Photos: FAO Mediabase

Chapter 3

LAND AND WATER SYSTEMS AT RISK

The previous chapters have highlighted the current and future threats to agricultural systems across the world. It is clear that current practices and models of agricultural development that have been followed during the last 50 years are far from satisfactorily addressing the challenges of poverty reduction, food security and environmental sustainability. A total of 975 million people, most living in rural areas, do not have the food security they deserve. Under pressure from agriculture, both soil and water are being harmed, erosion accelerated, salinization and seawater intrusion progressed, and groundwater depleted. In addition, the current model of intensive agriculture is associated with a high carbon and greenhouse gas footprint, while at the same time many agricultural systems are highly vulnerable to the predicted impacts of climate change.

The situation, however, varies substantially from one region to another in response to a combination of biophysical and socio-economic factors: climate, soil, water, population and economic development, as well as national policies and global changes. In the framework of this global study, it is thus necessary to describe and analyse the world's main agriculture production systems and the particular challenges they face. The problems discussed in this chapter include the growing competition for land and water, land and water degradation, and the expected impacts of climate change. They occur with varying incidence and severity in the different agricultural land- and water-use systems across the world, and the main systems at risk are discussed at the end of this chapter.

Map 1.3 in Chapter 1 shows a global overview of major agricultural production systems. Both rainfed and irrigated areas are experiencing degradation or risk due to limitations in land and water resources, to current land and water use and management practices, and to institutional and socio-economic factors.

Growing competition for land and water

With increased pressure on land and water resources, a problem is that some of the countries experiencing the fastest population growth are those where land and water resources are least abundant. Land and water for crop production, already constrained in some locations, will experience rising competition, particularly from fast-growing urban settlements. Increasing respect for conserving broader ecosystem services will further limit access to land and water. Competition within agriculture will increase too.

Patterns of increasing water stress due to irrigation withdrawals

Globally, the expected increases in water withdrawals for irrigation from 6 to 7 percent, or in developing countries from 8 to 9 percent, may not seem to be very alarming, but this is without accounting for the fact that a large part of irrigation is practised in water-scarce regions. There are wide regional and country-level variations in water resource availability, with a number of countries already experiencing water stress.

In industrial and transition countries, water withdrawals for irrigation are expected to stabilize or even to reduce. Overall, withdrawals in the high-income countries are expected to decline by 17 percent. By contrast, withdrawals in the low-income, food-deficit countries are expected to increase by 10 percent. The largest increases in absolute terms are expected in Southeast Asia (where irrigation is already very important – an increase of 55 km^3 annually, or 19 percent of current withdrawal levels) and in Southern America (an increase of 59 km^3, or 53 percent over present withdrawal levels). In relative terms, the increase in water withdrawals for irrigation is also expected to be high in sub-Saharan Africa (21 percent), although there is currently relatively little land irrigated, so in absolute terms the growth in water withdrawals remains modest (22 km^3). In all three of these regions, the share of water resources withdrawn for irrigation will remain low (less than 5 percent), and water availability will not generally be a constraint.

The regions that cause most concern are the Near East and Northern Africa, where water withdrawals are already near or above total renewable resources and where precipitation is low. In Northern Africa, pressure on water resources due to irrigation is extremely high, resulting in extensive water recycling and groundwater overdraft.

Just as global averages mask regional differences, variations at the country level can be hidden. In at least three countries (Libya, Saudi Arabia and Yemen) evaporation rates due to irrigation in 2005–7 were higher than each of their annual renewable water resources (FAO, 2010c). In China, for example, regional stresses are greater in the north of the country, and this will intensify. Areas dependent on non-renewable groundwater, such as parts of the Arabian peninsula, face a particular challenge: the potential depletion of their entire resource (Nachtergaele *et al*., 2010b).

