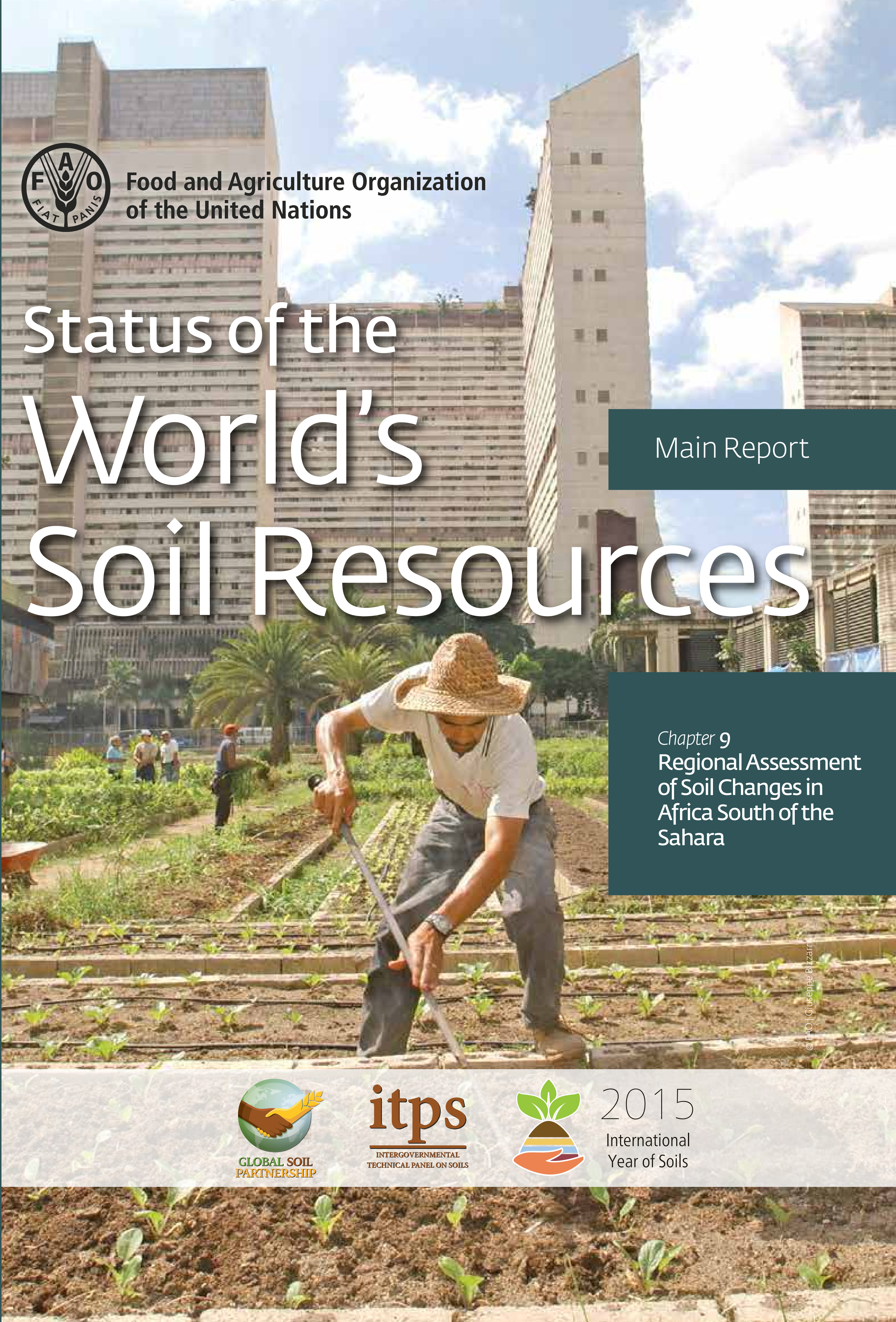
Food and Agriculture Organization of the United Nations

Status of the World's Soil Resources

Main Report



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Chapter 9
Regional Assessment of Soil Changes in Africa South of the Sahara

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9 | Regional Assessment of Soil Changes in Africa South of the Sahara

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9.1 | Introduction

Land degradation in sub-Saharan Africa (SSA) is believed to be expanding at an alarming rate, accompanied by the lowest agriculture and livestock yields of any region in the world. While cereal production has increased marginally over the past two decades, more than 70 percent of this growth is due to area expansion rather than yield increases. The region also suffers from the world's highest rate of deforestation, with some countries having lost more than 10 percent of their forest cover in the five years up to 2009 (IFAD, 2009) and is most likely continuing at the same rate to this day.

There is a growing and long-standing recognition among both policy-makers and soil specialists that soil degradation is one of the root causes of declining agricultural productivity in sub-Saharan Africa and that, unless the process of degradation is controlled, many parts of the continent will suffer increasingly from food insecurity (e.g. see Lal, 1990; UNEP, 1982). The consequences of allowing the productivity of Africa's soil resources to continue on its present downward spiral will be severe, not only for the economies of individual countries, but for the welfare of the millions of rural households across the continent who are dependent on agriculture (FAO, 1999).

Soil degradation is the decline in soil quality caused its improper use by humans, usually for agricultural, pastoral, industrial or urban purposes. Soil degradation may be exacerbated by climate change and encompasses physical, chemical and biological deterioration. Examples of soil degradation cited by Charman and Murphy (2005) are: loss of organic matter; decline in soil fertility; decline in structural condition; topsoil loss and erosion; adverse changes in salinity, acidity or alkalinity; and the effects of toxic chemicals, pollutants and excessive flooding.

There is no consensus on the exact extent and severity of land degradation or its impacts in SSA as a whole (Reich et al., 2001; GEF, 2006). Lack of information and knowledge is considered to be one of the major obstacles for reducing land degradation, improving agricultural productivity, and facilitating the adoption of sustainable land management (SLM) among smallholder farmers (Liniger et al., 2011). The recent publication of the first Soil Atlas of Africa has provided a first comprehensive overview of the soil resources of Africa (Jones et al., 2013).

Four continental-scale studies have assessed the extent of soil degradation in Africa. A literature review by Dregne (1990) of 33 countries found compelling evidence of serious land degradation in sub-regions of 13 countries: Algeria, Ethiopia, Ghana, Kenya, Lesotho, Mali, Morocco, Nigeria, Swaziland, Tanzania, Tunisia, Uganda, and Zimbabwe. In another literature review, focused on drylands only, Dregne and Chou (1992) estimated that 73 percent of drylands were degraded and 51 percent severely degraded. They concluded that 18 percent of irrigated lands, 61 percent of rainfed lands, and 74 percent of rangelands located in SSA drylands are degraded.

The Global Assessment of Soil Degradation (GLASOD) expert survey found that 65 percent of soils on agricultural lands in Africa had become degraded since the middle of the twentieth century, as had 31 percent of permanent pastures, and 19 percent of woodlands and forests (Oldeman, Hakkeling and Sombroek, 1991). Serious degradation affected 19 percent of agricultural land. A high proportion (72 percent) of degraded land was in drylands. The most widespread cause of degradation was water erosion, followed by wind erosion, chemical degradation (three-quarters from nutrient loss, the rest from salinization), and physical degradation. In terms of causes of degradation, overgrazing was responsible for half of all degradation, followed by agricultural activities, deforestation, and overexploitation.

The Land Degradation Assessment in Drylands project (LADA) started in 2006 with the general purpose of creating the basis for informed policy advice on land degradation at global, national and local levels. This goal is being reached through the assessment of land degradation at different spatial and temporal scales in six countries and through the creation of a baseline at global level for future monitoring (FAO, 2010). Two of the six countries involved (Senegal and South Africa) are within SSA and national results are reported at the end of this chapter.

Lal (1995) calculated continent-wide soil erosion rates from water using data from the mid to late 1980s, and then used these rates to compute cumulative soil erosion for 1970-90. The highest erosion rates occurred in the Maghreb region of Northwest Africa, the East African highlands, eastern Madagascar, and parts of Southern Africa. Excluding the 42.5 percent of arid lands and deserts with no measurable water erosion, Lal found that the land area affected by erosion fell into the following six classes of erosion hazard: none, 8 percent; slight, 49 percent; low, 17 percent; moderate, 7 percent; high, 13 percent; and severe, 6 percent.

Soils host the majority of the world's biodiversity and healthy soils are essential to securing food and fibre production. Soils assure an adequate and clean water supply over the long term, as well as providing cultural functions. Ecosystem services provided by soils are integral to the carbon and water cycles. Major increases in agricultural production have been associated with different kinds of soil degradation, especially since the agricultural growth came in part from extensive clearing of new agricultural lands. Yet, even with this expansion, arable land per capita in Africa declined from just under 0.5 ha in 1950 to just under 0.3 ha in 1990 (FAO, 1993). During this time period, yield increases on land already in production thus contributed far more to the total production. For example, more than 90 percent of the growth in developing country cereal production between 1961 and 1990 came from yield growth (World Bank, 1992). Agricultural expansion and yield growth at such a scale is inevitably associated with some degradation of soil resources. However, the type and extent of degradation vary in the different ecological/farming systems (IFPRI, 1999).

9.2 | Stratification of the Region

The region is diverse in terms of relief, climate, lithology, soils and agricultural systems. A combination of some of these have been used to stratify the region into agro-ecological zones (AEZs) (Fischer *et al.*, 2002; Global HarvestChoice, 2010). Table 9.1 shows the AEZs into which the region has been grouped and some of their characteristics, while Figure 9.1 shows the distribution of the AEZs in the region.

9.2.1 | Arid zone

The arid zone occupies 36 percent of the land area of SSA, most of which is in West and East Africa. Rainfall is low and extremely variable in this zone. The annual rainfall of less than 500 mm, combined with high temperatures and consequent high rates of evapotranspiration, make this zone capable of sustaining plant life for less than 90 plant growth days (or length of growing season).

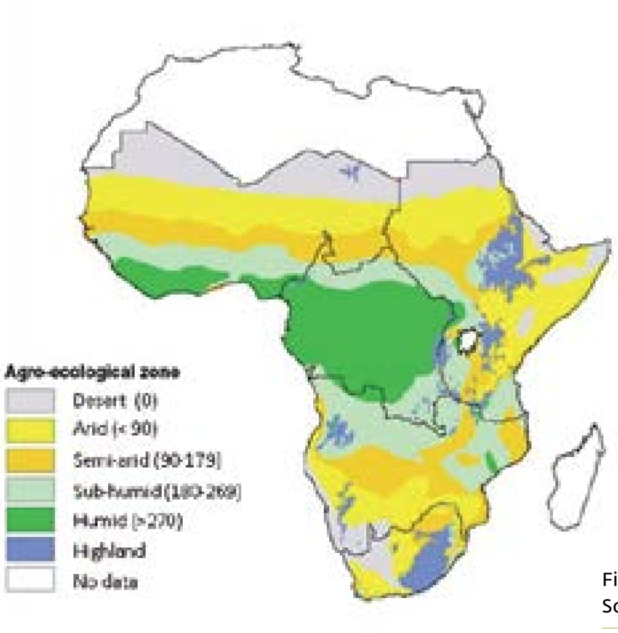

Figure 9.1 | Agro-ecological zones in Africa South of the Sahara.
Source: Otte and Chilonda, 2002.

Table 9.1 | Characteristics and distribution of agro-ecological zones in Africa
Source: ILCA, 1987, after Jahnke, 1982.

[a]pgd = plant growth days; [b]Areas with mean daily temperature during the growing period less than 20°C; [c]: n.a. = not available.

Zone	Definition	Rainfall range (mm)	Area (percent)				
			West Africa	Central Africa	East Africa	Southern Africa	Area of zone (percent)
Arid	<90 pgda	0–500	54	1	52	20	36
Semi-arid	90–180 pgd	500–1000	20	7	18	34	18
Sub-humid	180–270 pgd	1000–1500	16	29	16	38	22
Humid	>270 pgd	1500+	10	59	2	7	19
Highlandsb	<20°C	n.a.c	0	4	12	1	5
Total			**100**	**100**	**100**	**100**	**100**
Total area (10^6 km²)			**7.3**	**5.3**	**5.8**	**3.2**	

The arid zone is mostly associated with sandy soils (Arenosols, Psamments) which are weakly differentiated and are often of aeolian origin. Water and air move freely through these soils, which are low in all nutrients.

The accompanying vegetation consists of short annual grasses, legumes, scattered shrubs and trees. Mobile herds of sheep, goats, cattle and camels browse the herbage and shrubs, while farmers use most of the trees and shrubs for fuel. The low rainfall and its erratic distribution make cropping uncertain in most years. Owing to this unreliability, arable farming is mostly restricted to opportunistic cultivation of short-season millets, except in topographically favourable sites such as oases or irrigated areas. Opportunities for livestock development are limited but existing techniques could be improved upon, if not to increase productivity, then at least to sustain it.

9.2.2 | Semi-arid zone

The semi-arid zone receives 500 to 1000 mm of rainfall annually which can be capable of sustaining 90 to 180 plant growing days. This zone occupies 18 percent of the land area of SSA. Semi-arid lands are found in all regions of SSA except central Africa. The low rainfall and the long dry season make the semi-arid zone a relatively healthy environment for humans and livestock. Arenosols (Psamments) and Cambisols (Inceptisols) are widespread and include coarse sandy soils, fine sands, and loamy sandy soils. Water retention is poor and nutrient contents, including N, P and S levels, are generally low. The permeability of the undisturbed soil is good, but algal skins contribute to the formation of surface crusts. The natural vegetation is an open low-tree grassland but this has been severely modified in many regions.

The lower rainfall areas of this zone are used for grazing. Cropping and crop–livestock systems dominate the areas with higher rainfall where farmers commonly grow millet, sorghum, groundnut, maize and cowpeas.

9.2.3 | Sub-humid zone

The sub-humid zone occupies 22 percent of SSA, mainly in southern and central Africa. The zone receives 1 000 to 1 500 mm of rain annually which can sustain plants for 180 to 270 plant growing days. Within the climatic definition, this is a very varied zone in terms of climate, soils and land use. Luvisols (Alfisols) and Cambisols (Inceptisols) occur widely, parent material is often strongly weathered, and the levels of mineral nutrients as well as the clay fraction are low. Cambisols (Inceptisols) have fewer constraints to plant production than the older, more weathered soils, since their high base status provides adequate Ca and eliminates constraints related to low pH levels. The fertility of many soils in this zone is low, especially due to leaching of NO_3–, accompanied by the loss of cations and P adsorbtion. In addition, structural stability in these soils can be poor, with crusting and hardening occurring when soils are dry.

The natural vegetation is typically medium height or low woodland with understory shrubs and a ground cover of medium to tall, mainly perennial, grasses; *Hyparrhenia* spp. are common.

Food and cash crops are grown, including cassava, yams, maize, fruits, vegetables, rice, millet, groundnut, cowpeas and cotton. From these crops, products such as cottonseed cakes and the residues of the crops are available as feed for livestock. In some areas of this zone farmers grow soybean and leguminous forage crops.

The humid zone occupies 19 percent of SSA mostly in central and west Africa. The zone receives more than 1 500 mm of rainfall annually which can sustain plants for 270 to 365 plant growing days. The zone is found at low latitudes north and south of the equator. Soils in this zone include Ferralsols (Oxisols), Acrisols (Ultisols) and Luvisols (Alfisols), the last of which are commonly encountered at the forest-savannah boundary. Vegetation consists of rain forest and derived savannahs with natural vegetation dominated by tall, closed forest which may be evergreen or semi-deciduous and which is often floristically rich. The herbaceous vegetation often contains large amounts of the major nutrients.

