

## **DRY LANDS AND DESERTIFICATION**

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

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### **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 depopulation 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).

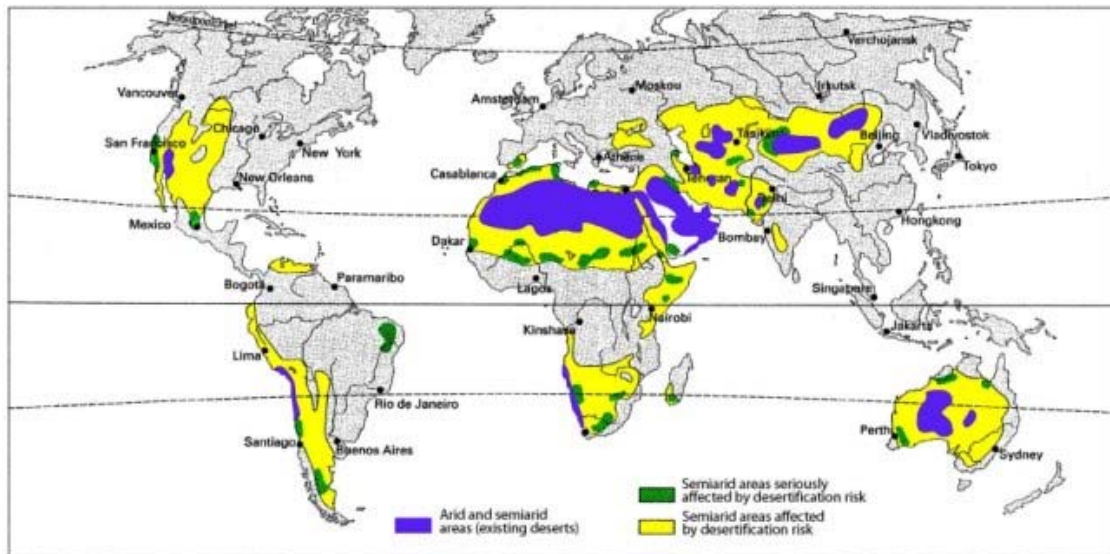


Figure 1: Geographical location and extension of arid areas in the world

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.

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).

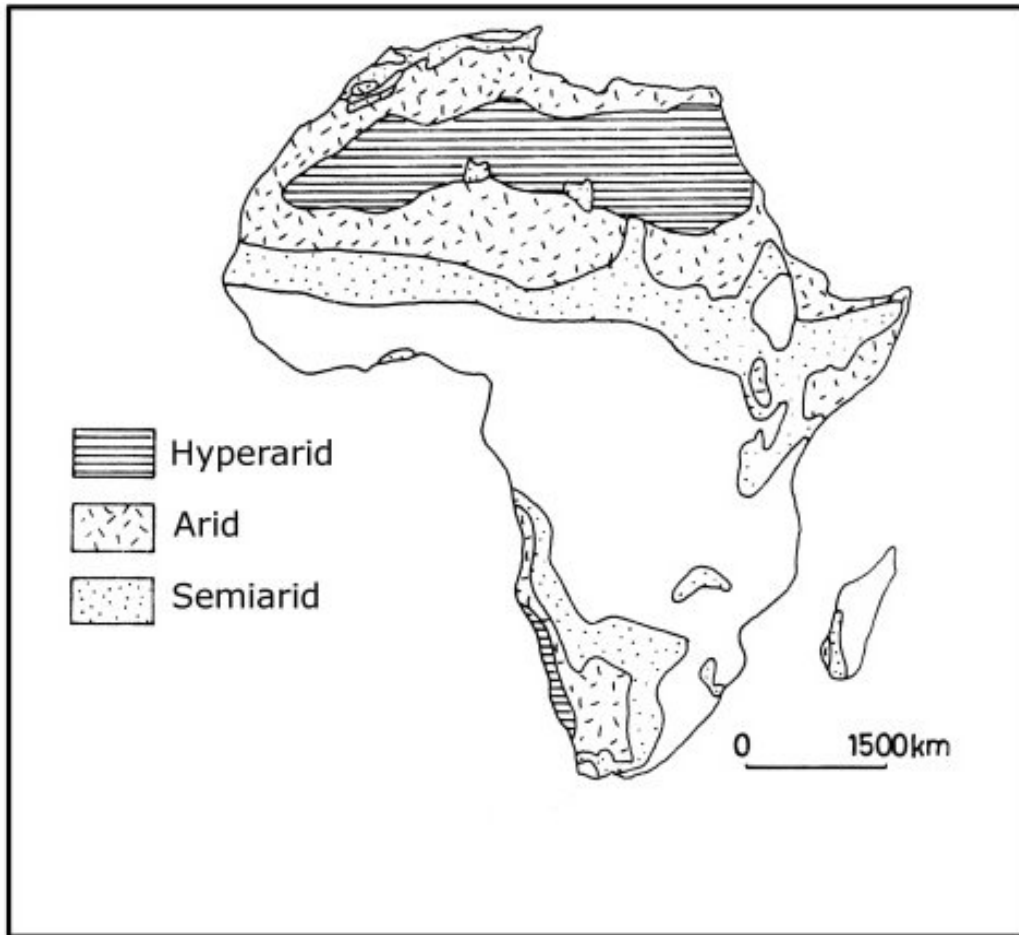


Figure 2: Extension of dry lands in Africa

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 km<sup>2</sup>. 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 km<sup>2</sup>. 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 km<sup>2</sup>, 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 km<sup>2</sup> 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 km<sup>2</sup>). 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 km<sup>2</sup>) 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.