Urbanization

Crop production will have to compete with growing needs for land and water from other users. Urbanization will continue, and the expansion of urban areas and land required for infrastructure and other non-agricultural purposes is expected to at least keep pace with population growth. Growing cities, industries and tourism will have priority for water supply, and this is likely to reduce the water available locally to agriculture and thus lead to further loss of cultivated land, particularly in dry areas. This phenomenon is already under way in the Sana'a Basin in Yemen and in the Oum er Rbia River in Morocco, where water is being transferred to municipal and industrial uses, and the area under irrigation is progressively dwindling.

Competition for land with growing cities will be strongest in developing countries, which will account for more than 90 percent of the additional urban and built-up land required. At the same time, rapid urbanization will create markets for high-value agriculture, and intensive peri-urban market gardening is likely to be a growth sector. A useful synergy will be the safe re-use of wastewater in peri-urban agriculture. Treated wastewater provides a year-round supply of low-cost water rich in nutrients and organic matter, and its re-use lessens the pollution load on downstream watercourses. It needs, however, clear guidelines for safe re-use and an effective regulatory framework (Mateo-Sagasta and Burke, 2010; Fischer *et al*., 2010).

Increasing attention to environmental requirements

Changes from other land and water uses to cultivation have important impacts on ecosystem services, and poor management may diminish the ability of ecosystems to support the functions or services required to ensure their sustainability (Molden, 2007). As awareness grows about the interdependence of parts of ecosystems, pressures will grow for agriculture to reduce negative impacts on ecosystems (for example, by reducing erosion or maximizing carbon storage). At the limit, land- and water-use planning will increasingly constrain the release of resources for cultivation purposes. Already cultivation is partially to totally restricted on 1.5 billion ha (11 percent of global land area) that have been declared protected areas (Fischer *et al*., 2010).

Livestock production

Competition for water is expected to grow as result of changing patterns of livestock production and the demand for fodder. Dietary preferences for animal protein are changing consumption patterns across the world (FAO, 2006b,c) and this is expected to increase demand for fodder significantly. The fodder–animal protein conversion involves a loss – it takes five times more fodder to produce the equivalent calories for human consumption (Fischer *et al*., 2010). The expansion of land for livestock grazing has led to deforestation in many countries. Intensive livestock production is also a major source of pollution. Livestock farming also contributes less than 2 percent of global GDP, and yet it is said to produce some 18 percent of GHGs (FAO, 2006b).

Up to 2030 and beyond, growth in consumption of livestock products is expected to continue, but the rate will vary. In high-income countries, where population growth is slow, the scope for growth will be limited as the consumption of livestock (meat and dairy) products is already very high (around 305 kg per person per year). This against 60 kg per person per year in low- and middle-income countries and a world average of 115 kg per person per year. In 2050, these figures are projected to be 330, 110 and 150 kg per person per year, respectively. At the same time, health and food safety concerns focused on animal fats and the emergence of new diseases may hold back demand for meat (FAO, 2006c).

Inland fisheries and aquaculture

Disputes over uses of water for irrigation and fisheries are often difficult to resolve due to the different spatial and temporal water needs of crops and fish. Expansion and intensification of crop production through draining of wetlands, extension of irrigation systems, flood protection, and increased use of fertilizer and pesticides will affect fisheries negatively. Any water development project should therefore take into consideration the needs of fish and fisheries in terms of water quantity and quality. In most developed countries and in some developing countries, strict regulations for environmental flow and water quality criteria are now in place, which is helpful in sustaining fish and fisheries while competing with other users for water resources. Some problems can be mitigated, and with proper planning and a holistic approach to development, farming and fisheries are not incompatible practices. The rice field fisheries in Asia are excellent examples of how the two activities coexist. There are, for instance, many examples that demonstrate that fish have a positive impact on the rice crop, and where fish are present there is less need for applying pesticides.

Large-scale acquisition of cropland

In recent years, two new areas of investment in commercial agriculture have emerged. One is where countries with high dependence on food imports seek to assure food supplies through agricultural investment in developing countries. The other is investment in liquid biofuel feedstock production (see below). Several drivers underpin inward investment in agriculture: commodity prices, land values, policy shifts in investing and recipient countries, and concerns about food and energy security. The shock of global food price rises experienced in 2007 and the persistent high levels of energy prices have sharpened interest. Key investor countries are in Europe and Africa, as well as the Gulf, and South and East Asia. Land acquisitions by domestic investors are also significant. Sub-Saharan Africa, South-east Asia and Latin America are the main target areas (Cotula, 2010).

