low intensity can be lost through evaporation when the rain falls on a dry soil surface. Molden and Oweis (2007) state that as much as 90% of the rainfall in arid environments evaporates back into the atmosphere leaving only 10% for productive transpiration.

Ponce (1995) estimates that only 15–25% of the precipitation in semiarid regions is used for evapotranspiration and that a similar amount is lost as runoff. Evapotranspiration is the sum of transpiration and evaporation during the period a crop is grown. The remaining 50–70% is lost as evaporation during periods when beneficial crops are not growing.

During the last 20,000 years, the extension and the position of arid lands have changed to a great extent, that is, from glacial maximum 20,000 years ago, to the humid optimum 11,000–7000 years ago, and finally by drier conditions which have continued till the present day.

The problem of desertification is particularly acute in Africa, which has 37% of the world's arid zones. About 66% of its land is either desert or arid lands. The impact is also severe in Asia, which holds 33% of the world's arid zones. At present, almost 2.5 billion people inhabit in arid and semiarid lands meaning they are the home to one in three people in the world today. According to UN-Habitat, the 18.5% population growth rate in the arid lands was faster than that of any other ecological zone. Population density increases as aridity decreases. It ranges from 10 people per km^2 in the deserts to 71 people in the dry subhumid (rangelands) areas (Table 1.5). They are traditionally, hunter-gatherers, agriculturalists (rainfed or irrigated) and pastoralists. These traditional lifestyles are now rapidly fading under the influence of ever-expanding urbanization, mining, industrialization and tourism. The arid regions in general contribute significantly to the economy of the respective country in terms of employment, land holding, mineral assets, crop, forage and livestock production, including dairy products and industrial production. This is being supported despite a hostile climate and limited natural resource base.

Table 1.5 Population distribution in arid lands

Ecosystem	Total population	Share of global population
Desert	101,336	1.7
Semi-desert	242,780	4.1
Grassland	855,333	14.4
Rangelands	909,972	15.3
Total	2,109,421	35.5

Source: http://www.un.org/en/events/desertification_decade/whynow.shtml

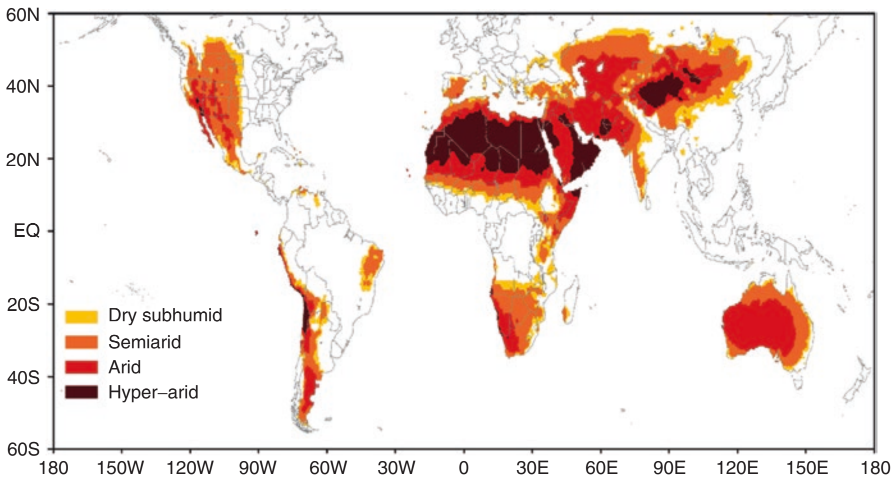

Fig. 1.2 Global distribution of drylands for 1961–1990 climatology derived from P/PET ratio based on observations (After Feng and Fu 2013)

Actually, arid and semiarid lands have been listed in Agenda 21 (UNCED 1992) among the fragile ecosystems of the world although they are described as being important ecosystems, with unique features and *resources*. These ecosystems are regional in scope, as they transcend national boundaries. Desertification is land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities. The most obvious impact of desertification, in addition to widespread poverty, is the degradation of 3.3 billion hectares of the total area of rangeland, constituting 73% of the rangeland with a low potential for human and animal carrying capacity, as well as decline in soil fertility and soil structure on about 47.2% of the arid lands (United Nations Conference on Environment & Development, Rio de Janeiro, Brazil, June 1992).