The soils are strongly weathered and hence have high levels of iron and aluminium oxides and low levels of phosphorous. The organic matter content is therefore generally low and the soils are fragile and easily degraded when the vegetative cover is lost. This zone has limited potential for livestock development, particularly because of the threat of the trypanosomiasis-transmitting tsetse fly.

9.2.5 | Highlands zone

The highland zone represents 5 percent of the land area of SSA, most of which is in eastern Africa, and half in Ethiopia. This zone occupies areas above 1 500 m altitude that have a mean daily temperature of less than 20 ºC. The main highland areas in sub-Saharan Africa (SSA) are in Ethiopia, Kenya, Uganda, Rwanda, Burundi, western Zaire, Tanzania, Angola and Lesotho. There are also many other areas above the 1500 m contour and some of these afford tsetse-free grazing (e.g. Fouta Djallon and Bamenda). The highland areas vary in climate, topography, soils and land use.

Topography varies from gently rolling hills to deeply incised valleys and steep slopes. Soils are sometimes deep and fertile Vertisols and Nitosols, but shallow soils of inherently low fertility are widespread. In many mountain grassland areas, soils only have a very shallow surface horizon that is fertile. Undisturbed upland areas are normally stable, although some soils exhibit 'slumping' even where undisturbed. Cultivating the so-called 'duplex' soils[5] and soils that form a surface crust on slopes results in high run-off. Unless soil conservation measures are taken and soils are sufficiently covered with vegetation, overland flow removes large amounts of soil. The zone receives bimodal rainfall (>1000 mm annually) and there are two growing seasons. Livestock rearing is widespread: farmers grow fodder, and animal traction is of increasing importance. Population pressure is encouraging crop–livestock integration, for which the cool highlands have high potential

9.3 | General soil threats in the region

The various threats to soil health and ecosystem services in SSA include: (1) erosion by water or wind; (2) loss of soil organic matter; (3) soil nutrient depletion; (4) loss of soil biodiversity; (5) soil contamination; (6) soil acidification; (7) salinization and sodification; (8) waterlogging; and (9) compaction, crusting and sealing/capping (Mabogunje, 1995; Oldeman, 1991; Meadows and Hoffman, 2002; World Bank, 1997; IFPRI, 1999).

9.3.1 | Erosion by water and wind

About 77 percent of SSA is affected by erosion, with the most serious erosion areas in the Republic of South Africa, Sierra Leone, Guinea, Ghana, Liberia, Kenya, Zaire, Central African Republic, Ethiopia, Senegal, Mauritania, Nigeria, Niger, Sudan and Somalia.

According to the GLASOD results (ISRIC/UNEP, 1990), about 494 million ha of the land in SSA is affected by one form of degradation or another. Of this, 227 million ha (46 percent) is by water erosion, 187 million ha (38 percent) by wind erosion, 62 million ha (12 percent) by chemical degradation and 18 million ha (4 percent) by physical degradation. The intensity of water erosion has been described as very high to extreme on about 102 million ha (45 percent of the total SSA area affected), moderate on about 67 million ha (30 percent) and slight on about 58 million ha (25 percent) (Oldeman, 1991).

Water erosion: This is the most widespread soil degradation type in SSA. Water erosion increases on slopes where vegetation cover is reduced due to deforestation, overgrazing or cultivation that leaves the soil surface bare. It is further aggravated where there has been a loss of soil structure or infiltration rates have been reduced. The areas particularly affected are humid and sub-humid zones. Almost 70 percent of **Uganda** was degraded by soil erosion and soil nutrient depletion between 1945 and 1990. More than 20 percent of agricultural land and pastures in the country have been irreversibly degraded.

Water erosion poses the greatest threat to soils in **Nigeria**, where it affects over 80 percent of the land (NEST, 1991). Wind, sheet, gully and beach erosion affect different parts of the country at varying intensities, but attention will focus here on the impact of erosion on agricultural land. While wind erosion is confined to the arid north, sheet erosion by water is ubiquitous throughout the country. Areas most prone to sheet erosion are where farming has cleared the original vegetation, and the soils became impoverished scrubland. Gully erosion is by far the most alarming type of erosion, particularly in the Eastern region, because it often threatens settlements and roads. Although it affects a small fraction (less than 0.1 percent) of Nigeria's 924 000 km^2 of landmass, gully erosion claims large amounts of public funds annually for remedial action.

Wind erosion: Wind erosion occurs most frequently in the arid and semi-arid parts of SSA, especially in areas with sandy or loamy soils. Wind erosion leads to loss of topsoil over extended areas causing soil fertility decline. Bielders, Michels and Rajot (1985) stated that wind erosion can remove up to 80 tonnes of soil from 1 ha in a given year. In SSA wind erosion is second in importance to water erosion, constituting 38 percent of the total erosion in the region (ISRIC/UNEP, 1990) and affecting about 186 million ha of land in the region. The intensity of wind erosion is strong on about 9 million ha (5 percent), moderate on 89 million ha (48 percent) and light on 89 million ha (48 percent) (Oldeman, 1991). Over 99 percent of wind erosion in Africa occurs in the dry land zone, with less than 1 percent affecting the humid zone.

Wind erosion is a natural process that commonly occurs in deserts and on coastal sand dunes and beaches. During drought, it can also occur in agricultural regions where vegetation cover is reduced. If the climate becomes drier or windier, wind erosion is likely to increase. Climate change forecasts suggest that wind erosion will increase over the next 30 years due to more droughts and more variable climate. The combination of a changing climate and consequent increase in wind erosion will cause a series of changes affecting soils:

- less rain, which will support less vegetation
- lower soil moisture, which will decrease the ability of soil particles to bind together into larger, heavier aggregates
- increased wind speeds, which will result in more force exerted on the ground surface and more wind erosion (if wind speed doubles, the erosion rate increases eight times)
- large losses of soil and nutrients
- more large dust storms, which will impact soils and the community
- poorer air quality, increased respiratory health risks, and temperature and rainfall changes due to atmospheric pollution (all off-site effects).

9.3.2 | Loss of soil organic matter

Land degradation leads to a release of carbon to the atmosphere through oxidation of soil organic matter (Oldeman, Hakkeling and Sombroek, 1991). Africa's current major negative role in the global carbon cycle can be attributed to the substantial releases of carbon associated with land use conversion from forest or woodlands to agriculture (Smith, 2008). In the 1990s, these releases accounted for approximately 15 percent of the global net flux of carbon from land use changes (Hooper *et al.*, 2006). Land management following conversion also impacts carbon status, soil fertility, and agricultural sustainability – a point underlined by many including Lal (2006), Ringius (2002), Zivin and Lipper (2008) and Tieszen, Tappan and Toure (2004). Soils often continue to lose carbon over time following land conversion (Woomer, Toure and Sall, 2004; Tschakert, Khouma and Sene, 2004; Liu *et al.*, 2014), resulting in further reductions in crop yields and impoverishment of the farming population. However, these carbon stocks can be replenished with combinations of residue retention, manuring, nitrogen (N) fertilization, agroforestry, and conservation practices (Lal, 2006).

In most sub-humid and semi-arid areas, much of the grazing land is burned annually during the dry season to remove the old and coarse vegetation and to encourage the growth of young and more nutritious grasses. Burning causes the loss of soil organic matter (released as CO_2) and thus impairs agricultural productivity.

It exposes the soil to the erosive forces of the wind during the dry season and of the rain during the rainy season. Furthermore, the annual burn of the vegetation severely reduces the return of organic matter to the soil. This results in loss of the benefits of soil organic matter, including fertility, structure, water retention and biodiversity. The soil becomes biologically, chemically and physically poorer (FAO, 2001). Land degradation further leads to a release of carbon to the atmosphere through the oxidation of soil organic matter which results from soil disturbance and from the consequent exposure of new soil surfaces to the weather.

In agricultural land, the challenge has been to produce increasing quantities of food in an economic and institutional context where the means to improve productivity in a sustainable fashion are generally not available (e.g. lack of sustainable technological packages, absence of extension, training or affordable inputs etc.). Pressures to increase output in the absence of these supporting factors has led to: (I) the rapid expansion of agricultural land (over 65 percent in the last three decades); and (II) the shortening of the fallow periods in traditional, extensive land use systems, which reduced the rehabilitation of soil fertility through natural processes. The increased use of fire as a clearing tool has led to the further loss of nutrients in many systems. Fertilizer consumption has not increased to compensate for the loss of soil nutrients resulting from the intensification of land use. Hence, there has been widespread mining of soil organic matter and nutrients. As a consequence of this poor land management combined with the vulnerable nature of many soils, much of SSA's cropland is now characterized by low organic matter content, often in combination with a low pH and with aluminium toxicity. On degraded soils with low organic matter, inorganic fertilizers are also easily leached, which is likely to have negative long-term effects on agricultural productivity and on the quality of downstream water resources.

9.3.3 | Soil nutrient depletion

Soils in a large part of SSA are strongly weathered and inherently low in organic matter. Because of the increasing pressure on land, natural replenishment of nutrients during fallow periods is now insufficient to maintain soil productivity over the long-term. Insufficient nutrient replacement in agricultural systems on land with poor to moderate potential results in soil degradation. Already soil moisture stress inherently constrains land productivity on 85 percent of soils in Africa (Eswaran, Reich and Beinroth, 1997). Now soil fertility degradation places an additional serious human-induced limitation on productivity.

The low nutrient status of most soils in SSA is further exacerbated by insufficient use of fertilizers and manure and by the practice of mono-cropping. Overall use of inorganic fertilizers in SSA is just 12 kg ha^{-1}, the lowest in the World, and soil nutrient depletion is widespread in croplands. Approximately 25 percent of soils in Africa are acidic, and therefore deficient in phosphorus (P), calcium and magnesium with often toxic levels of aluminium (McCann, 2005). Use of fertilizer in the region involves average applications of less than 9 kg of nitrogen and 6 kg of phosphorus per ha, compared with typical crop requirements of 60 kg of nitrogen and 30 kg of phosphorus per ha. Recent research estimates that on average every country in SSA has a negative soil nutrient balance; in all countries studied, the amount of nitrogen, phosphorus and potassium (K) added as inputs was significantly less than the amount removed as harvest or lost by erosion and leaching (Swift and Shepherd, 2007). Although many farmers have developed soil management strategies to cope with the poor quality of their soil, low inputs of nutrients, including of organic matter, contribute to poor crop growth and to the depletion of soil nutrients.

Stoorvogel, Smaling and Janssen (1993) calculated nutrient balances for arable soils in 38 sub-Saharan countries and for 35 crops for 1982-1983 and made forecasts for 2000. Subtracting values of the output (made up of harvest, removal of residues, leaching, denitrification and erosion) from the values of the input (made up of fertilizers, manures, rain, dust, biological N-fixation and sedimentation), the study reported alarming average nutrient losses for SSA as follows: 1982-1983: 22 kg N, 2.5 kg P and 15 kg K; 2000: 26 kg N, 3 kg P and 19 kg K. This indicated persistent nutrient mining over time (Bationo *et al*., 2012). Other estimations claim that each year 4 million tonnes of nutrients are harvested annually in SSA against <0.25 million tonnes returned to the soils in the form of fertilizers.

Sub-national studies of nutrient depletion found annual losses of 112 kg per ha of N, 2.5 kg of P, and 70 kg of K in the western Kisii highlands of Kenya. Significantly lower losses were, however, recorded in southern Mali (Smaling, 1993; Smaling, Nandwa and Janssen, 1997). Farm monitoring and modelling of nutrient cycles for the western highlands of Kenya found that more nitrogen (63 kg per ha) was being lost through leaching, nitrification, and volatilization than through removal of crop harvests (43 kg per ha). Depending on the type of farm management practice, net nitrogen balances on cropped land varied between -39 and 110 kg per ha per year, and net phosphorus balances between -7 and 31 kg per ha per year (Shepherd and Soule, 1998).

9.3.4 | Loss of soil biodiversity

Loss of soil biodiversity is considered the fourth major threat in SSA. Biodiversity loss occurs in a number of ways including destruction of habitat, land use change, introduction of new species, and harvesting and hunting of individual wild species. It has been estimated that in the mid-1980s in Sub-Saharan Africa (SSA), 65 percent of the 'original' ecosystems had been converted (Perrings and Lovett, 1999). The most important factors affecting soil biodiversity are: (I) habitat fragmentation; (II) resource availability – the amount and quality of nutrients and energy sources; (III) temporal heterogeneity e.g. seasonal effects; (IV) spatial heterogeneity - spatial differences in the soil; (V) climate variability; and (VI) interactions within the biotic community.

Habitat destruction and/or fragmentation remains the primary threat to soil biodiversity in SSA. For instance, the once great equatorial forest that stretched from western Africa into eastern Africa is now fragmented into pockets represented by Lamto forest in Ivory Coast, Mbalmayo forest in Cameroun, Congo forest in Democratic Republic Congo, Kabale, Budongo and Mabira forests in Uganda and Kakamega forest in Kenya. The surrounding communities still rely heavily on these forests for basic needs such as fuelwood, charcoal, timber, poles, and other building materials. Due to human encroachments, the forests are subject to a mosaic of different land uses. There are patches of secondary forest, fallow and arable fields amidst significant remnants of primary vegetation. In the process of conversion and change in land use, soil biota have not been spared. Studies by Okwakol (2000) and Ayuke *et al.* (2011) have shown that up to 50 percent of soil macrofauna species within the forest area have been lost due to habitat destruction or fragmentation.

Other threats to soil biodiversity in SSA include land use and land cover change, mainly through conversion of natural ecosystems, particularly forests and grasslands, to agricultural land and urban areas. In a study conducted across different ecosystems of Eastern (Kenya), Western (Nigeria, Burkina Faso, Ghana, Niger) and Southern Africa (Malawi), Ayuke *et al.* (2011) demonstrated a substantial reduction in the number of species and abundance of soil macrofauna groups such as earthworms and termites because of conversion of native or undisturbed ecosystems into arable systems. Continuous cultivation also exacerbates soil biodiversity loss because of loss of soil organic matter and hence of food resources for the soil organisms (Ayuke *et al.*, 2011). It is likely that land clearing and deforestation will continue, further threatening genetic diversity as more species are lost (IAASTD, 2009). Sub-Saharan Africa suffers the world's highest annual deforestation rate because of overexploitation of forest resources and conversion of forested land to agriculture. Although deforestation occurs throughout the continent, particularly affected areas are the moist forests of Western Africa and the highland forests of the Horn of Africa (FAO, 2007; Hansen *et al.*, 2013).

Mulugeta (2004) reported that in Ethiopia deforestation and subsequent cultivation of the tropical dry Afromontane forest soils endangered the native forest biodiversity not only through the outright loss of habitat but also by impairing the soil seed banks. The results showed that the contribution of woody species to the soil seed bank declined from 5.7 percent after seven years to nil after 53 years of continuous cultivation. However, soil quality and native flora degradation are reversible through reforestation. In fact, reforestation of abandoned farm fields with fast-growing tree species was shown to restore soil quality. Tree plantations established on degraded sites also fostered the recolonization of diverse native forest flora under their canopies. An important result from studying the effects of reforestation is that good silviculture, particularly selection of appropriate tree species, can significantly affect the rate and magnitude of restoration processes for both soil quality and biodiversity.

In many African cultures, harvesting of soil fauna groups such as the termite alates and queens, chafer grubs for food, and the use of earthworms as bait by fishermen can also be a threat to soil biodiversity, and may in the long run contribute to substantial loss of many species of soil fauna.