### 3. Definition of Dry Lands and Aridity

Aridity can be defined in different ways. The most direct definition uses climatic parameters, either as a single rainfall figure or as a combination of such figures into an aridity index. Aridity can, however, also be expressed by other features like vegetation, landform characteristics or soil composition, using indirect diagnostic criteria for describing and delimitating arid lands.

#### 3.1. Climate-based Definitions

Climatic parameters, in particular those related to rainfall, are the easiest and most straight-forward criteria to define aridity. Their advantage is that they are objective, simple and easy to apply, and that they use data which are currently available.

In its **simplest way** aridity and arid areas are defined by a single rainfall figure for annual precipitation ( $P$ ). Dry lands can then be subdivided into arid and semi-arid zones characterized by  $0 < P < 200$  mm for the arid and  $200 < P < 500$  mm for the semi-arid zones respectively.

In a somewhat **more complex** approach, the single precipitation criterion is replaced by an expression of effective rainfall. This is achieved by adjusting the precipitation data (annual rainfall  $P$  in mm) by evaporative loss, itself reflected by temperature ( $T$  = mean annual temperature, expressed in °C), and the introduction of a climatic index ( $I$ ). Examples of this approach are:

- the rain-factor of Lang:  $I = P/T$  whereby arid areas correspond to zones with  $I < 5$ , semi-arid areas to  $5 < I < 35$  and sub-humid areas to  $I > 35$ ;
- the Angström index  $I = P/1.07^T$  where  $T$  = mean annual temperature, and the hyper-arid area is then defined by  $I < 20$ , the arid zone by  $20 < I < 55$  and the semi-arid zone by  $55 < I < 180$ .
- the aridity index of De Martonne, initially defined as  $I = P/(T+10)$ . In this system the hyper-arid zone has  $I < 3$ , the arid zone has  $3 < I < 8$  and the semi-arid zone corresponds to  $8 < I < 20$ . In a revised version (De Martonne, 1962) the aridity index ( $I$ ) was redefined as  $I = np/(T+10)$  whereby  $n$  = number of rainy days,  $p$  = mean precipitation per day, and  $T$  = mean temperature of the selected period. When calculated on an annual basis, arid climates have  $I < 20$  and semi-arid zones have an index  $20 < I < 30$ .

The classification proposed by Hare (1985) follows a similar approach in that it uses the Budyko-Lettau dryness ratio as an aridity index for defining and differentiating dry lands. This is the ratio of the annual net radiation energy at the earth's surface to the heat energy required to evaporate a year's rainfall. A dryness ratio of 2 is considered to be the upper limit of the arid zone (edge between arid and semi-arid areas), and a ratio of 10 represents the desert margin (limit between arid and hyper-arid zones). In this classification true desert climates with a dryness ratio in excess of 10 do not occur in North America and Australia. The index of 2 lies close to the humid edge of the semi-arid zone in most areas. On the basis of this criterion the total dry land area is estimated at 30 million km<sup>2</sup> of arid lands (20 % of the world's land surface) and 50 million km<sup>2</sup> (34 %) of arid plus semi-arid lands. These figures are fairly in line with the surface estimations based on other criteria.

The most generally accepted classification of dry climates, though more than 70 years old, is the **Köppen system** (Köppen and Geiger, 1936). It is based on the assumption that (1) the higher the temperature, the greater the amount of precipitation that will result in the same degree of aridity, and (2) relatively less precipitation is needed if it is concentrated during the cool season, more is required if distribution throughout the year is uniform, and the highest requirement is associated with precipitation that is concentrated in the warm season.

The Köppen system forms part of a larger worldwide classification by the same author, including five major categories of world climates, of which only one is termed dry. The dry climates are then subdivided into deserts (BW or arid climates), in which rainfall is insufficient for arable crop production, and steppe (BS or semi-arid climates), in which rainfall is sufficient for certain types of crops when adequate management techniques are adopted and grasses constitute an important element of the native vegetation. Table 1 displays the extension of BW and BS climates in the world.

Later, Köppen introduced two additional criteria for further refining the system. In a first stage he considered also the impact of the seasonal rainfall distribution (Table 2), i.e. according to whether the greater part of the annual precipitation occurs during the six cooler months (winter precipitation) or the six warmer months of the year (summer precipitation). In a second stage the author made a distinction between hot and cool dry climates, according to whether the mean annual temperature is above or below 18° C, respectively. Since latitude is the principal determinant of temperature, the dry lands in this system can be classified into : low latitude (or hot) deserts and low latitude (or hot) steppes, and middle latitude (or cool) deserts and middle latitude (or cool) steppes.