Feng and Fu (2013) have examined the changes in the areal extent of arid lands by analyzing observations for 1948–2008 and simulations for 1948–2100 from 27 global climate models participating in phase 5 of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012). They have shown that global arid lands have expanded in the last 60 years and will continue to expand in the twenty-first century. By the end of this century, the arid lands under a high greenhouse gas emission scenario are projected to be 5.8×10^6 km^2 (or 10%) larger than the 1961–1990 climatology (Fig. 1.2). Expansion of arid lands associated with an increase in aridity as a result of climate change has a direct consequence on the desertification (i.e. land degradation in arid, semiarid and dry subhumid areas) and is a central issue for sustainable development, especially in the face of population growth (Reynolds et al. 2007).

Livelihood sustainability in these regions is threatened by a complex and interrelated range of social, economic, political and environmental changes that present significant challenges to researchers, policymakers and, above all, rural land users (Reynolds et al. 2007). Improper utilization of the most scarce resource, i.e. water, is leading to severe land degradation in the canal command area. The fixation of sand dunes has contained movement of sand dunes and thus making possible their utilization for cultivation or plantation. It has curtailed the apprehension of desert expansion, but desertification is still occurring through lateral routes of degradation of pasture lands, wind erosion and deposition, water erosion, salinization of irrigated lands and ill-managed mining activities. Shortage of forages for a very high population of livestock often makes life miserable for the livestock husbandry practitioners, thereby denting the traditional social fabric of the region (Kar et al. 2009).

New and innovative ways of generating and promoting technological options that take into account social and economic conditions of the people involved use bottom-up approaches by involving people in decision-making, apply vast indigenous knowledge and adopt integrated farming system approaches in arriving at solutions for complex problems of the arid ecosystem that are the need of the hour (Kar et al. 2009).

Human well-being is at risk from arid land degradation. Unsustainable land and water use and the impacts of climate change are driving the degradation of arid lands. Approximately 6 million km^2 of arid lands (about 10%) bear a legacy of land degradation. Such degradation – sometimes also referred to as 'desertification' – can take the form of soil erosion, nutrient depletion, water scarcity, altered salinity or the disruption of biological cycles. Degradation reduces biological productivity and can impact the ability of ecosystems to absorb and use rainwater. Combined with poor crop and soil management, and the use of poorly adapted varieties of crop, this can lead to 'agricultural droughts'. Climate change is already causing significant decreases in crop yields in some rainfed African agricultural systems.

This is likely to worsen by 2020 because climate change will cause grassland productivity to decline between 49% and 90% in semiarid and arid regions. It is also forecasted that high levels of desertification and soil salinization, and increasing water stress, will occur in parts of Asia, sub-Saharan Africa and Latin America. Situation is accentuated due to poor land management and irrigation practices in the drylands of the world where economy is primarily based on agriculture. Any shortage of water for agricultural use is likely to have cascading effect on various sectors of economy. Climatic fluctuations may be most pronounced in the poorest regions with high levels of chronic undernourishment and a great degree of instability. Food price fluctuations already represent a risk to vulnerable populations that is expected to increase with climate change. Arid land degradation costs developing countries an estimated 4–8% of their national gross domestic product (GDP) each year. It has been estimated that about 1–6% of arid land human populations live in desertified areas, while a much larger number is under threat from further desertification. Land degradation and poverty are mutually reinforcing, but the former has low public visibility. It is hard to deal with the problem due to cyclical swings in rainfall, land tenure which is not well adjusted to environmental conditions, and regional and global forces driving local management. Inaction would mean a cumulative addition to a long, historical legacy of degradation, from which recovery has already previously proven difficult (UN EMG 2011).