Harsh climatic conditions and/or climate change may also contribute to changes in soil biodiversity in SSA. For example, a more than average numbers of earthworm and termite taxa are found under relatively warmer, drier conditions (Ayuke *et al.*, 2011). This is contrary to the observation that earthworm and termite diversity increases with increases in rainfall or soil moisture, as generally found in temperate climates (Bohlen *et al.*, 1995; Curry, 2004). However, seasonality of rainfall in the tropical regions means rainfall amounts per season may be more important than the annual total. Lower taxonomic richness among sites in Eastern Africa may be attributable to less favourable conditions arising from high rainfall and low temperatures at higher altitudes (Ayuke *et al.*, 2011).

Intense management practices that include application of pesticides and frequent cultivation affect soil organisms, often altering community composition of soil fauna. Soil biological and physical properties (e.g., temperature, pH, and water-holding characteristics) and microhabitat are altered when natural habitat is converted for agricultural production (Crossley, Mueller and Perdue, 1992). Changes in these soil properties may be reflected in the distribution and diversity of soil meso fauna. Organisms adapted to high levels of physical disturbance become dominant within agricultural communities, thereby reducing the richness and diversity of soil fauna (Paoletti, Foissner and Coleman, 1993).

The extent of soil sterilization and loss of soil biodiversity in SSA has yet to be quantified on a large-scale across the region. However, it is clear that unsustainable soil management practices have depleted soil organic matter, promoted soil degradation and may have caused soil fauna and flora imbalances. This land degradation will continue unless land users in SSA adopt an agro-biological approach to managing their soils (Van der Merwe *et al.*, 2002).

9.3.5 | Soil contamination and pollution

Chemical fertilizers and pesticides have had negative effects on the environment in most SSA countries. However, soil pollution through agrochemical use in SSA has been of less concern compared to other regions of the world, mainly because of the low levels of application. However, with the increasing push towards higher use of fertilizer, pesticide and herbicide to boost productivity, efforts will be needed to reduce the associated negative impacts on soil quality (IAASTD, 2009).

Chemical pollution has emerged as a threat to soil quality. According to a United Nations Environment Programme (UNEP, 2007) environmental assessment in ten communities in Ogoni land in southeastern Nigeria which had been affected by crude oil spills, drinking water, the air and agricultural soils contained over 900 times the permissible levels of hydrocarbon and heavy metals. The report acknowledged that, even if all its recommendations were implemented, recovery might take 30 years. Other published research work suggests that heavy metal pollution is occurring across SSA. Heavy metal (Pb, Cd, Hg, Cu, Co, Zn, Cr, Ni, As) pollution of soils has been reported in Nigeria, Kenya, Ghana and Angola (Fakayode and Onianwa, 2002; UNEP, 2007; Odai et al, 2008).

Change of land use, particularly urbanization, is another factor in soil contamination. National data from South Africa indicate that areas under urban, forestry and mining land uses have all increased over the last decade, whereas the cultivated area has decreased. The urban area has increased from 0.8 percent of total area to 2 percent, forestry from 1.2 percent to 1.6 percent, and mining from 0.1 percent to 0.2 percent, while the cultivated area has decreased from 12.4 percent to 11.9 percent. The increase in the urban and mining areas is a major concern in terms of soil conservation and future use. Urban development involves soil sealing which irreversibly removes soils from other land uses. Mining results in serious chemical and physical soil degradation which subsequently can only be partially restored.

9.3.6 | Soil acidification

In SSA, extremely acid soils, mainly potential or actual acid sulphate soils, occur only in a small area around the Niger delta and sporadically along the coastal plains of West Africa. Other acid soils occupy about 15 percent of the continent and are mainly found in the moist parts of the semi-arid zones and in sub-humid areas. Many of the Acrisols (Ultisols) and some Lixisols (Alfisols) have acid surface and subsurface horizons which, coupled with the moisture stress conditions, makes these soils extremely difficult to manage under low-input conditions. In West Africa, the annual additions of dust from the Sahara brought by the *Harmattan* winds raise the pH of the surface horizons. The problem is therefore less acute there, although subsoil acidity remains (Eswaran *et al.*, 1996). Another region of acid soils occurs south of the tropic of Capricorn and includes parts of South Africa (Beukes, Stronkhorst and Jezile, 2008a,b) where it poses a serious soil chemical problem and is in fact one of the greatest production-limiting factors.

9.3.7 | Salinization and sodification

Salinization is defined as a change in the salinity status of the soil. This can be caused by improper management of irrigation schemes, particularly in the arid and semi-arid regions. Irrigation-induced soil acidity is aggravated when irrigation is practiced on soils unsuitable for irrigation (Barnard *et al.*, 2002). Salinization can also be caused if sea water intrudes into coastal regions either on the surface or into groundwater. It may also arise in closed basins when there is excessive abstraction of groundwater from aquifers of different salt content. Salinization also takes place where human activities lead to increased evapotranspiration from soils on salt-containing parent material or where saline ground water is being pumped out (Oldeman, 2002).

In the arid and semi-arid parts of Africa, soil salinity and alkalinity are major problems affecting about 24 percent of the continent. Soils with $pH>8.5$ are designated as alkaline (Eswaran *et al.*, 1996). Soil salinity and sodicity problems are common in arid and semi-arid regions where rainfall is insufficient to leach salts and excess sodium ions out of the rhizosphere. More than 80 million ha of such soils are found in Africa.

Increasing temperatures may result in high evaporative demands that may activate the capillary rise of salts, leading to soil salinization. The results of a study in Sudan showed a significant increase in salinity in the Dongla area in the north, where the annual rainfall is the lowest in the country. This increase is associated with fluctuation and erratic distribution of rainfall, as well as with a rise in temperature (Abdalla *et al.*, 2011).

9.3.8 | Waterlogging

Human intervention in natural drainage systems may lead to waterlogging or flooding by river water. Most waterlogging threats are due to effects of human-induced hydromorphy. Causes include a rising water table (for example, due to construction of reservoirs or irrigation) or increased flooding caused by higher peak flows of rivers. The technology of flooding in paddy fields to provide a proper environment for paddy rice is generally not considered a threat to ecosystem services, although it may increase the emissions of GHG. It is estimated (Oldeman, Hakkeling and Sombroek, 1991) that waterlogging constitutes 1.5 percent of the non-erosion soil degradation threats in Africa.

9.3.9 | Compaction, crusting and sealing

The population of the Sub-Saharan Africa (830 millions) is approximately 12 percent of the world population. SSA population has been growing at a rate of 2.6 percent year during the last decade, although the rate is now declining. The tendency in the region is towards the concentration of growing populations in moderately large cities (rather than mega-cities). Since the early 1970s, several SSA countries have experienced accelerated urban expansion, recording some of the highest urban growth rates in the world of up to 5 percent per year (Todaro, 2000). There are numerous examples of single-city dominance in the region. For instance, in Mozambique, Maputo accounts for 83 percent of the country's urban population, while the figures for Dakar, Lome, Kampala and Harare are 65, 60, 52 and 50 percent respectively (World Bank, 2002). Nigeria and South Africa represent exceptions to this single-city dominance, as they have several large and well distributed urban centres. South Africa and Nigeria are also the countries recording the highest amount of impervious surface area (ISA) in the region, and they have high Urbanization Indexes (the ratio between the total area of the country and the urbanized area) (Figure 9.2).

9.4 | The most important soil threats in Sub-Saharan Africa

Of the threats to soils and related ecosystem functions in SSA listed in Section 9.3, the most critical are soil erosion, loss of soil organic matter and soil nutrient depletion (UNEP, 2013). Loss of soil biodiversity is also a significant threat in SSA. These four threats are interrelated. More is known about the first three and these are discussed in greater detail in this section.

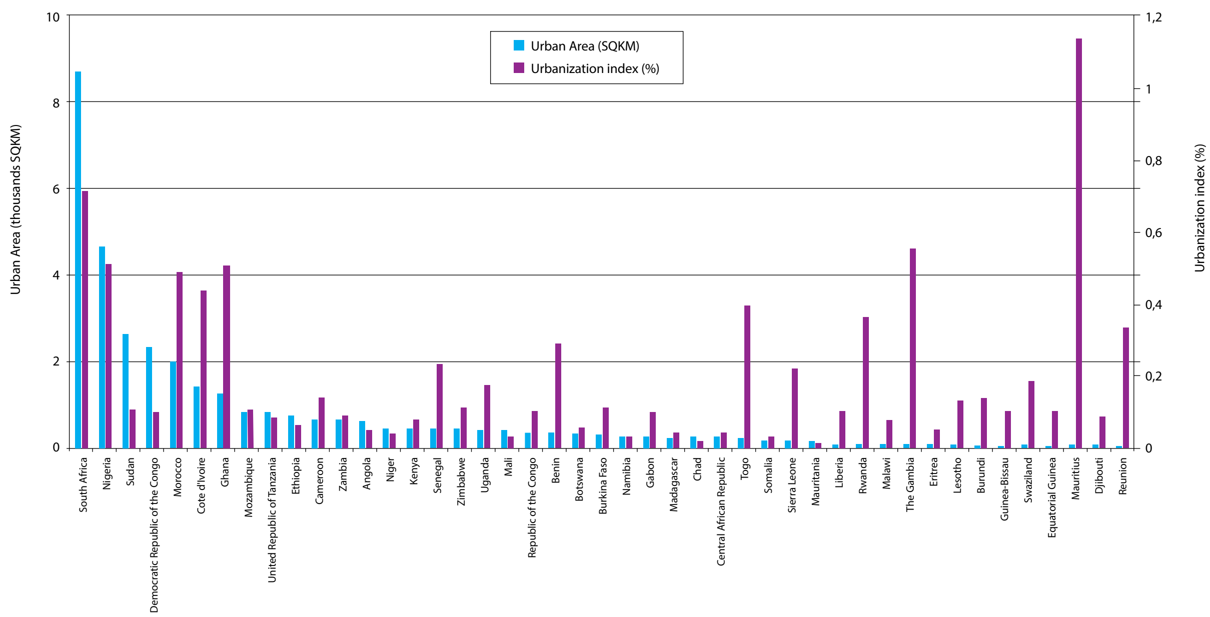

Figure 9.2 | Extent of urban areas and Urbanization Indexes for the Sub-Saharan African countries. Source: Schneider, Friedl and Potere, 2010.

9.4.1 | Erosion by water and wind

Direct causes of soil erosion

Expansion of land for agriculture: Soil erosion can be a natural process but it is also often caused or accelerated by human activities that involve inappropriate land use. As discussed above (Section 9.3), much of the change in land use practices in SSA has been driven by the need to increase production and incomes in an economic and institutional context where the means to improve productivity in a sustainable fashion are generally not available. The processes involved - rapid expansion of agricultural land, shortening of fallow periods, increased use of fire – are discussed in full in Section 9.3.2 above.

As fertilizer consumption did not increase to compensate for the loss of soil nutrients resulting from the intensification of land use, there has been widespread mining of soil nutrients and soil organic matter. As a consequence of the type of soils that occur in the region and because of generally poor land management, many SSA croplands now have low soil organic matter contents and soils that have a low pH and suffer from aluminium toxicity. On degraded soils with low organic matter, inorganic fertilizers are also easily leached, and this process has devastating long-term effects for agricultural productivity. Alternative means of maintaining soil fertility, such as crop rotation with biological nitrogen fixing (BNF) species, application of green manure, agroforestry, composting, rock phosphates, etc., have proved to be highly effective at the local scale. However, these technologies have not been applied widely enough to have an impact at a national let alone continental scale.

Overgrazing: There has been much debate on the impacts in SSA of high grazing pressures on vegetation composition in rangelands. The current understanding is that continued high grazing pressure may affect rangeland productivity, particularly in the long term. Vegetation studies also show that high grazing pressures lead to changes in species composition, which may reduce the resilience of rangelands to drought (Hein and De Ridder, 2006). During a drought, degraded rangelands show a much stronger decline in productivity than non-degraded rangelands. Recent years have seen droughts with severe impacts on livestock and local livelihoods in parts of Niger and in the East African drylands (Uganda and Kenya).

Deforestation: Most forests and woodlands in SSA are experiencing rapid rates of deforestation. Deforestation is driven by a number of processes, in particular: (I) the continued demand for agricultural land; (II) local use of wood for fuel, charcoal production and construction purposes; (III) large-scale timber logging, often without effective institutional control of harvest rates and logging methods; and (IV) population movements and resettlement schemes in forested areas. The amount of cropped land in SSA has increased by about 40 million ha in 30 years (1975-2005), most of it at the expense of forests and woodlands (FAO, 2015). Further expansion of cropland would be at the expense of forests or rangeland.

Socio-economic causes of soil erosion

Population expansion: Behind these direct drivers of erosion lies the demographic driver of a continuously growing population (Figure 9.3). The rate of SSA population growth has moderated in recent years and is currently 2.1 percent per year. Nonetheless, in the next 15 years SSA will have to accommodate at least 250 million additional people, a 33 percent increase (UNDP, 2005). With the increase in population comes an increased demand for living space and food which will directly affect soil use in the region.

Poverty: General poverty of the farming population and the low potential of the farming systems characteristic of SSA pose considerable challenges to sustainable agricultural growth and poverty reduction. Poverty is particularly prevalent in the pastoral/agro-pastoral, highland perennial and forest based farming systems which constitute one-third of the total SSA production systems (FAO and World Bank, 2001). From Figure 9.4 it is clear that SSA has many countries where a large percentage of the population is living below the poverty line.

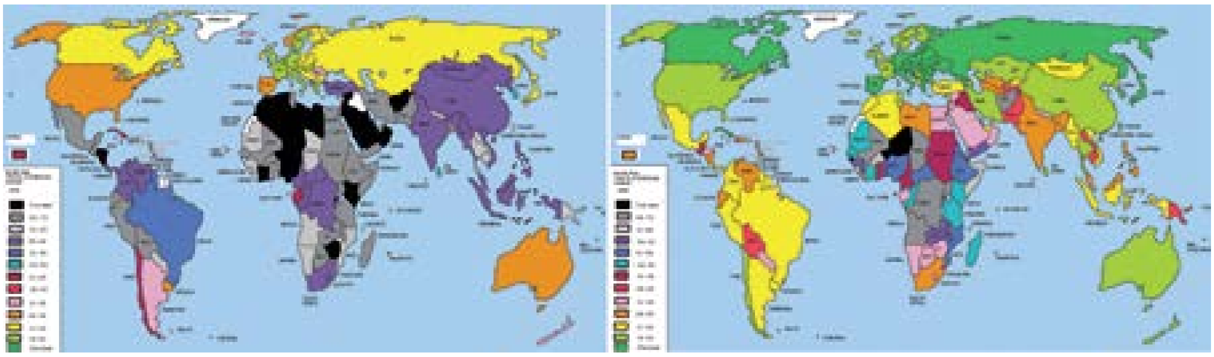

Figure 9.3 | The fertility rate (the number of children a woman is expected to bear during her lifetime) for 1970 and 2005. Source: Fooddesert.org

Climate Change: Climate change is predicted to affect SSA agro-ecosystems on a significant scale in the coming decades. The continent has a long history of rainfall fluctuations of varying lengths and intensities. Severe droughts affected East and West Africa alike during the 1910s. Drought episodes were generally followed by increasing rainfall levels, but negative trends were observed again from the 1950 onwards, culminating in the droughts of the early 1970s and mid-1980s. These droughts had an impact on the susceptibility of soils to erosion.