Geographic area	BW climate*	BS climate*	All dry lands (BW + BS)*
Australia	3.9	2.2	6.1
Eurasia	9.6	5.9	15.5
Africa	11.5	5.7	17.2
North America	0.8	2.6	3.4
South America	0.9	1.7	2.6
Total	26.7	18.1	44.8

\* All surfaces expressed in million km<sup>2</sup>.



Table 1: Extension of Köppen’s BW (desert) and BS (steppe) climates in the world, expressed in million km<sup>2</sup>

Climatic class	Under conditions of winter rainfall	Under conditions of no clear rainy season	Under conditions of summer rainfall
Desert	$P < T$	$P < T + 7$	$P < T + 14$
Steppe	$T < P < 2T$	$T + 7 < P < 2(T + 7)$	$T + 14 < P < 2(T + 14)$
Sub-Humid	$P > 2T$	$P > 2(T + 7)$	$P > 2(T + 14)$

\*  $P$  = annual rainfall in cm;  $T$  = mean annual temperature in °C.

Table 2: Köppen classification of dry climates, Source: Köppen and Geiger (1936)

Köppen’s system had the disadvantage that **plant moisture consumptive use** was only indirectly defined by a temperature parameter. In an attempt to overcome this problem Thornthwaite introduced the concept of evapotranspiration ( $ET$ ) in 1948. This involves the use of a water balance model whereby water supply (or input) is registered as precipitation ( $P$ ), while water needs (or output) are expressed by evapotranspiration. A period is considered moist when  $P > ET$  and dry when  $P < ET$ .

The key issue in this approach is the effective measurement of evaporative demands. Therefore, Thornthwaite differentiated between actual ( $AET$ ) and potential evapotranspiration ( $PET$ ), whereby the latter corresponds to the amount of water that would be transpired and evaporated under ideal conditions of soil moisture and vegetative cover. This  $PET$  depends exclusively on climatic parameters and can therefore be computed by an empirical formula involving mean monthly temperature and average day-length. When the monthly curves of  $PET$  and  $P$  are plotted as smooth curves, and the two curves are compared, it is possible to determine whether and when  $P$  is greater or smaller than  $PET$ .

The critical point of implementing this method lies in the correct calculation of the potential evapotranspiration. The values of important factors influencing evaporation such as wind, air humidity and solar radiation are considered to be linked with the variations in temperature and were therefore omitted from the formula in order to simplify the method without affecting its usefulness. This shortcoming and the fact that the method was developed in a climate of summer rainfall, make that the results are not entirely satisfactory when applied in various parts of the world.

In 1979 **UNESCO** introduced a worldwide classification system, based in first instance on the ratio of annual precipitation to annual potential evapotranspiration calculated by the standard Penman method which is much more reliable for assessing plant water consumption (see also *Management of Dry Lands and Desert Areas*). This classification incorporates at the same time a number of vegetation and land use elements, and in this respect it makes a difference between arid and hyper-arid (or extremely arid) areas. It reads as follows:

- Hyper-arid areas ( $P/PET < 0.03$ ) characterized by a very low and irregular rainfall, high inter-annual variability and almost no perennial vegetation; agriculture and grazing are not possible.
- Arid areas ( $0.03 < P/PET < 0.2$ ) with an annual rainfall of 80-150 mm (winter rainfall regime) to 200-350 mm (summer rainfall regime) and a moderately high inter-annual variability; the vegetation is scattered and consists of thorny shrubs which can be used for extensive grazing; rain-fed agriculture is however not possible.
- Semi-arid areas ( $0.2 < P/PET < 0.5$ ), characterized by a mean annual rainfall between 300-400 mm (winter rainfall regime) and 700-800 mm (summer rainfall regime), with a relatively low inter-annual variability; there is a more or less perennial grass cover which holds possibilities as good pasture land; rain-fed agriculture is possible for drought-tolerant crops and with some risks.

Over the past years the UNESCO classification has been validated and slightly adapted in terms of its diagnostic criteria (Table 3). It is now the current standard for dry land classification and identification. The UNEP World Atlas of Desertification, discussed in more detail in *Desertification and De-forestation in Africa*, uses these new diagnostic criteria.

Dry lands area classification	$P/PET$ ratio	% World terrestrial area
Extremely arid	$<0.05$	-
Arid	$0.05 < P/PET < 0.20$	14.9%
Semi-arid	$0.20 < P/PET < 0.50$	11.9%
Dry sub-humid	$0.50 < P/PET < 0.65$	7.8%
Sub-humid	$0.65 < P/PET$	-

Table 3: Differentiating criteria for dry lands as applied in the World Atlas of Desertification. Source: UNEP (1997)

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## 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

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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.

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