Climate change associated with changes in precipitation and PET would lead to changes in aridity (i.e. P/PET) and thus the areal extent of arid lands. The global arid lands from observations have been expanding during the past 60 years (Feng and Fu 2013). The area of global arid lands of the past 15 year (1991–2005) is ~2.4×10^6 km^2 (or 4%) larger than that during the 1950s. The areas of individual arid land components (except hyperarid regions) show increases. The observed maximum (minimum) area of semiarid (arid) regions during 1970s is a result of large positive precipitation anomalies in the southern hemisphere over Australia, Southern Africa and Patagonia (Hulme 1996), which led to a transition of arid to semiarid regions.

Evidence from both observations and models shows that over the past few decades, the tropics have widened (e.g. Fu et al. 2006; Hu and Fu 2007; Lu et al. 2007; Seidel et al. 2008; Johanson and Fu 2009; Zhou et al. 2011; Fu and Lin 2011), which results in shifts in precipitation patterns (Seidel et al. 2008) and especially a reduction of precipitation in the latitudes between subtropical arid zones and mid-latitude precipitation belts (Zhou et al. 2011; Scheff and Frierson 2012). Extensive land use and other human activities may further amplify these changes (Reynolds et al. 2007). Another important consequence of these changes is the desertification, i.e. the land degradation in arid, semiarid and dry subhumid regions resulting from various factors, including climatic variations and human activities (UNCCD 1994).

1.6 People and Land Use

Arid land populations are frequently some of the poorest in the world due to frequent drought, famine and internal civil wars. The population distribution patterns vary within each region and among the climate zones comprising arid lands. The population distribution patterns vary within each region and among the climate zones comprising arid lands. Regionally, Asia has the largest percentage of population living in arid lands: more than 1400 million people or 42% of the region's population. Africa has nearly the same percentage of people living in arid lands (41%) although the total number is smaller at almost 270 million. South America has 30% of its population in arid lands or about 87 million people (Table 1.6).

Table 1.6 Human populations of the world's arid lands

	Aridity zone							
	Arid		Semiarid		Dry subhumid		All arid lands	
Region	1000 km^2	%	1000 km^2	%	1000 km^2	%	1000 km^2	%
Asia (incl. Russia)	161,554	5	625,411	18	657,899	19	1,444,906	42
Africa	40,503	6	117,647	18	109,370	17	267,563	41
Oceania	275	1	1342	5	5318	19	6960	25
North America	6257	2	41,013	16	12,030	5	59,323	25
South America	6331	2	46,852	16	33,777	12	86,990	30
C. America and the Caribbean	6494	6	12,888	11	12,312	8	31,719	28
Europe	629	0	28,716	5	111,216	20	140,586	25
World total	222,043	4	873,871	4	941,922	17	2,038,047	37

Source: UNSO/UNDP (1997)

The population growth in semiarid regions has been quite rapid, and the number of people inhabiting these regions has grown tremendously during the recent decades as in the rest of the world.

Rural people living in arid lands can be grouped into nomadic, seminomadic, transhumant and sedentary smallholder agricultural populations. Nomadic people are found in pastoral groups that depend on livestock for subsistence and, whenever possible, farming as a supplement. Following the irregular distribution of rainfall, they migrate in search of pasture and water for their animals. Seminomadic people are also found in pastoral groups that depend largely on livestock and practise agricultural cultivation at a base camp, where they return for varying periods.