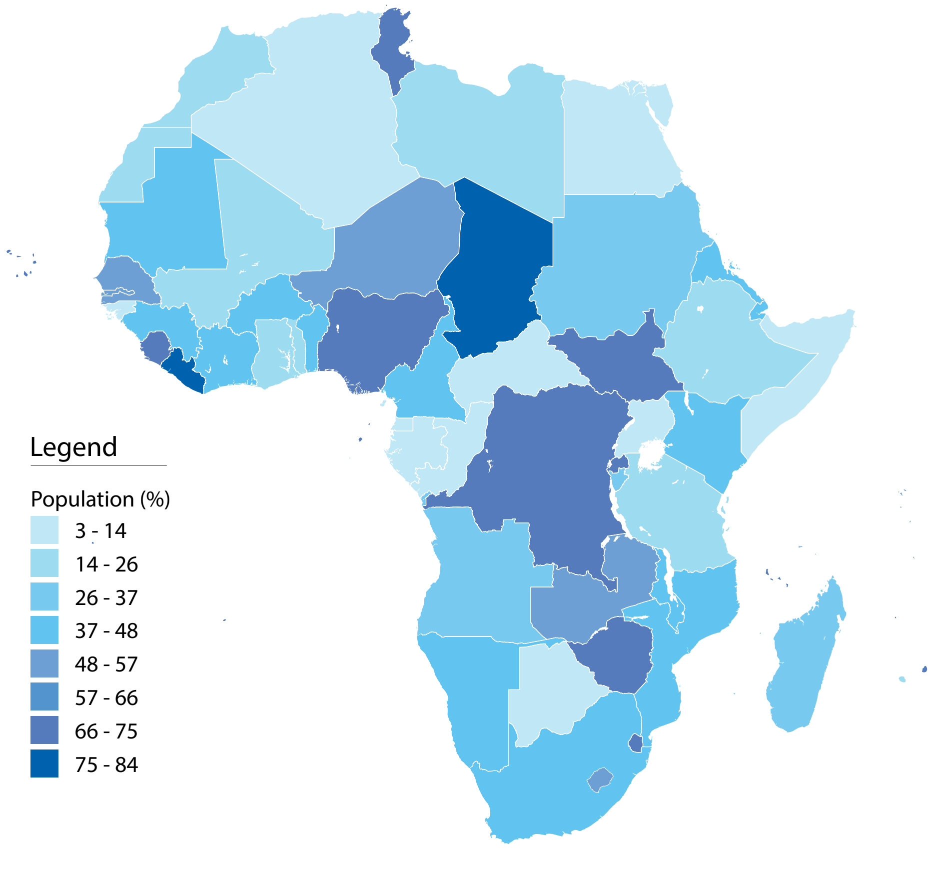

Figure 9.4 | Percentage of population living below the poverty line. Source: CIA World Factbook, 2012.

Water erosion: its extent and distribution in the region

Water erosion constitutes 46 percent of the land degradation types in SSA, and wind erosion accounts for a further 38 percent (FAO, 2005). The most recent continent-wide assessment shows that 494 million ha, or 22 percent of the agricultural land (including rangelands) in Africa, are affected by water erosion (Oldeman, Hakkeling and Sombroek, 1991). The assessment confirms common field observations that overgrazing is the main cause of soil erosion, followed by inappropriate cultivation techniques on arable land. In this context it is important to note that the number of cattle in Africa almost doubled in the period 1961-1994, while the area of grazing lands hardly increased (FAO, 2015). For the future, the expected intensification of use on currently cultivated lands, expansion of cultivation into more marginal areas, reduction in grazing lands and the increasing numbers of livestock are likely to increase vulnerability to erosion.

As discussed above (9.3.1), severely eroded areas in Africa can be found in South Africa, Sierra Leone, Guinea, Ghana, Liberia, Kenya, Nigeria, Zaire, Central African Republic, Ethiopia, Senegal, Mauritania, Niger, Sudan and Somalia. More than 20 percent of SSA's agricultural land and pasture has been irreversibly degraded, mainly by soil erosion (UNSO/SEED/BDP, 1999).

Erosion has assumed a serious dimension in Nigeria, affecting every part of the country. In the eastern part of the country, erosion has ravaged wide areas. Active and inactive gullies have formed with surface areas ranging from 0.7 km^2 in Ohafia to 1.15 km^2 in Abiriba in Abia State. The width of the gullies ranges between 0.4 km in Ohafia and 2.4 km in Abiriba. A gully with a depth of 120 m has been recorded at Abiriba (Ofomata, 1985). In addition, agricultural practices have contributed to the problems of widespread sheet erosion. Erosion is thus exerting major pressure on soil resources with far-reaching consequences for both the population and the environment (Jimoh, 2000). In the northern areas of Nigeria, erosion is equally serious, especially in places like Shendam and Western Pankshin in Plateau State, as well as at Ankpa and Okene in Kogi State. Gully erosion is also prominent in Efon-Alaaye, Ekiti State in the western part of the country (Adeniran, 1993).

The areas of Nigeria most affected by erosion are the Agulu and Nanka districts of the eastern part of Nigeria, and the Shendam and western Pankshin areas of Plateau State, Nigeria (Udo, 1970; Okigbo, 1977). Elsewhere, the Imo State government has estimated that about 120 000 km^2 of land has been devastated by gully erosion. As a result, eight villages have been destroyed and 30 000 people needed to be resettled. Erosion damage in Imo and Anambra states was estimated to cause the loss of over 20 tonnes of fertile soil per annum, at an economic cost of over 300 million naira per annum. Gullies extended to depths of over 120 m and widths up to 2 km wide (Adeleke and Leong, 1980). In 1994, about 5 000 people were rendered homeless due to erosion in Katsina State, Nigeria. Properties worth over 400 million naira were destroyed and many lives lost. Other areas affected by erosion include Auchi in Edo State, Efon Alaye in Ondo State, Ankpa and Okene in Kogi State, and Gombe in Bauchi State. In many areas, erosion has resulted in a physical loss of available land for cultivation. For example, about 1 000 ha of cultivable land has been lost to erosion at the Agulu-Nanka area of Nigeria. Thus the loss of homes and crops, disruption of communication routes, financial losses and attendant hydrological problems can all stem from erosion problems.

Nearly 90 percent of rangelands and 80 percent of farmlands in the West African Sahel, Sudan, and northeast Ethiopia are seriously affected by land degradation, including soil erosion. More than 25 percent of South Africa is seriously degraded by erosion. Almost 70 percent of Uganda's territory was degraded by soil erosion and soil nutrient depletion between 1945 and 1990. Across SSA, more than 20 percent of agricultural land and pastures has been irreversibly degraded, affecting more than 65 percent of Africa's population (Global HarvestChoice, 2011).

Considering that over 80 percent of South Africa's land surface is covered by natural vegetation, the estimated annual soil loss of 2.5 tonnes soil per ha is excessive. These rates of soil loss far exceed tolerance levels and are almost ten times the estimated rate of soil formation, which has been estimated at 0.31 tonnes ha^{-1} yr^{-1} in the case of a 1 m thick solum of a tropical soil (Van der Merwe, 1995; see Section 6.1). Soil organic matter (SOM) plays a major role in ensuring soil stability. There is a general decline in SOM in South African soils. An estimated 20 percent of the country's total surface area is potentially highly erodible. Bearing in mind the country's geology, rainfall and topographic characteristics in addition to declining SOM, soil erosion is likely to stay a dominant soil degradation process.

Sediment movement by erosion contributes significantly to shifts in soil fertility. Sediment movement is widespread in South Africa as reflected by the annual losses of 3 300 tonnes N, 26 400 tonnes P and 363 000 tonnes K estimated by Du Plessis in 1986 (Van der Merwe, 1995). Periodic floods transport massive amounts of sediment and nutrients within catchments. The Demoina flood in 1984, for instance, deposited as much as 34 million tonnes of sediment in the Mfolozi flats (Scotney and Dijkhuis, 1990). One 1985 study used a siltation approach to estimate the siltation load carried by the Tugela River, finding soil loss from the catchment area as high as 4.4 tonnes ha^{-1} yr^{-1} (De Villiers *et al.*, 2002). It has been estimated that water erosion affects 6.1 million ha of cultivated soils in South Africa. Of this area, 15 percent of soils are seriously affected, 37 percent moderately affected, and the rest slightly affected.

Wind erosion in the region

Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clays and silts, thus removing the most fertile part of the soil and lowering soil productivity (Lyles, 1975). In SSA, soil erosion by wind occurs mainly in the arid and semiarid regions. The occurrence of wind erosion at any one site is a function of weather events interacting with soil and land management through the effects of weather on soil structure, tilth and vegetation cover. At the southern fringe of the Sahara Desert, a special dry and hot wind, locally termed *Harmattan*, occurs. These North-easterly or Easterly winds normally blow in the dry winter season under a high atmospheric pressure system. When the wind force of *Harmattan* is beyond the threshold value, sand particles and dust particles will be blown away from the land surface and transported for several hundreds of kilometres across the land and as far as the Atlantic Ocean (WMO, 2005). Areas in SSA most susceptible to wind erosion are the southern fringe areas of the Sahara, Botswana, Namibia, Zimbabwe, Tanzania and South Africa (Favis-Mortlock, 2005).

It is estimated that 25 percent of South Africa is affected by wind erosion (Laker, 2005), amounting to an estimated 10.9 million ha. Of this area, 7 percent is seriously affected, 29 percent moderately and 64 percent slightly (Barnard *et al.*, 2002). Wind erosion is particularly evident on drift sands in the coastal areas, but also on cultivated land in the Highveld areas. The seriousness of wind erosion can be deduced from the situation in the Eastern Cape Province where there are over 14 000 ha of drift sand (Barnard *et al.*, 2002). Most of South Africa's prime agricultural soils in the relatively arid western part of the country are wind-blown sand deposits (De Villiers *et al.*, 2002).

Wind erosion may cause off-site effects, such as the covering of the terrain with wind-borne soil particles from distant sources. It is estimated that more than 100 million tonnes of dust per annum are blown westward from the African continent across the Atlantic. The amount of dust arising from the Sahel zone has been reported to be around or above 270 million tonnes per year which corresponds to a loss of 30 mm per m_2 per year or a layer of 20 mm of soil particles over the entire area (WMO, 2005).

9.4.2 | Loss of soil organic matter

The loss of vegetative cover and decline in the level of soil organic matter (SOM) are the root cause of most soil degradation, since all the physical, chemical and biological problems follow a drop in SOM content. Soil organic matter is a key component of any terrestrial ecosystem, and any variation in its abundance and composition has important effects on many of the processes that occur within the system. The amount of organic matter and size of soil carbon stock results from an equilibrium between the inputs into the system, which are mostly from biomass detritus, and outputs from the system, largely decomposition and volatilization. These processes are driven by various parameters of natural or human origins (Schlesinger and Winkler, 2000; Amundson, 2001; Section 2.1). A decrease of organic matter in topsoil can have dramatic negative effects on the water holding capacity of the soil, on the soil structure stability and compactness, on nutrient storage and supply, and on soil biological components such as mycorrhizas and nitrogen-fixing bacteria (Sombroek, Nachtergaele and Hebel, 1993).

Direct causes of SOM decline

Apart from climatic factors that influence carbon changes in the soil, inappropriate land uses and practices are the main cause of decline in SOM. These uses and practices include: monoculture cereal production; intensive tillage; short to no fallow; and reduction or absence of crop rotation systems. The long-term effects of these management actions are now being experienced across SSA.

The SSA experience is not unique. Across the globe, the carbon balance of terrestrial ecosystems is being changed markedly by the direct impact of human activities. Land use change was responsible for 20 percent of global anthropogenic CO_2 emissions during the 1990s (IPCC, 2007). In SSA, land use change is the primary source, much of it through burning of forests.

The impact of land use change varies according to the land use types. The clearing of forests or woodlands and their conversion into farmland in tropical SSA reduces the soil carbon content mainly through reduced production of organic inputs, increased erosion rates and the accelerated decomposition of soil organic matter by oxidation. Various reviews agree that the loss amounts to 20 to 50 percent of the original carbon in the topsoil, with deeper layers less affected, if at all (Sombroek, Nachtergaele and Hebel, 1993; Murty *et al.*, 2002; Guo and Gifford, 2002). However, conversion of forests to pasture does not necessarily change soil carbon (Guo and Gifford, 2002) and may actually increase the soil organic matter content (Sombroek, Nachtergaele and Hebel, 1993). Where shifting cultivation is practiced, soil carbon has been found to reduce to half the level before the land was cleared for use (Detwiler, 1986). Surprisingly, studies suggest that commercial logging and tree harvesting do not result in long-term decreases in soil organic matter (Knoepp and Swank, 1997; Houghton *et al.*, 2001; Yanai *et al.*, 2003). Clearly many factors are at play: changes in the amount of soil organic matter following conversion of natural forests to other land uses depend on several factors such as the type of forest ecosystem undergoing change (Rhoades, Eckert and Coleman, 2000), the post conversion land management practiced, the climate (Pastor and Post, 1986) and the soil type and texture (Schjønning *et al.*, 1999).

Socio-economic causes of SOM decline

In Sub-Saharan Africa, socio-economic pressures to increase production and incomes create incentives for farmers to reduce the length of fallow periods, cultivate continuously, overgraze fields, or remove much of the above-ground biomass for fuel, animal fodder and building materials. These practices can result in the reduction of SOM, water holding capacity and nutrients. They also increase the soil's vulnerability to erosion (Lal, 2004).

Extent of SOM decline in the region

As with negative nutrient balances (see below, 9.4.3), SOM decline threatens soil productivity. In SSA, the concentration of organic carbon in the top soil is reported to average 12 mg kg^{-1} for the humid zone, 7 mg kg^{-1} for the sub-humid zone and 4 mg kg^{-1} or less in the semi-arid zone (Williams *et al.*, 1993). These inherently low concentrations of soil organic carbon are due not only to the low root growth of crops and natural vegetation but also to the rapid turnover rates of organic materials caused by high soil temperature associated with abundant micro-fauna, particularly termites (Bationo *et al.* 2003). There is considerable evidence for rapid decline in SSA of soil organic C levels where cultivation of crops is continuous (Bationo *et al.*, 1995). For sandy soils, average annual losses in soil organic C may be as high as 5 percent, whereas for sandy loam soils reported losses are much lower, averaging 2 percent (Pieri, 1989). Results from long-term soil fertility trials indicate that losses of up to 0.69 tonnes carbon ha^{-1} yr^{-1} in the soil surface layers are common in Africa, even with high levels of organic inputs (Nandwa, 2003; Bationo *et al.*, 2012).

Responses to SOM decline

Appropriate land management could reverse the trend of SOM decline and contribute to soil carbon sequestration. In fact, increasing the SOM content is crucial for future African agriculture and food production (Bationo *et al.*, 2007; Sanchez, 2000). Several studies on SSA have shown that a synergetic effect exists between mineral fertilizers and organic amendments and that this synergy leads to both higher yields and higher SOC content (Palm *et al.*, 2001, Vågen *et al.*, 2005; Bationo *et al.*, 2007).

Barnard *et al.* (2002) emphasized the importance of establishing and maintaining an effective and intimate association between soils and growing plants. Biological measures for stabilizing slopes and decreasing the rate of runoff are essential. It is often necessary to undertake some form of land shaping prior to this, together with chemical amelioration and nutrient augmentation.

There is abundant evidence that soil organic matter plays a major role in stabilizing soil and in preventing its physical, chemical and biological deterioration. This has been demonstrated under South African conditions by several scientists as reported by Barnard *et al.* (2002). For example, Folscher (1984) pointed out that micro-organisms played a vital role in the chemo-biological condition of soils. Under predominantly heterotrophic microbial activity, physical and chemical stability could be expected, while under autotrophic microbial activity, acidification and nutrient decline could be forecast. Much more attention therefore needs to be paid to the dynamic nature of soil and its physical, chemical and biological interactions.