The scale of the phenomenon is considerable, and competition with existing agricultural uses is heightened because investor interest tends to focus on higher-value lands in terms of higher fertility, greater irrigation potential, better infrastructure or greater proximity to markets. These lands are usually keenly sought after by local people for smallholder cultivation, and there is a risk to local livelihoods and food security if they are assigned to estate cultivation without proper consultation and safeguard (Cotula, 2010).

IBRD (2011) examines the issue by distinguishing countries on the basis of land that may be suitable for cropland expansion and yield gap, with the implication that different development pathways to deal with the associated risks and opportunities may be appropriate, depending on local context. The significant interest in countries with weak governance (notably, those pertaining to local rights) is cited as a major factor contributing to several risks (e.g. inadequate compensation, delays in implementation, low job creation, etc.). While opportunities may exist through these investments to remove existing constraints to agricultural production (e.g. access to technology, capital, infrastructure), this would require, among others, a strategic approach that proactively engages investors, changes in land governance and policy, and greater institutional capacity.

Liquid biofuel feedstock production

Currently, bioenergy represents about 10 percent of global energy use, and is used mainly for traditional cooking and heating in developing countries. Approximately 2.5 billion people in developing countries depend on traditional biomass as their main cooking fuel. But among these traditional bioenergy products it is the increasing production of liquid biofuels (bioethanol and biodiesel) that is expected to have the greatest impact on land and water use. Bioenergy has begun to compete with food production for land and water resources, and this competition is likely to increase as food crops, ethanol and biodiesel feedstock production have virtually the same land suitability requirements. The rises in recent world prices of food have been partly attributed to diversions for liquid biofuels.

Liquid biofuel has been forecast to account for 5 percent of total road transport energy use by 2030, and pressures for carbon savings may increase this. To produce this volume, land use for liquid biofuel feedstocks would need to more than double between 2007 and 2030 to 3–4.5 percent of cultivated land. Implementing all current national liquid biofuel policies and plans worldwide could already take 30 Mha of cropland (2 percent of the current cultivated land), displacing current food crop production and driving further conversion of current forest and grassland (Fischer *et al*., 2010).

Liquid biofuel production also places pressure on water resources – the water required to produce one litre of liquid biofuel is approximately the amount needed to produce food for one person for one day. Currently, global irrigation water used for liquid biofuel production is estimated to be 1–2 percent of world total irrigation water use. If all current national liquid biofuel plans were implemented, liquid biofuel production could require 5–10 percent of worldwide irrigation water (Hoogeveen *et al*., 2009).

However, these ambitious expansion plans may be scaled back, as there are concerns about competition of bioenergy and food over resources, related impacts on food security, and questions over the environmental sustainability of production (Tilman *et al*., 2009). In addition, there are questions about the extent of net greenhouse gas emissions savings, particularly where forest or grassland has been converted for liquid biofuel production.

These considerations have led many countries to reassess their near-term production targets (Box 3.1) and to evaluate the potential of second-generation liquid biofuels derived largely from biomass waste, which does not compete directly with food crops.

BOX 3.1: TRENDS IN LIQUID BIOFUEL DEMAND AND PRODUCTION

Global liquid biofuel supply reached 0.7 million barrels (Mb) daily in 2007, an increase of 37 percent on 2006, equivalent to 1.5 percent of road transport fuel. Trends indicate worldwide demand will rise significantly to 1.6 Mb/d by 2015 and to 2.7 Mb/d in 2030, thus meeting 5 percent of total world road transport energy demand. A coordinated global commitment to stabilize the concentration of greenhouse gases at 450 ppm of CO_2 equivalent would require a further doubling of global liquid biofuel demand in 2030, with increased use of liquid biofuels in the transport sector accounting for 3 percent of CO_2 savings.