Transhumant populations combine farming and livestock production during favorable seasons, but seasonally they might migrate along regular routes using vegetation growth patterns of altitudinal changes when forage for grazing diminishes in the farming area. Sedentary (smallholder) farmers practise rainfed or irrigated agriculture (Ffolliott et al. 2002) often combined with livestock production. The proliferation of woody vegetation in drylands has been a consequence of heavy grazing by the cattle and small ruminants that has removed most of the herbaceous (grass) species. Simultaneously, arid and semiarid regions are being pushed across a bioclimatic threshold induced by the interaction of land management and climate variability. The drylands in Uzbekistan face a significant and growing threat of degradation, because forestry and extensive pastures have to compete for land use. It has significant direct implications for local rural populations as well as also have a significant national implications for food security and long term sustainable development because of the impact on biodiversity.

The human populations of the arid lands live in increasing insecurity due to land degradation and desertification and as the productive land per capita diminishes due to population pressure. The sustainable management of arid lands is essential to achieving food security and the conservation of biomass and biodiversity of global significance (UNEP 2000).

The rapid population growth in arid lands due to improvements in health conditions and other factors has placed tremendous pressure on the natural resource base. Often, the inevitable result of increasing population in resource-poor areas is land degradation defined as the loss of production capacity of the land (FAO 2000). The simple view of population pressure in a fragile environment causing permanent environmental degradation has been subject to re-evaluation. In the Yatenga province of Burkina Faso, farmers rescued their fields from imminent desertification by erecting low stone walls along the contours of hillsides to keep soil and water on the land. The Dogon people of eastern Mali practise some of the most intensive irrigated agriculture in Africa to feed a rapidly rising population in an era of declining rainfall – but do so without causing desertification. Elsewhere, Sahel communities have adopted rainwater harvesting methods to halt soil loss and improve the productivity of their land. Desertification makes 12 million hectares of land useless for cultivation every year. Since 1965, one sixth of the populations of Mali and Burkina Faso have lost their livelihoods and fled to cities. In Mauritania between 1965 and 1988, the proportion of the population who were nomads fell from 73% to 7%, while the proportion of the population in the capital Nouakchott rose from 9% to 41%.

But desertification is not exclusively a problem of the developing world. Commercial agriculture and livestock farming can cause as much damage to arid ecosystems as pastoralism and subsistence agriculture. Australia, one of the world's richest but least densely populated countries, has serious land degradation problems. In arid and semiarid regions, uncontrolled grazing – the single largest form of land use – takes place in areas often considered to be "commons" or "grazing lands" which are usually common property resources and over 25% of grasslands and marginal lands have been converted to cropland to meet foodgrain demand.

Important features of arid land soils for agricultural production are their water holding capacity and their ability to supply nutrients to plants. Arid zone soils which cover approximately one-third of earth's surface, are vulnerable to both wind and water erosion due to dryness. Arid and semi-arid soils are mainly found in Africa (Sahara, Namibian and Kalahari deserts), the Middle East (Arabia desert, Iran, Afganistan, Thar desert of India, etc.), North and South America (Mohave desert, Chile, etc) and Australia. As there is little deposition, accumulation or decomposition of organic material in arid environments, the organic content of the soils is low and, therefore, natural soil fertility is also low. Arid lands are inhabited by more than 2.5 billion people, nearly 30% of the world's population.