Because nitrogen dynamics are so important in establishing a stable C:N ratio in soil, alternative sources of natural forms of nitrogen such as suitable legumes should be included in rotations. Rhizobial and mycorrhizal associations need to be stimulated and soil organic carbon and nutrient levels need to be systematically monitored and evaluated. Other soil quality indicators relating to specific situations need to be developed and utilized, with emphasis on earthworm populations as an indicator of soil quality. Reduced, minimum and no-till systems also need to be investigated and implemented where possible. These have been introduced worldwide and are being adopted in many parts of South Africa (Van der Merwe *et al.*, 2000).

Land degradation leads to a release of carbon to the atmosphere through oxidation of soil organic matter. With present concerns about climate change and the increase in atmospheric CO_2, it has been suggested that this process could be reversed and that the soil could be used to capture and store carbon. Soil organic matter could be gradually built up again through carbon sequestration. Among the land use changes which could be promoted with this objective in mind are improved agricultural practices, the introduction of agroforestry, and reclamation of degraded land. By such means, the carbon stored in soils could be substantially increased by amounts of the order of 30–50 tonnes ha^{-1}. Thus land use changes which are beneficial to local communities would, in addition, fulfil a global environmental objective.

9.4.3 | Soil nutrient depletion

Nearly 3.3 percent of agricultural gross domestic product (Agricultural GDP) in Sub-Saharan Africa is lost annually due to soil and nutrient losses (Global HarvestChoice, 2011). In Africa, harvesting grains and crop residues from the land removes considerable quantities of soil carbon content. As lost nutrients in SSA are only very partially replaced with fertilizers, these losses contribute to negative nutrient balances (Gray, 2005). As a result, soil fertility decline has been described as the single most important constraint on food production and food security in SSA. Soil fertility decline (also described as soil productivity decline) is a deterioration of chemical, physical and biological soil properties. Besides soil erosion, the main processes contributing to nutrient depletion in SSA are:

- Decline in organic matter and soil biological activity
- Degradation of soil structure and loss of other soil physical qualities
- Reduction in availability of major nutrients (N, P, K) and micro-nutrients
- Increase in toxicity, due to acidification or pollution

In the first assessment of the state of nutrient depletion in SSA, which was carried out in 1990, nutrient balances were calculated for the arable lands of 38 countries across the continent. Four classes of nutrient-loss rates were established (Table 9.2). As discussed above (9.3.3), the average nutrient loss in 1990 was estimated to be 24 kg nutrients ha^{-1} per year (10 kg N; 4 kg P_2O_5, 10 kg K_2O). Countries with the highest depletion rates, such as Kenya and Ethiopia (Table 9.3), also have severe soil erosion.

Table 9.2 | Classes of nutrient loss rate (kg ha^{-1} yr^{-1}). Source: Stoorvogel and Smaling, 1990.

Class	Low	Moderate	High	Very High
N	<10	10-40	21-40	>40
P_2O_5	<4	4-7	8-15	>15
K_2O	<10	10-40	21-40	>40

Direct causes of nutrient decline

Fertility decline is caused by a negative balance between output (harvesting, burning, leaching, and so on) and input of nutrients and organic matter (manure/fertilizers, returned crop residues, mineral deposition through flooding). The estimate of nutrient depletion in SSA cited above is worrying. However, some scientists (Roy *et al.*, 2003) have expressed concern about the approach used, as it is based on approximation and aggregation at country level which could be misleading, masking the 'bright' spots and the 'hot' spots where urgent nutrient replenishment is required. Assessment of fertility decline at micro-watershed or community level would be more appropriate.

Socio-economic causes of nutrient decline

There are various factors that indirectly influence nutrient depletion in SSA and they vary between ecological regions and amongst countries and locations within a given ecological region. The cost of buying mineral fertilizer can put it beyond the reach of many SSA smallholders (World Bank, 1998). Farm-level fertilizer prices in Africa are among the highest in the world (Bationo *et al.* 2012). One metric tonne of urea, for example, costs about US$ 90 in Europe, US$ 500 in Western Kenya and US$ 700 in Malawi. These high prices can be attributed to the removal of subsidies, high transaction costs, poor infrastructure, and poor market development, inadequate access to foreign exchange and credit facilities, transportation costs and lack of training to promote and utilize fertilizers. For example, it costs about US$ 15, US$ 30 and US$ 100 to move 1 tonne of fertilizer 1 000 km in the United States, India and SSA respectively (Bationo *et al.*, 2012).

Many farmers do not follow recommended fertilizer application rates because of cash or labour constraints. In much of Southern and Western Africa there is a dry season lasting 7 to 8 months. In the first weeks of the rainy season many farm operations such as planting, weeding, and fertilizing must take place in rapid succession. Farmers who weed maize twice at critical periods can achieve a higher yield with half the amount of fertilizer used by farmers who only weed once (Kabambe and Kumwenda, 1995), but many farmers do not have sufficient labour to weed more often.

Output price instability is an important factor posing risks for fertilizer users in Western Africa (Byerlee *et al.*, 1994). When markets are sparse, as they are in many rural areas dominated by subsistence production, the variations in market prices of crops tend to be wider than in regions where markets are more fully developed. Overall, the economics of fertilizer use are often not sufficiently positive, especially under rainfed conditions; farmers are cash-poor and so cannot buy expensive inputs; and farmers are highly averse to making cash outlays in unpredictable climatic conditions and with uncertain commercial returns.

Extent of nutrient decline in the region

The results of an FAO study (1983-2000) (Lesschen *et al.*, 2003; Stoorvogel and Smaling, 1990) which assessed N, P and K balances by land use system and by country revealed a generally downward trend in soil fertility in Africa. Overall, the study suggests that all African countries except Mauritius, Reunion and Libya show negative nutrient balances every year. The result for 2000 showed a deteriorating nutrient balance for almost all countries. This was influenced by the FAO estimates for crop production in 2000 and an accompanying expected decrease in fallow areas. For SSA as a whole, the nutrient balances were: -22 kg ha^{-1} in 1983 and -26 kg ha^{-1} in 2000 for N; -2.5 kg ha^{-1} in 1983 and -3.0 in 2000 for P; and -15 kg ha^{-1} in 1983 and -19 kg ha^{-1} in 2000 for K.

Table 9.3 lists nutrient balances for several SSA countries. The study found substantial differences between countries. In 1993-1995 the difference between nutrient inputs and nutrient losses in the continent ranged from -14 kg of NPK per ha per year in South Africa to 136 kg in Rwanda. Burundi and Malawi also experienced rates of nutrient depletion above 100 kg of NPK per ha per year.

Densely populated and hilly countries in the Rift Valley area (Kenya, Ethiopia, Rwanda and Malawi) had the most negative values, owing to high ratios of cultivated land to total arable land, relatively high crop yields, and significant erosion problems. In the semiarid, arid, and Sudano-Sahelian areas that are more densely populated, soils were found to lose 60-100 kg of nitrogen, phosphorus, and potassium (NPK) per ha each year. The soils of these areas are shallow, highly weathered, and subject to intensive cultivation with low-level fertilizer use.

Short growing seasons contribute to additional pressure on the land. In important agricultural areas in the sub-humid and humid regions and in the savannas and forest areas, nutrient losses vary greatly. Rates of nutrient depletion range from moderate (30 - 60 kg of NPK per ha per year) in the humid forests and wetlands in southern Central Africa, to high (> 60 kg NPK per ha per year) in the East African highlands.

More countries fall into the high depletion range than the medium range. Nutrient imbalances are highest where fertilizer use is particularly low and nutrient loss, mainly from soil erosion, is high. The low gains in nutrients, inherently low mineral stocks in these soils, and the harsh climate of the interior plains and plateaus aggravate the consequences of nutrient depletion. The estimated net annual losses of nutrients vary considerably by sub-region: 384 800 metric tonnes for North Africa, 110 900 metric tonnes for South Africa, and 7 629 900 metric tonnes for Sub-Saharan Africa as a whole. This represents a total loss of US$ 1.5 billion per year in terms of the cost of nutrients as fertilizers.

Table 9.3 | Estimated nutrient balance in some SSA countries in 1982-84 and forecasts for 2000.
Source: Stoorvogel and Smaling, 1990; Roy et al., 2003.

Country	N		P		K	
	1982-84	2000	1982-84	2000	1982-84	2000
	(kg ha^{-1} yr^{-1})					
Benin	-14	-16	-1	-2	-9	-11
Botswana	0	-2	1	0	0	-2
Cameroon	-20	-21	-2	-2	-12	-13
Ethiopia	-41	-47	-6	-7	-26	-32
Ghana	-30	-35	-3	-4	-17	-20
Kenya	-42	-46	-3	-1	-29	-36
Malawi	-68	-67	-10	-10	-44	-48
Mali	-8	-11	-1	-2	-7	-10
Nigeria	-34	-37	-4	-4	-24	-31
Rwanda	-54	-60	-9	-11	-47	-61
Senegal	-12	-16	-2	-2	-10	-14
United Republic of Tanzania	-27	-32	-4	-5	-18	-21
Zimbabwe	-31	-27	-2	2	-22	-26

More nitrogen and potassium than phosphorus get depleted from African soils. Nitrogen and potassium losses primarily arise from leaching and soil erosion. These soil problems result mainly from continuous cropping of cereals without rotation with legumes, inappropriate soil conservation practices, and inadequate amounts of fertilizer use. Among West African countries, Guinea Bissau and Nigeria experience the highest annual losses of nitrogen and potassium. Nitrogen loss in East Africa is highest in Burundi, Ethiopia, Malawi, Rwanda, and Uganda, and phosphorus loss is highest in Burundi, Malawi, and Rwanda (IFPRI, 1999).

Responses to nutrient decline

The negative nutrient balances clearly indicate that not enough nutrients are being applied in most areas (Bationo *et al.*, 2012). Annual application of nutrients in SSA averages about 10 kg of NPK per ha. Fertilizer tends to be used mostly on cash and plantation crops because of the higher profitability of fertilizer application in the production of cash crops. Food crops receive less fertilizer because of unfavourable crop/fertilizer price ratios and financial constraints faced by farmers. In addition, food crops are only partly commercialized.

To maintain current average levels of crop production without depleting soil nutrients, Africa as a whole (including North Africa) would require approximately 11.7 million metric tonnes of NPK each year, roughly three times more than the continent currently uses (3.6 million metric tonnes) (Henao and Baanante, 1999). Of this quantity, Sub-Saharan Africa would need by far the largest proportion (76 percent) because the current average level of fertilizer use is so low. Total nutrient requirements per ha per year range from Botswana's 24.5 kg ha^{-1} NPK (a figure 350 percent above current usage) to Reunion's 437.3 kg ha^{-1}NPK (about 20 NPK per ha less than the country consumes). Burkina Faso would have to increase its NPK consumption more than 11 times to maintain crop production levels without depleting nutrients and Swaziland would have to double its consumption. Estimated average use for SSA as a whole would have to increase about 4 times to meet nutrient needs at the current level of production. Generally, more nitrogen is required than potassium, and more potassium than phosphorus.

9.5.1 | Senegal

Introduction

The main objective of the national land resources assessment undertaken in Senegal between 2000 and 2010 was to identify for each land use system the status and trends of land degradation and the major sustainable land management interventions present in the country. This assessment used national and local technical expertise, including that of the land users themselves. The findings have been reported in several documents, maps and web-sites (Ndiaye and Dieng, 2013).

The methodology was based on the premise that land degradation is largely driven by the way people use the environment in which they live. The level of degradation or sustainable use of a given land resource depends to a great extent on the needs and objectives of the land user, which are limited by technical knowledge and level of access to production factors (capital, labour etc.). Choices about land use take place within an integrated production system (Jouve, 1992). Consequently, defining the units in which both degradation and sustainable land management are to be described requires the identification of areas with similar geographic characteristics and then the mapping of the different production or land use systems. In Senegal this mapping was carried out using the 'Framework for characterization and mapping of agricultural land use' (George and Petri, 2006).

In Senegal the following major land use systems were identified and characterized:

1. Aquaculture and fishing, which takes place in areas covered with mangrove and other aquatic vegetation that are regularly flooded.
2. Rainfed subsistence agriculture, which is characterized by the absence of livestock and minimal use of inputs.
3. Agropastoral systems, characterized by a significant presence of rainfed agriculture but with greater levels of livestock activity. These systems are located in areas that receive between 400 and 700 mm of rainfall.
4. Riverbank agriculture, characterized by the use of receding floodwaters to produce crops.
5. Irrigated agriculture, characterized by intensive management and relatively high use of inputs.
6. Forest based systems that exploit trees for timber.
7. Conservation areas that are protected to preserve biodiversity
8. Peri-urban agriculture, characterised by a mix of activities aimed at producing high-value products close to urban markets.
9. Nomadic grazing, which takes place in the driest areas of the country and is characterized by shifting livestock and no permanent agriculture.

The distribution of these land use systems and their extent within the country are given in Figures 9.5 and 9.6 respectively.

The national assessment of land degradation and sustainable management was carried out using available hard data and a questionnaire developed by FAO in collaboration with WOCAT (Liniger *et al.*, 2011). The evaluation describes the actual situation and assesses the trends of land change over the last ten years. The method used local observations and measurements and expert opinion and covered the whole of Senegal. It has achieved the identification and characterization of land change in terms of degradation types, their extent, degree, level, trend, causes and impacts on ecosystem services. Each of these parameters has been mapped and examples are given in Figure 9.7 (extent of dominant degradation type) and Figure 9.8 (rate of change of degradation). All information collected has been captured in a national database and analysed statistically (SOW-VU, 2010).

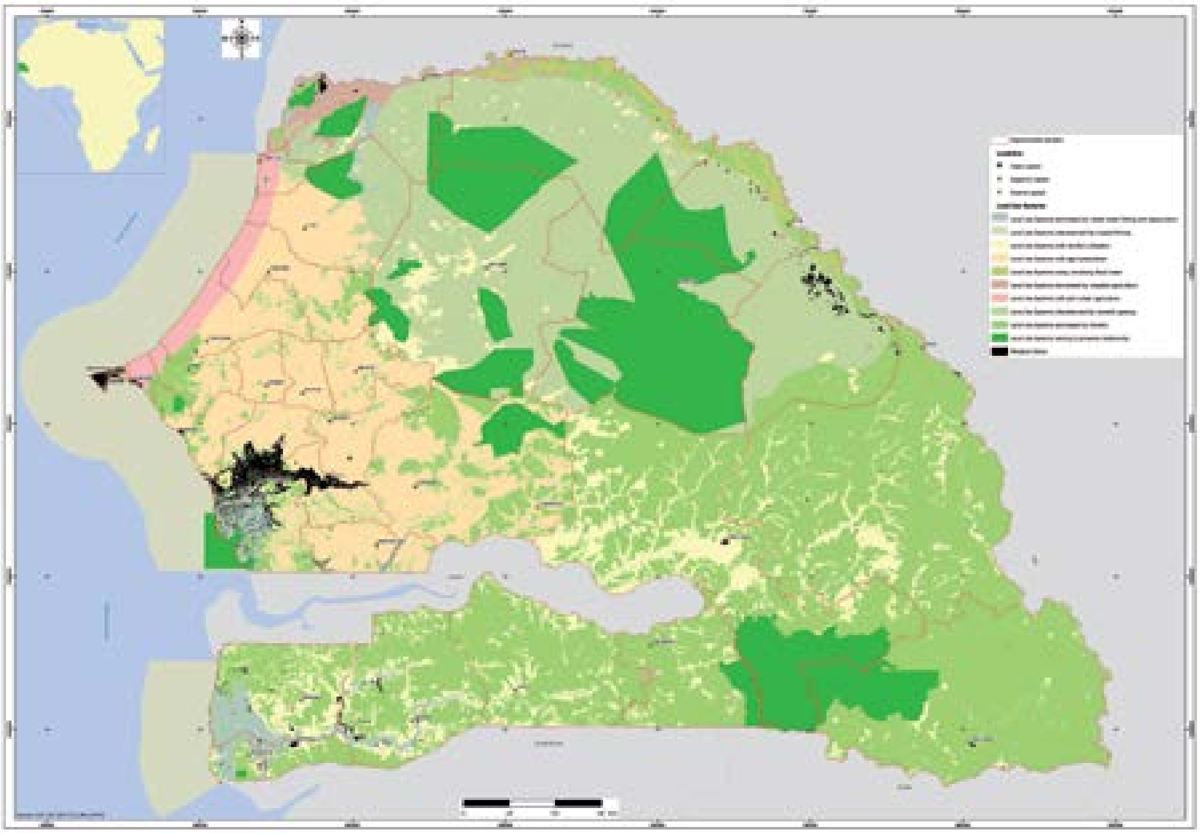

Figure 9.5 | Major land use systems in Senegal.
Source: FAO, 2010.

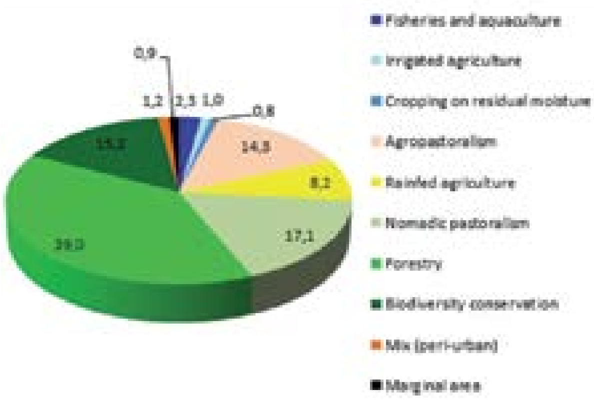

Figure 9.6 | Proportional extent of major land use systems in the Senegal.
Source: Ndiaye and Dieng, 2013.

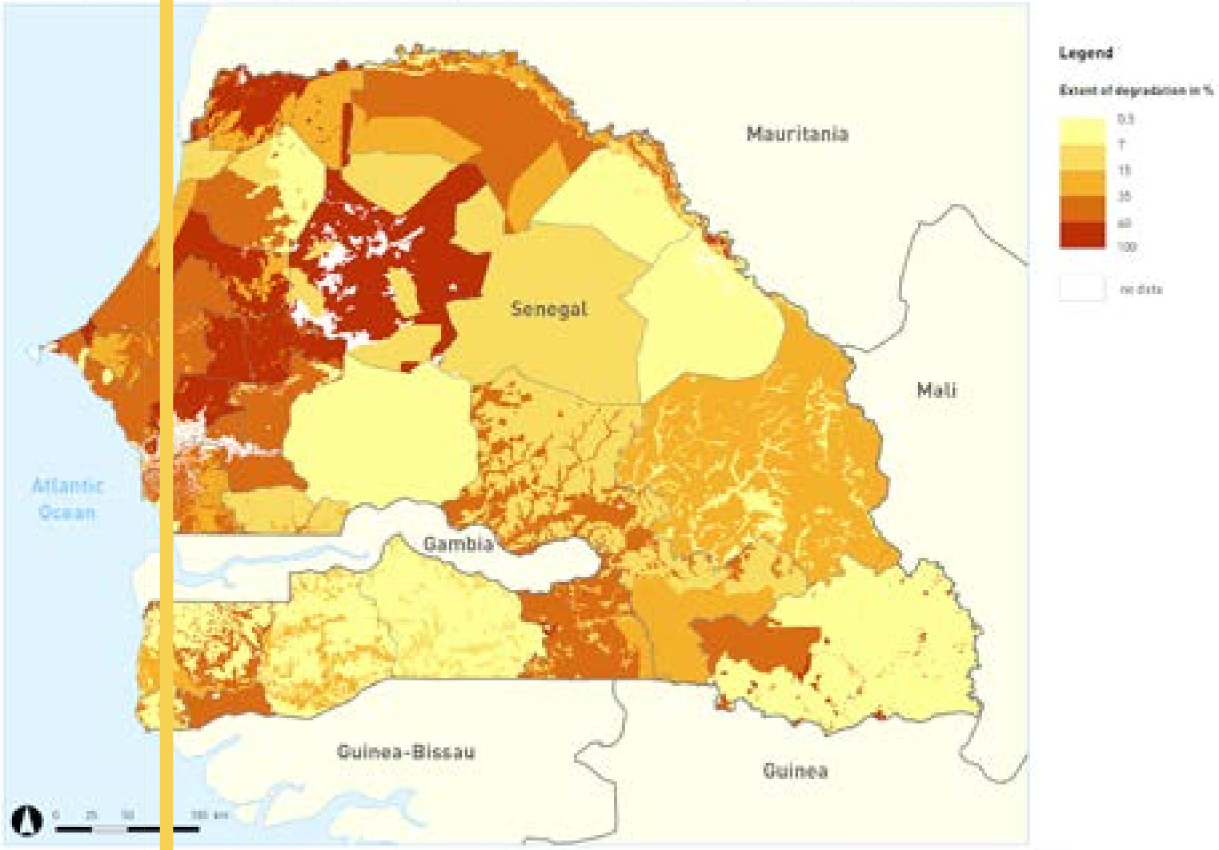

Figure 9.7 | Extent of dominant degradation type in Senegal.
Source: FAO, 2010.

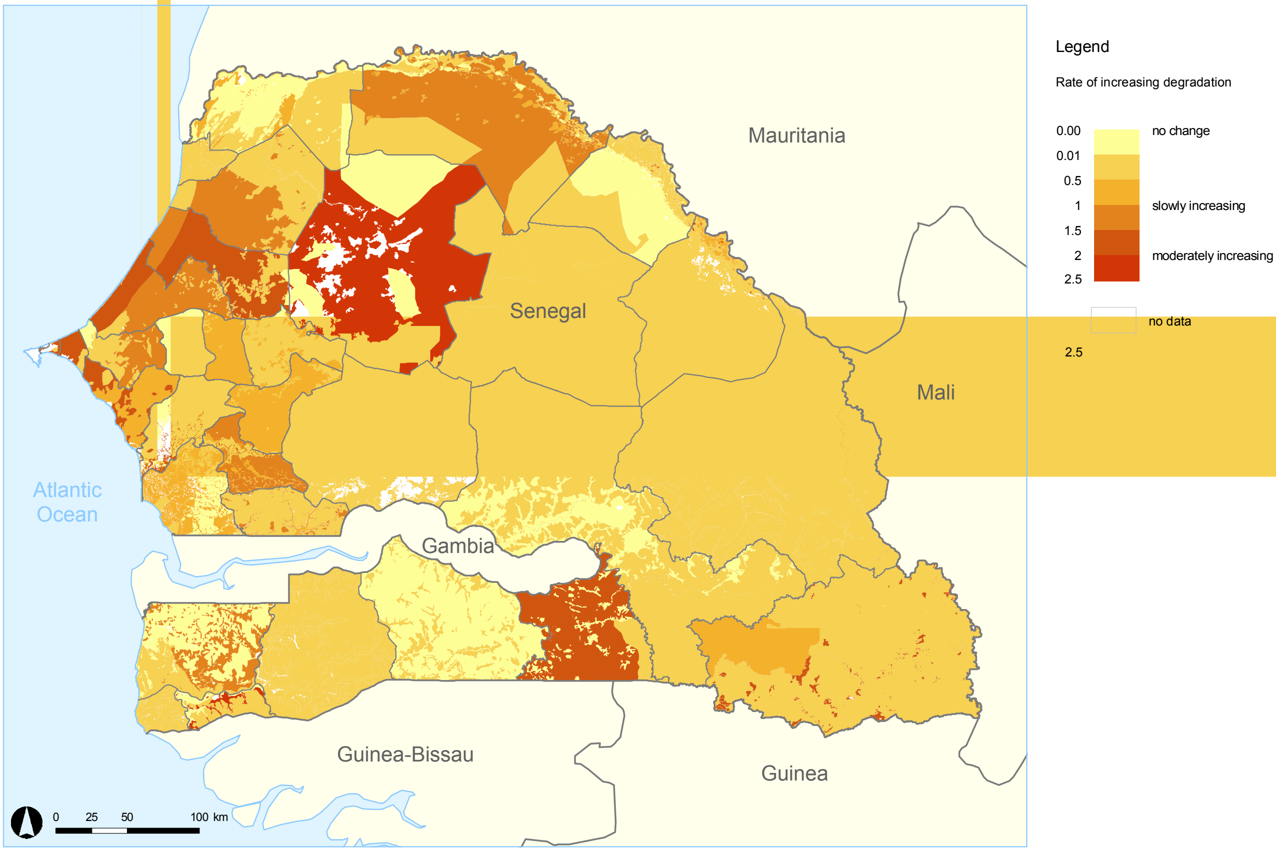

Figure 9.8 | Average rate of degradation in Senegal.
Source: FAO, 2010.

Some examples of analysis of the data show the value of the national assessment:

1. The analysis of the socio-economic drivers of land degradation in the country showed that poverty and population pressure are the main drivers, while governance and education are also significant. Land tenure and conflict situations were reported to be of minor importance as drivers of land degradation in Senegal.
2. It is population pressure and poverty which lead in a majority of cases to deforestation and overgrazing and which, together with lack of access to extension services, lead to unsustainable soil and crop management. Urbanisation and mining are minor pressures in the country.
3. Impacts of land degradation on ecosystem goods and services fell mainly on the productive services (affecting 15 percent of the area), while impacts on ecological services, in particular on biodiversity, were slightly less (13 percent). The influence on the socio-cultural provisioning services was the smallest, affecting only 6 percent of the area.
4.

Further field and socio-economic studies were undertaken at the local level, both in areas that were considered 'hotspots' for degradation and in 'bright spots' where degradation was less prevalent and sustainable management was practiced.

The analysis of results in these local areas is illustrated in Figure 9.9 which gives the impact of degradation on the various ecosystem services. There is a major impact on the net returns of the farmers in all areas, but there are also important differences according to the different situations in each zone.

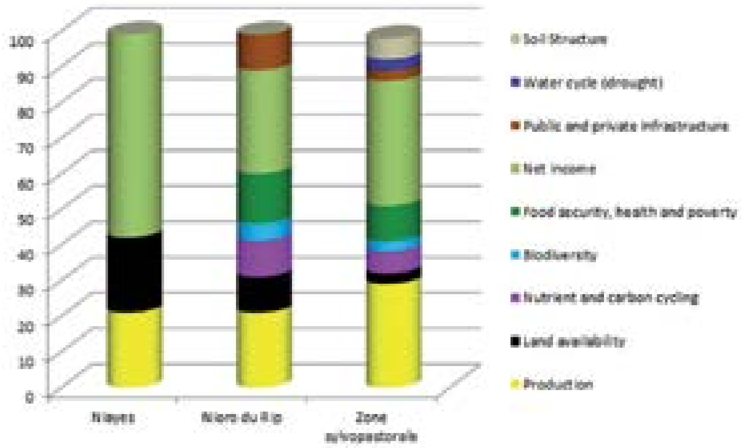

Figure 9.9 | Impact of degradation on ecosystem services in the local study areas in Senegal. Source: Ndiaye and Dieng, 2013.

Responses have included measures implemented by the government, NGOs, the communities themselves and local producers. The principal responses were: assisted natural regeneration, agro-forestry, application of organic amendments, introduction or extension of fallow periods, composting, and using a millet/groundnut rotation. Most of these responses have proved to be efficient, but their adoption by land users has been slow, affected by lack of information and by economic and/or political constraints.

9.5.2 | South Africa

Of South Africa's total area of 123.4 million ha, arable land accounts for only 11-15 percent. Of this arable land, only about a quarter is high potential. This high potential land is thus a critical resource which needs to be protected. South Africa's soils are diverse and complex as a result of varied soil formation and weathering processes. The largest proportion (81 percent) are slightly weathered and calcareous soils. More than 30 percent of soils are sandy (e.g. less than 10 percent clay content) and almost 60 percent of soils have low organic matter content (Scotney, Volschenk and Van Heerden, 1990). The most important soil limitations are shallow depth, extremes of texture, rockiness, severe wetness and high erosion hazard. In terms of soil management, it is important to note that agriculture in South Africa has a dualistic nature, with a well-developed commercial sector on the one hand, and a predominantly subsistence or small-scale agricultural sector in communal areas on the other.

The first, and to date only, nationwide study of soil distribution was done by the Land Type Survey Staff (2003) from 1970 to 2003. The study delineated areas known as 'land types' at 1:250 000 scale - land types were defined as areas displaying a marked degree of uniformity in terms of terrain form, soil pattern and climate. The study included an in-depth analysis of a number of soil profiles, termed modal profiles, selected to represent the range of soils encountered during the survey. Soils from 2 380 profiles across the country were described and analysed for morphological and chemical data and classified according to the binomial classification system developed for South Africa (MacVicar *et al.*, 1977). Each land type includes a collection of soils and their relative distribution in terms of area per landscape position, as well as their characteristics in terms of physical and chemical properties. The resultant national map of broad soil patterns is shown in Figure 9.10.

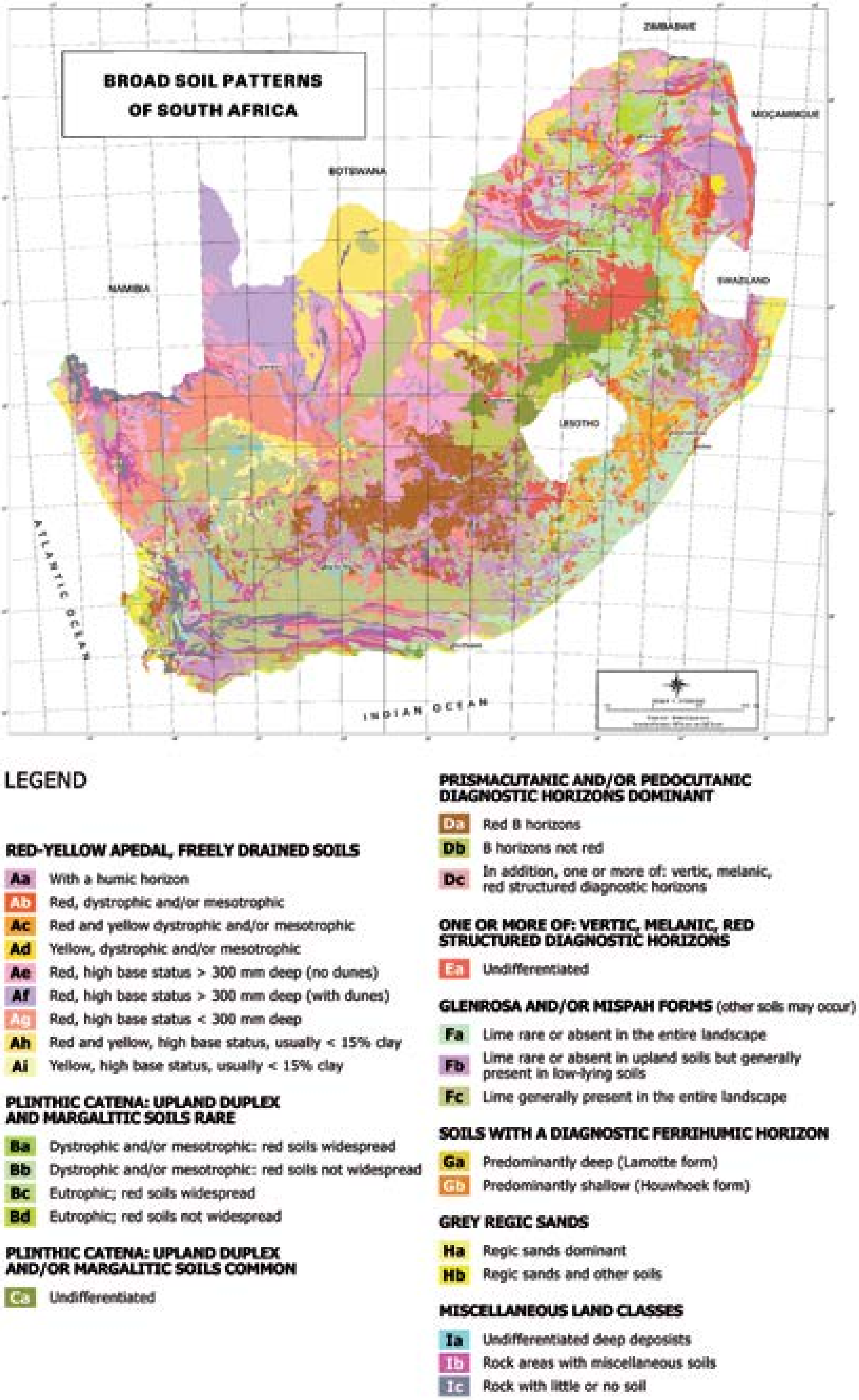

Figure 9.10 | Broad soil patterns of South Africa.
Source: Land Type Survey Staff, 2003.