1.7 Conclusion

In spite of large-scale scientific studies, misconceptions about the arid lands still persists. '*Desert creep*', '*rejuvenation of deserts*', '*desert encroachment*', etc. are various melodramatic terms keep on making headlines, without any basis or reality. Various agencies have been involved in the mapping of arid lands. Due to differences in perspectives, objectives and methodologies, differences in area are also visible. As such, climatic shifts are the main indication of any such severe problems in arid lands. Whereas, presently available scientific evidence neither substantiate it. Anthropogenic role not only in the arid lands but elsewhere is much more visible and documented. These arid lands' most important and distinguishing environmental characteristic is the lack of precipitation. Intense heat waves during summers and severe cold below freezing point in many parts of the arid world during winter are quite common and characteristic phenomenon. Further, significant achievements have been made in the technology of arid lands agriculture, water use efficiency (through highly efficient, highly sophisticated irrigation systems), livelihood and economic resources. Large-scale intensive systems for dairy, poultry and feed and fodder have been developed. Large quantities of low-cost energy, in the form of wind and solar, have been generated. Higher dependency on rainfed agriculture in the arid lands is still a cause of concern. Further, due to lack of perennial sources of water resources, dependency on groundwater resources either for irrigation or drinking purpose is increasing to cater needs of the teeming population. Existing agricultural production systems are part of a vicious cycle due to poor carrying capacities of the land resources. The social costs of continuing with these agricultural production systems are shocking and threatening. The dry lands ecosystems are so heavily stressed; the consequences of land degradation are inevitable. Human impact in arid and semiarid lands has led to soil degradation through salinization, waterlogging and wind erosion and has entailed desertification now affecting almost 70% of the region. Desertification describes a situation where a productive land becomes less and less productive due to degradation until it becomes non-productive and desertified. Desertification is a serious situation that has to be monitored, controlled and combated through local, regional, national and international efforts for it has to be viewed as a global problem (Barakat 2004).

References

K.N. Brooks, P.F. Ffolliott, H.M. Gregersen, L.F. DeBano, *Hydrology and the Management of Watersheds* (Iowa State University Press, Ames, 1997)

FAO, *Water and Cereals in Drylands* (Earthscan & FAO Publication, 2008), p. 105

FAO, Land resource potential and constraints at regional and country levels, in *World Soil Resources Report* No. 90 (Rome, 2000)

FAO, *Compendium of Agricultural-Environmental Indicators (1989–91 to 2000)* (Statistics Analysis Service, Statistics Division, Food and Agriculture Organization of United Nations, Rome, 2003)

FAO, *Carbon Sequestration in Dryland Soils. World Soil Resources Reports No. 102* (Food and Agriculture Organization for the United Nations, Rome, 2004)

S. Feng, Q. Fu, Expansion of global drylands under a warming climate. Atmos. Chem. Phys. **13**, 10081–10094 (2013)

P. Ffolliott, J.O. Dawson, J.T. Fisher, I. Moshe, T.E. Fulbright, A. Al Musa, C. Johnson, P. Verburg, Dryland environments. Ar. Land. News **52** (2002)

Q. Fu, C.M. Johason, J.M. Wallace, T. Reichler, Enhanced mid-latitude tropospheric warming in satellite measurements. Science **312**, 1179 (2006)

Q. Fu, P. Lin, Poleward shift of subtropical jets inferred from satellite-observed lower stratospheric temperatures. J. Clim. **24**, 5597–5603 (2011)

K.W. Glennie, Desert sedimentary environments, past and present – a summary. Sediment. Geol. **50**, 135–166 (1987)

A.T. Grove, The ancient ergs of Hausaland, and similar formations on the south side of the Sahara. Geogr. J. **124**, 528–533 (1958)

R.L. Heathcote, *The arid lands; Their use and abuse* (Longman, London, 1983)

T. Hilhorst, F. Muchena (eds.), *Nutrients on the Move: Soil Fertility Dynamics in African Farming Systems* (International Institute for Environment and Development, London, 2000)

Y. Hu, Q. Fu, Observed poleward expansion of the Hadley circulation since 1979. Atmos. Chem. Phys. **7**, 5229–5236 (2007). doi:10.5194/acp-7-5229-2007

M. Hulme, Recent climatic change in the world's drylands. Geophys. Res. Lett. **23**, 61–64 (1996)

E. Humphreys, D. Peden, S. Twomlow, J. Rockström, T. Oweis, A. Huber-Lee, L. Harrington, *Improving Rainwater Productivity: Topic 1 Synthesis Paper* (CGIAR Challenge Program on Water and Food, Colombo, 2008.) 19 p