From 2006, several further national studies were conducted to assess the status of soils, land use trends, land degradation and sustainable land management implementation in the country. Results are summarized in this section. There is much evidence of mismanagement of soil resources which has led to widespread erosion by both wind and water, loss of soil fertility, compaction and acidification.

National land degradation assessment

Since land use is considered the single most important driver of land (and soil) degradation, land degradation assessments were conducted based on land use categories. For this purpose, a national stratification map was developed for South Africa based on amendments to the Land Use System Approach as described by Nachtergaele and Petri (2008) as well as by Pretorius (2009). On this basis, the stratification map adopted the following 18 land use categories:

- Desert
- Azonal vegetation
- Savanna
- Forest
- Grassland
- Nama-Karoo
- Indian Ocean Coastal Belt
- Succulent Karoo
- Fynbos
- Albany Thicket
- Open Water
- Urban
- Cultivated – commercial – rain-fed
- Cultivated – irrigated
- Cultivated – subsistence – rain-fed
- Plantations
- Mines
- Protected areas

By integrating the local municipality boundaries with those of land use, a total of 2 447 unique units were derived for further assessment, as illustrated in Figure 9.11. Land degradation and sustainable land management implementation were then assessed in each of the 2 447 mapping units. The assessment was carried out from 2008 to 2010 and was based on a participatory approach as part of a Land Degradation Assessment in Drylands (LADA) project. The approach relied strongly on the inputs from a range of experienced contributing specialists and land users who were conversant with the areas to be assessed. Data capturing was done through a series of 33 Participatory Expert Assessment (PEA) Workshops throughout the country, involving 728 contributing specialists (Wiese, Lindeque and Villiers, 2011).

In terms of soil, the main forms of degradation at national level were soil erosion by water, biological degradation and chemical soil degradation. For soil erosion, sheet and gully erosion were considered the most serious threats, with river or stream bank erosion and off-site sedimentation considered less critical. Soil acidification and salinization were also highlighted, although their occurrence was more localized and area-specific.

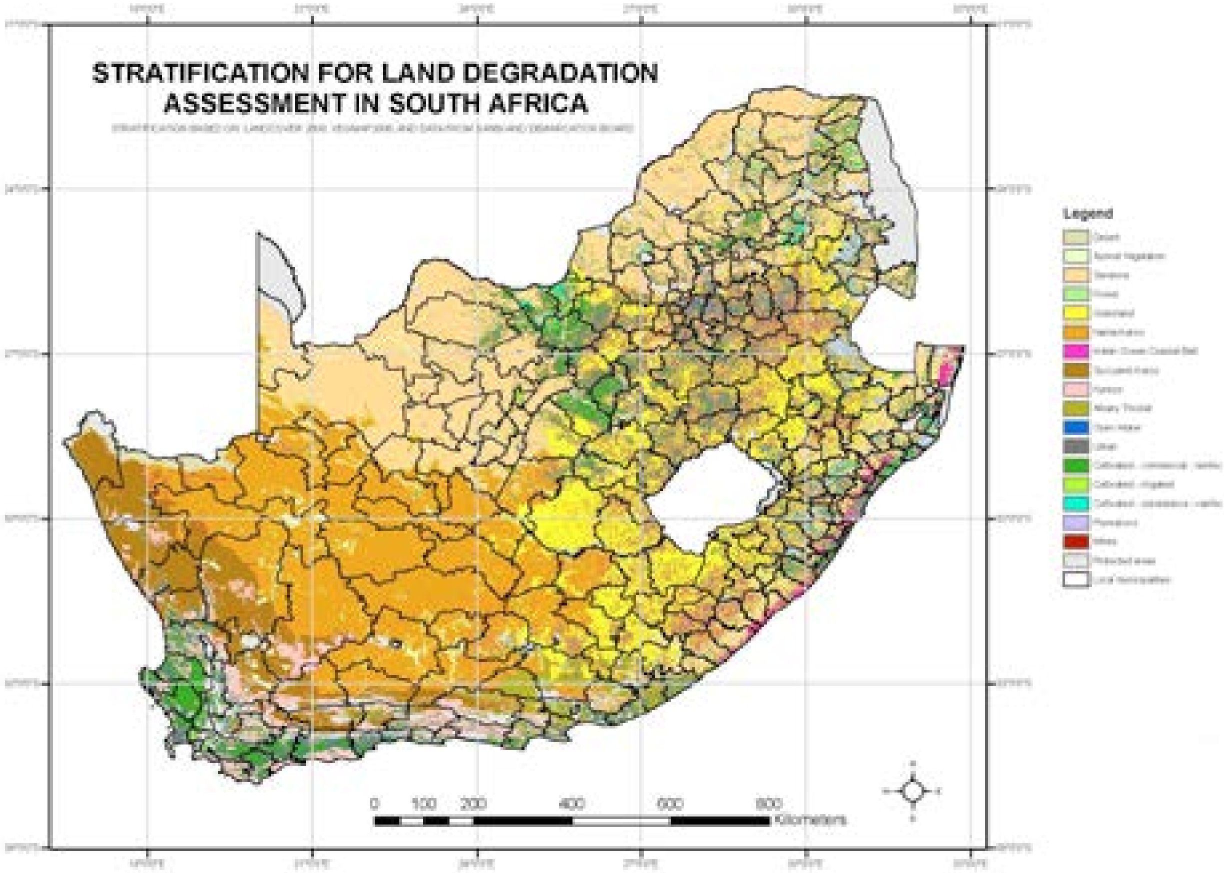

Figure 9.11 | The national stratification used for land degradation assessment in South Africa, incorporating local municipality boundaries with 18 land use classes.
Source: Pretorius, 2009.

Erosion assessment

A separate spatial study was conducted on the extent of gully erosion in South Africa (Le Roux *et al.*, 2008). The study also assessed national erosion potential in terms of soils, climate and topography (Le Roux, 2012). The assessment of water erosion susceptibility indicated that around 20 percent (26 million ha) of the country is classified as having a moderate to severe erosion risk (mainly based on sheet-rill erosion). The affected areas are concentrated in the south-eastern and north-eastern interior, mainly in the Eastern Cape, KwaZulu-Natal, Mpumalanga and Limpopo Provinces. All of these areas are characterized by a combination of high (often intense) rainfall, duplex soils derived from sodium-rich parent materials, and steep slopes (see Figure 9.12). These natural conditions are often exacerbated by poor land use practices, such as incorrect cultivation methods, overgrazing by livestock and high population density. Under such circumstances, potential soil loss can easily be in the 'Very High' class of more than 50 tonnes ha^{-1} yr^{-1} (Le Roux *et al.*, 2006).

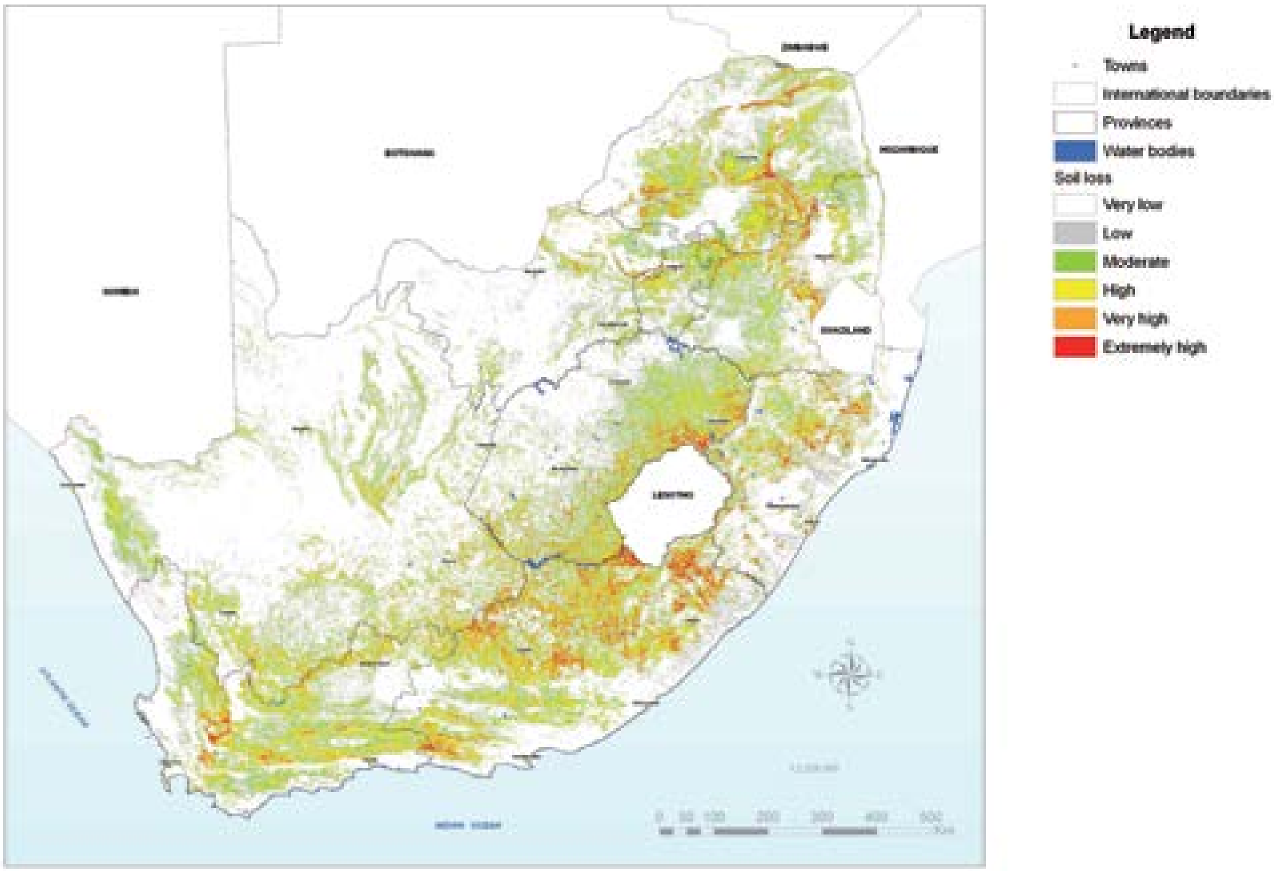

Figure 9.12 | Actual water erosion prediction map of South Africa.
Source: Le Roux et al., 2012.

The erosion process starts when the vegetation cover is disturbed or removed, allowing the rainfall to impact directly on bare soil. If measures to restrict surface run-off are not put in place, the effect is generally two-fold: firstly, the water flowing on the soil surface removes a significant amount of topsoil ('sediment'), especially on steeper slopes; and secondly, the duplex nature of the soils (sandy topsoil abruptly overlying a structured clay subsoil) results in the formation of a surface seal. As a result, very little water is actually able to infiltrate the soil. Research in South Africa (Levy, 1988; Rapp, 1998; Bloem, 1992) indicated that exchangeable sodium percentage (ESP) values play an important role in erosion risk, with problematic values being over 12, although values as low as 5 or 6 (Bloem and Laker, 1994; Laker and D'Huyvetter, 1988) can also cause erosion under poor land use conditions.

Combating soil erosion by water remains a huge challenge in many affected areas of the country due to a combination of lack of resources, poor knowledge or awareness and poor infrastructure, mainly roads. The challenges of treating erosion and the more difficult task of rehabilitating large areas of land, combined with the off-site effects such as silting up of dams, together pose one of the most serious soil management challenges in South Africa today.

Soil nutrient depletion, acidity and organic matter

Although soil erosion by water was confirmed as the main soil degradation type in the country, there are areas in South Africa affected by wind erosion, nutrient depletion, loss of organic matter, soil acidity, salinity and sodicity as well as pollution from mining and industrial sources. Desktop assessments of soil nutrient depletion, acidity and organic matter in South Africa were conducted during 2007-2008 (Beukes, Stronkhorst and Jezile, 2008a,b; Du Preez *et al.*, 2010; Du Preez *et al.*, 2011a,b; Rantoa, Du Preez and Van Huyssteen, 2009).

Nutrient depletion and acidity

A multitude of soil nutrient and acidity studies have been conducted over time in South Africa (Bierman, 2001; Bloem, 2002; Buhmann, Beukes and Turner, 2006; Conradie, 1994; Eweg, 2004; Farina, Manson and Johnston, 1993; Mandiringana *et al.*, 2005; Meyer *et al.*, 1998; Miles and Manson, 2000; Thibaud, 2005). These studies included extensive reviews of international and national documentation, interviews with experts from various national and provincial institutions, and processing of data available from a number of national databases and soil analytical laboratories. Detailed results have been reported for each of the nine provinces in South Africa, but only a national summary is presented here (Beukes, Stronkhorst and Jezile, 2008a,b) with a focus on the agricultural sector.

The impact of the dualistic nature of South African agriculture on soil nutrient depletion was clearly evident, with soils from the **resource-poor/small-scale/upcoming** farmers generally being acidified, severely P depleted, and N, K, Ca and Mg deficient (Manson, 1996; Beukes, Stronkhorst and Jezile, 2008b). Within this group, two sub-groups can be distinguished, as these farmers produce crops at two levels. The first sub-group is the home garden where relatively high fertility levels are evident. This is mainly because these gardens are located next to the homesteads and are therefore easier to manage. The second sub-group consists of crop fields which are larger and further from the homesteads. As a result, these fields are less secure in terms of livestock access and there are transport constraints. In addition, most smallholder farmers are risk-averse due to their limited resources. These fields are therefore generally severely nutrient depleted, especially in terms of P and K deficiencies, while N, Mg and Ca deficiencies are also often noted.

By contrast, **commercial agriculture** operates on a much larger scale and higher levels of management and inputs are maintained on these farms to ensure higher productivity. This is especially the case in the sugar, vine and fruit farming sectors due to higher costs for crop establishment and maintenance. Soils in the commercial sector generally exhibit P deficiency as the main nutrient concern, with K deficiency also occurring in many areas. Commercial pastures may have fewer deficiencies: for example in KwaZulu-Natal, P deficiency is almost negligible and K, Ca and Mg appear well supplied (Beukes, Stronkhorst and Jezile, 2008b).