IIASA/FAO, *Compendium of Agricultural-Environmental Indicators (1989-91 to 2000)* (Statistics Analysis Service, Statistics Division, Food and Agriculture Organization of United Nations, Rome, 2003)

I.J. Jackson, *Climate, Water and Agriculture in the Tropics* (Longman, Singapore, 1989)

C.M. Johanson, Q. Fu, Hadley cell expansion: model simulations versus observations, J. Climate **22**, 2713–2725 (2009)

A. Kar, B.K. Garg, M.P. Singh, S. Kathju, *Trends in Arid Zone Research in India*. (CAZRI, 2009), p. 481, CAZRI
W. Köppen, in *Die Klimate der Erde* (Berlin, 1931)
J. Lu, G.A. Vecchi, T. Reichler, Expansion of the Hadley cell under global warming. Geophys. Res. Lett. **34**, L06805 (2007). doi:10.1029/2006GL028443.
E. de Martonne, L. Aufrère, Map of interior basin drainage. Geogr. Rev. **17**, 414 (1927)
W.G. McGinnies, Climatic and biological classifications of arid lands: A comparison. pp. 61–68. *In* Arid lands today and tomorrow. E.E. Whitehead, C.F. Hutchinson, B.N. Timmermann, and R.G. Varady (eds.). Boulder, Colo: Westview Press (1988). 1435 p
P. Meigs, World distribution of arid and semi-arid homoclimates. Arid Zone Res **1**, 203–210 (1952)
P. Meigs, *World Distribution of Arid and Semi-Arid Homoclimates, Arid Zone Hydrology* (Arid Zone Research Series. UNESCO, Paris, 1953)
Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Desertification Synthesis* (World Resources Institute, Washington, DC, 2005)
D. Molden, T.Y. Oweis, Pathways for increasing agricultural water productivity, in *Water for Food, Water for Life*, ed. By D. Molden, (Earthscan, Lsondon and International Water Management Institute, Colombo, 2007), pp. 279–310
M. Morris, V. Kelly, R. Kopicki, D. Byerlee, *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines* (Agriculture and Rural Development Division, World Bank, Washington, DC, 2007)
M. Mortimore, *Dryland Opportunities* (IUCN/HED/UNDP, Gland/London/New York, 2009)
National Weather Service, *What Is Meant by the Term Drought?* (U.S. Department of Commerce, Washington, DC, 2004.) (available at http://www.wrh.noaa.gov/fgz/science/drought.php)
A. Penck, *Morphologie der Erdoberflache* (Engelhorn, Stuttgart, 1894)
V.M. Ponce, Management of droughts and floods in the semiarid Brazilian northeast—the case for conservation. Soil Water Conserv. J. **50**, 422–431 (1995)
J.F. Reynolds, D.M. Stafford Smith, E.F. Lambin, B.L. Turner, M. Mortimore, S.P.J. Batterbury, T.E. Downing, H. Dowlatabadi, R.J. Fernandez, J.E. Herrick, E. Huber-Sannwald, H. Jiang, R. Leemans, T. Lynam, F.T. Maestre, M. Ayarza, B. Walker, Global desertification: building a science for dryland development. Science **316**, 847–851 (2007)
U. Safriel, Z. Adeel, Dryland systems, in *Ecosystems and Human Well-Being: Current State and Trends Volume 1*, eds. By R. Hassan, R. Scholes, N. Ash, (Island Press, Washington, DC, 2005), pp. 623–662
J. Scheff, D. Frierson, Twenty-first-century multimodel subtropical precipitation decline are mostly midlatitude shifts. J. Clim. **25**, 4330–4347 (2012)
D.J. Seidel, Q. Fu, W.J. Randel, T.J. Reichler, Widening of the tropical belt in a changing climate. Nat. Geosci. **1**, 21–24 (2008)
H.L. Shantz, in *The Future of Arid Lands*, ed. by G.F. White. History and Problems of Arid Lands Development, (American Association for the Advancement of Science, Washington, D.C., 1956), p. 3–25
K.E. Taylor, R.J. Stouffer, G.A. Meehl, An overview of CMIP5 and the experiment design. B. Am. Meteorol. Soc. **93**(485–498), 2012 (2012)
C.W. Thornthwaite, An approach toward a rational classification of climate. Geogr. Rev. **38**, 55–94 (1948)
S. Twomlow, D. Rohrbach, J. Dimes, J. Rusike, W. Mupangwa, B. Ncube, L. Hove, M. Moyo, N. Mashingaidze, P. Mahposa, Microdosing as a pathway to Africa's green revolution: evidence from broad-scale on-farm trials. Nutr. Cycl. Agroecosyst. **88**(1), 3–15 (2008)
UN (2010). http://www.un.org/en/events/desertification_decade/whynow.shtml
UNCCD (United Nations Convention to Combat Desertification), U. N. Doc. A/A C. 241/27, 33 I. L. M. 1328 (United Nations, 1994), UNCCD
UNCCD, An introduction to the United Nations Convention to Combat desertification (2000), available at http://www.unccd.int
UNCED. Agenda 21, Chapter 12, Paragraph 5, United Nations World Conference on Environment, Rio de Janeiro, Brazil, June 1992, (1992), p. 2