Naturally occurring acid soils are generally associated with high rainfall areas and certain geological materials which, in South Africa, are located in the western and southern Cape coastal belts, KwaZulu-Natal, Mpumalanga and Limpopo Province (see Figure 9.13). The extent of anthropogenic soil acidity in the country is not easy to estimate, but general trends can be observed. In the winter rainfall region, approximately 560 000 ha is under cultivation, and on 60 percent of this area soils indicate problems with acidity. In Kwa-Zulu-Natal, roughly 35 percent of the more than 660 000 ha of cultivated soils have acid saturation values above 15 percent. In the summer rainfall area west of the Drakensberg, 37 percent of topsoils in the cropped area are acidified (Beukes, 1995).

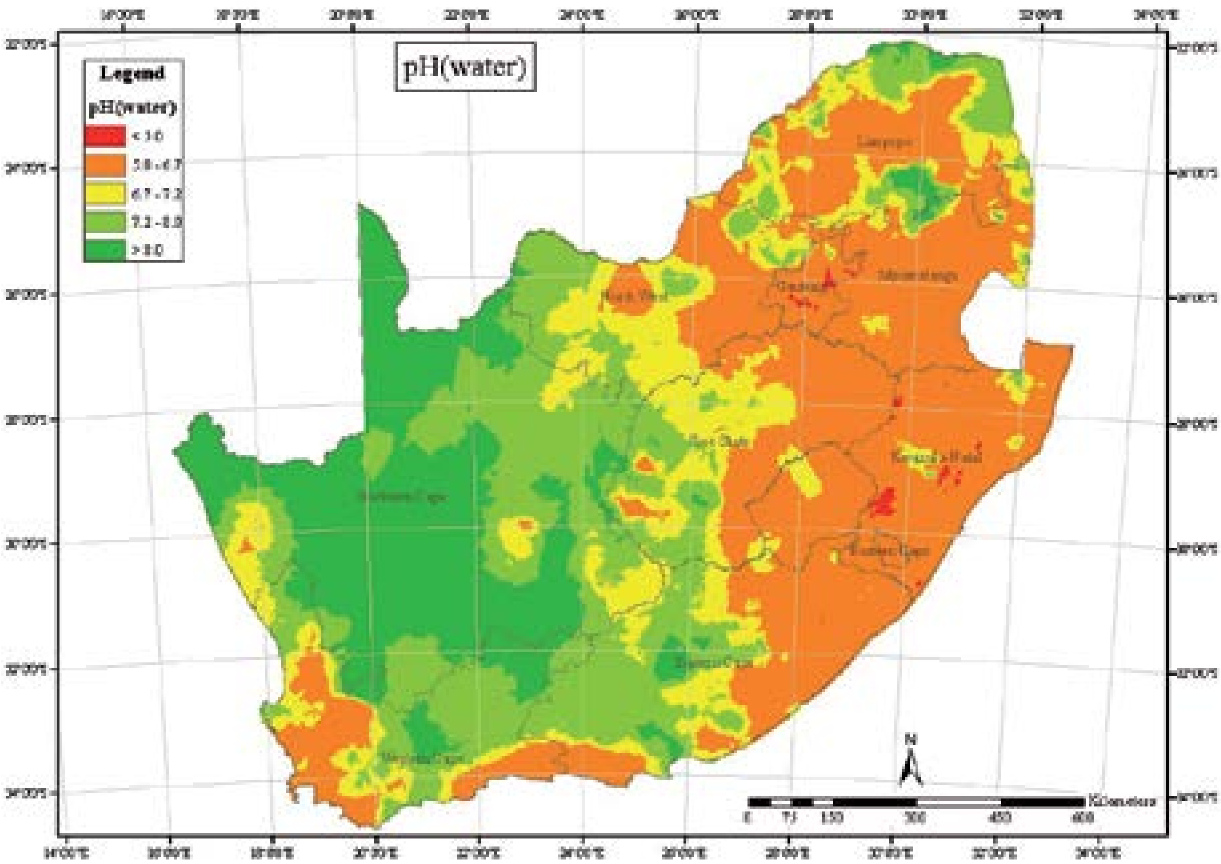

Figure 9.13 | Topsoil pH derived from undisturbed (natural) soils.
Source: Beukes, Stronkhorst and Jezile, 2008a.

Soil organic matter

Although data on soil organic carbon in South Africa are limited, fragmented and uncoordinated, general trends of SOC content can be derived from a range of studies conducted (Barnard *et al.*, 2000; McKean, 1993, Du Toit and Du Preez, 1993, Le Roux *et al.*, 2005; Mills and Fey, 2004; Prinsloo, Willshire and Du Proez, 1990; Van Antwerpen and Meyer, 1996; Birru, 2002; Du Preez, Mnkeni and Van Huyssteen, 2010, 2011a, b). A review of SOC research estimated that approximately 58 percent of South African soils contain < 0.5 percent organic C, 38 percent contain 0.5–2 percent organic C and 4 percent have > 2 percent organic C. These organic C contents vary greatly as a function of soil types, climate, vegetation, topography and soil texture, and are greatly influenced by management practices which result in organic C losses such as overgrazing, high levels of soil disturbance during cultivation, and the use of fire in rangeland management. Soil organic matter losses were generally associated with dryland cropping, but were less prevalent in irrigated agriculture. Increasing SOM is a slow process, but it has been achieved by implementing zero/minimum tillage, by mulching and through reversion of cropland to perennial pastures. Increases have mainly occurred in the upper 300 mm of soil, and in most instances, have been restricted to the upper 50 mm of soil.

Loss of SOM has been found to result in lower nitrogen and sulphur reserves, but not necessarily in lower phosphorus reserves. Loss of SOM also coincided with changes in the composition of amino sugars, amino acids and lignin. It further resulted in a decline of water stable aggregates which are essential in the prevention of soil erosion.

Rantoa, Du Preez and Van Huyssteen, (2009) used data from the approximately 2 200 modal profiles from the land type survey to estimate organic carbon stocks in South African soils with reference to master horizons, diagnostic horizons, soil forms and land cover classes. In summary, the average organic carbon content in the master horizons ranges from 16 percent in the O horizon to 0.3 percent in the C horizons. In the diagnostic horizons, the highest average organic C in topsoils ranged from 21 percent in the O horizons to 1.4 percent in the orthic A horizons. In the diagnostic subsoil horizons, however, values ranged from 1.2 percent in podzol B to 0.2 percent in the dorbank horizons.

Land Cover Change Assessment

Land use trends give an indication of land conversion from one land use to another, which directly affects soil use properties as a function of management. A study of land-cover change was conducted in 2010 based on land-cover data from 1994/1995, 2000 and 2005 employing a cost-effective approach which used Earth Observation data. The study was based on changes in five land-cover classes: urban, mining, forestry, cultivation, and other. These five classes are defined in Table 9.4 (Schoeman *et al.*, 2010).

Table 9.4 | Definitions of the five land-cover classes on which the land-cover change study was based. Source: Schoeman et al., 2010.

Land-cover class	Class definition
Urban	Human settlements, both rural and urban
Mining	Areas covered by mining and related mining activities (also includes mine dumps)
Forestry and plantations	All forestry and plantations including woodlots and clear fell areas (excludes indigenous natural forests)
Cultivation	All areas used for agricultural activities, including old fields and subsistence agriculture
Other	All other areas not covered by those listed above

The land-cover change results (Figure 9.14) indicated that at national level there was a total increase of 1.2 percent in transformed land, specifically associated with Urban, Cultivation, Forestry & Plantation and Mining. This represents an increase from 14.5 percent transformed land in 1994 to 15.7 percent in 2005 across South Africa. On a national basis the areas of Urban, Forestry & Plantation, and Mining have all increased over the 10-year period, whereas Cultivation areas have decreased. Urban has increased from 0.8 percent to 2 percent, Forestry & Plantation from 1.2 percent to 1.6 percent, and Mining from 0.1 percent to 0.2 percent, while Cultivation has decreased from 12.4 percent to 11.9 percent. The spatial patterns do, however, vary geographically across provinces in South Africa.

The increase in urban and mining areas are the biggest concern in terms of soil conservation and future use since urban development involves soil sealing which irreversibly removes soils from other land uses, while mining results in serious chemical and physical soil degradation which can only be restored to a limited extent. For this reason, it is essential that soil suitability and potential for agricultural and environmental purposes be assessed in order to ensure that the high potential and environmentally important soils are reserved and conserved for food production purposes.

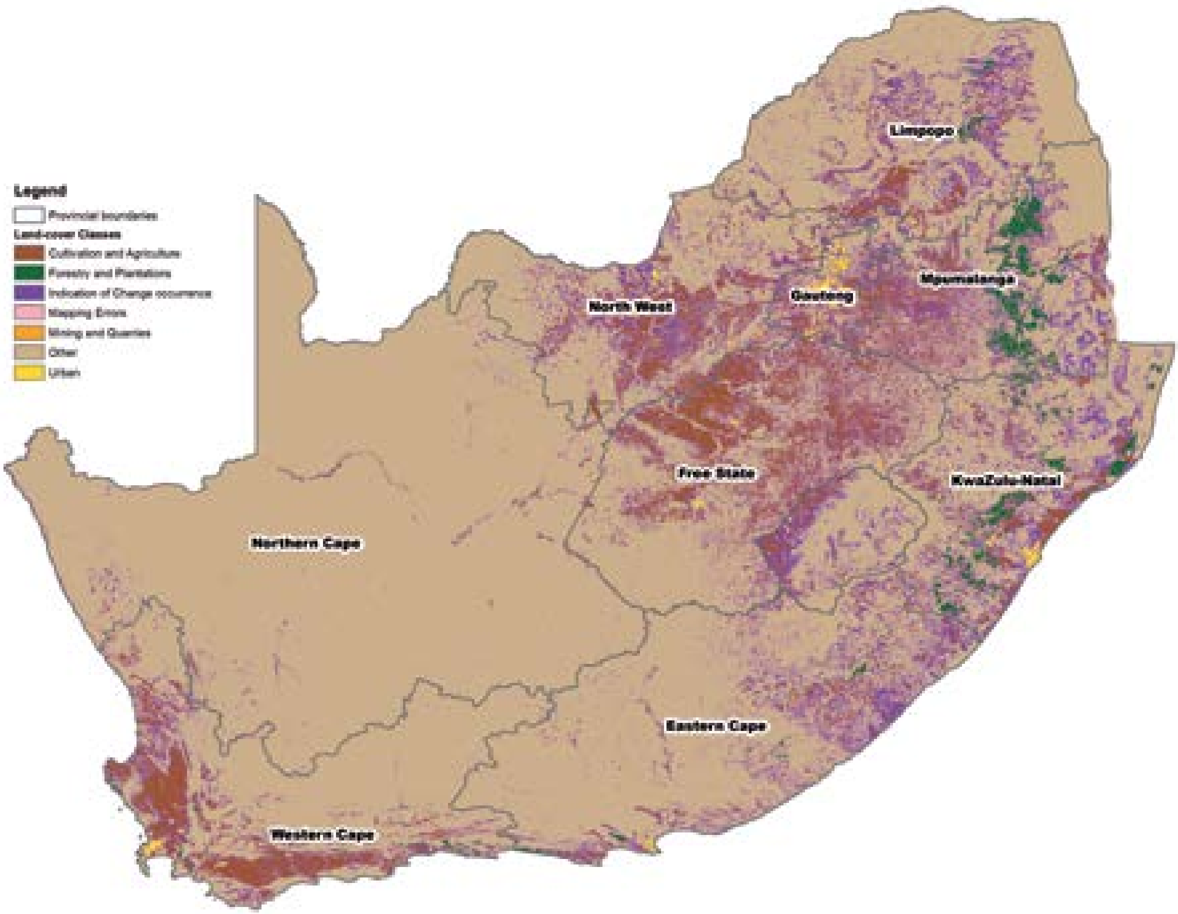

Figure 9.14 | Change in land-cover between 1994 and 2005 as part of the Five Class Land-cover of South Africa after logical corrections. Source: Schoeman et al., 2010.

9.6 | Summary of conclusions and recommendations

Based on the above finding, an assessment is made of the status and trend of the ten soil threats in order of importance for the region. At the same time an indication is given of the reliability of these estimates (Table 9.5).

Soil degradation is considered one of the root causes of stagnating or declining agricultural productivity in SSA. Unless soil degradation can be controlled, many parts of the continent are expected to suffer increasingly from food insecurity. If this decline in the productivity of Africa's soil resources continues, the consequences will be severe, not only for the economies of individual countries, but also for the welfare of the millions of rural households dependent on agriculture for meeting their livelihood needs.

There is an urgent need for proactive interventions to arrest and reverse soil degradation. Rehabilitation of degraded land and conservation of those not yet degraded is the most desirable step for every country in the region, but this can only be achieved if the characteristics of the soil resources are well defined and quantified and soil monitoring systems established in every country.

Stable	Variable	Improving	Deteriorating	Evidence and consensus is **low**	Evidence and consensus are **limited**	**Adequate** high-quality evidence and **high level** of consensus
=	↗↙	↗	↙			

Table 9.5 | Summary of soil threats status, trends and uncertainties in Africa South of the Sahara.

Threat to soil function	Summary	Condition and Trend					Confidence	
		Very poor	Poor	Fair	Good	Very good	In condition	In trend
Soil erosion	Soil erosion constitutes >80% of land degradation in SSA, affecting about 22% of agricultural land and all countries in the region. The majority of causes related to the exposure of the bare soil surface by cultivation, deforestation overgrazing and drought.		↙				Adequate	Adequate
Organic carbon change	The replacement of the natural vegetation reduces nearly always the soil carbon level. Further carbon release from the soil is caused by complete crop removal from farmlands, the high rate of organic mater decomposition by microbial decomposition accentuated by high soil temperature and termite activates in parts of SSA.		↙				Limited	Limited
Nutrient imbalance	Nutrient imbalance, which is generally manifested by the deficiency of key essential nutrients is mainly due to the fact that fertilization has not been soil and crop specific, farmers are unable to pay the price for fertilizers and the inability to follow the rates that are recommended. Nearly all countries in the region show a negative nutrient balance.		↙				Adequate	Limited

Loss of soil biodiversity	SSA suffers the world's highest annual deforestation rate. The areas most affected are the in the moist areas of West Africa and the highland forests of the Horn of Africa. Cultivation, introduction of new species, oil exploration and pollution reduce the population of soil organisms thus reducing faunal and microbial activities.			↙				
Soil acidification	Over 25% of soils in Africa are acidic. Most of these occur in the wetter parts of the continent. In South Africa it poses as a serious chemical problem and the greatest production-limiting factor.		↙					
Waterlogging	Most waterlogging threats are due to rise in water table due to poor infiltration/ drainage or occurrence of impervious layer in the subsoil. Waterlogging generally reduces crop productivity, but in paddy fields is deliberate and beneficial.				=			
Compaction	The major cause of compaction is pressure on the soil from heavy machinery. It is more serious in forested regions where land clearing (and even other cultivation activities) cannot be done without mechanization.				=			
Soil sealing and land take	These constitute problems mainly in peri-urban agriculture and valley sites used for dry season vegetable production.				=			
Soil pollution	Soil contamination by chemicals (fertilizers, petroleum products, pesticides, herbicides, mining) has affected agricultural productivity and other ecosystem services negatively. Nigeria and South Africa are the most affected.				↙			

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