UNDP/UNSO, *Aridity zones and drylands populations* (1997). AAAS Atlas of Population & Environment, American Association for the Advancement of Science

UNEP, *UNEP-World Conservation Monitoring Centre* (Assessing forest integrity and naturalness in relation to biodiversity. Cambridge, UK, 2000), p. 75

UNEP, *The Global Environment Outlook 4. Environment for Development* (UNEP, Nairobi, 2007)

United Nations Environment Management Group, *Global Drylands: A UN System-Wide Response* (United Nations, October 2011), p. 132, UN EMG Secretariat

WMO, *Glossary of Terms Used in Agrometeorology*. CAGM No. 40. WMO/TD-No. 391 (WMO, Geneva, 1990)

Y.P. Zhou, K.M. Xu, Y.C. Sud, A.K. Betts, Recent trends of the tropical hydrological cycle inferred from global precipitation climatology project and international satellite cloud climatology project data. J. Geophys. Res. **116**, D09101 (2011). doi:10.1029/2010JD015197

Further Readings

A. Oroda, J. Agatsiva, Environmental Conditions and Farming Systems in the Southern Catchment Area of Lake Nakuru. Third Annual Report for the EU – INCO-DC (International Co-operation with Developing Countries) Project *"Sustainable Use of Natural Resources in Rural Systems of Eastern African Drylands (Ethiopia, Kenya and Tanzania): Strategies for Environmental Rehabilitation"* (2000)

M. Stuttard, G. Narciso, G. Carizi, M. Suppo, R. Catani, L. Isavwa, J. Baraza, A. Oroda, *Monitoring Lakes in Kenya: An Environmental Analysis Methodology for Developing Countries*. Final Report for the CEC DG XII STD-3 Programme, (1995), pp. 17–23 and 32–130

D.S. Thomas, Nick Middleton (eds) World Atlas of Desertification 2nd ed. A Hodder Arnold Publication (1997). p. 182

UNFPA, World population prospects: the 2006 revision and world urbanization prospects: the 2005 revision (2008), http://esa.un.org/unpp

World Atlas of Desertification, in *World Atlas of Desertification*, ed. By E. Arnold, 2nd edn., (UNEP, London, 1997) 182 p

Websites

http://www.un.org/en/events/desertification_decade/whynow.shtml. Accessed 13 Oct 2016
http://www.eolss.net/sample-chapters/c12/e1-01-06-04.pdf. Accessed 10 Oct 2016
http://www.atmos.washington.edu/~qfu/Publications/acp.ff.2013.pdf. Accessed 14 Oct 2016