But concerns about competition of bioenergy and food over scarce land and water resources, impacts on food security, actual GHG emission savings, and environmental sustainability of production, have had many countries reassessing their near-term production targets for liquid biofuels. This is particularly true for 'first generation' liquid biofuels (i.e. those obtained largely from dedicated energy crops such as maize and sugar cane). Potential negative impacts on cropland and food security may be reduced by the introduction of second-generation liquid biofuels (i.e. fuels derived largely from biomass waste). By 2030 a quarter of liquid biofuel production could be of this origin.

Sources: Tubiello and van der Velde (2010); IEA (2009)

Degradation of land and water: impacts and causes

Past achievements in terms of agricultural production growth have been accompanied by negative side-effects or externalities on land and water resources, both on-farm and downstream. Part of this degradation has been caused by poorly adapted production systems, and part by deliberate choices or trade-offs to increase agricultural output at the expense of ecosystem services.

Land and water use and the ecosystem: definition of land degradation

Recent studies (Nachtergaele *et al.*, 2011) have broadened the definition of 'land degradation' beyond simply soil erosion or loss of soil fertility, extending it to the deterioration of a balanced ecosystem and the loss of the services that ecosystem provides. Land degradation thus needs to be considered in an integrated way, taking into account all ecosystem goods and services – biophysical as well as socio-economic.

Ecosystems in which cultivation, forest management or grazing are dominant activities are at present often negatively affected by human-induced causes, most importantly by land use and land-use changes (Box 3.2) that affect the biophysical characteristics of the land (e.g. pollution, salinization, nutrient depletion). Where management practices are poorly adapted to local ecological conditions, degradation can occur. Even a number of causes that are seemingly natural can have wholly or partly indirect human causes (bush invasion, forest fires, floods, landslides and droughts).

LADA: FAO's framework for assessing land degradation

A new, scalable and 'integrative' framework for assessing land degradation has been recently developed by FAO in close collaboration with the World Overview of Conservation Approaches and Technologies (WOCAT), as part of the Land Degradation Assessment in Drylands (LADA, 2010a). This programme was originally initiated at the request, and in support, of the UNCCD. It builds on the concept of ecosystem services developed by the Millennium Ecosystem Assessment (MEA, 2005), and reflects a methodological shift in evaluating the occurrence, severity, driving forces and impacts of land degradation, and extent and effectiveness of good management practices. This approach to assessment is different from earlier methods such as Global Assessment of Soil Degradation (GLASOD; Oldeman *et al.*, 1990), which focused primarily on soils (Box 3.3). 'Land degradation' is thus a broader concept than just soil degradation or water pollution. It also allows assessment of the inter-related components of the ecosystem and of the trade-offs that may exist between them: loss of biodiversity, for example, matched against improvements in economic services under intensive farming.

BOX 3.2: LOSS OF NATURAL FORESTS IN LATIN AMERICA AND THE CARIBBEAN

Logs felled to open new fields with traditional slash-and-burn practices in Santa Cruz, Bolivia

Between 1990 and 2010, the net forest area in the Latin America and Caribbean region decreased by about 87 Mha, or almost 9 percent (FAO, 2011c). In particular, the Amazon Basin, which contains the world's most extensive tropical rainforest, encompassing unique biodiversity, has one of the world's highest rates of deforestation. Commercial farmers have cleared large areas for soybean exports in Brazil, Bolivia and Paraguay, for coffee in Brazil, and for bananas in Central America, Colombia, Ecuador and the Caribbean. Small-scale farmers also cause forest degradation by employing slash-and-burn practices in migrating their agricultural practices around forests.

Source: CDE (2010) Photo: Wocat

The FAO-LADA framework for land degradation assessment has recently been applied at national level in several countries of the LADA project (Argentina, China, Cuba, Senegal, South Africa, Tunisia), for which the total area of selected types of biophysical degradation, land management practices and ecosystem impacts have been estimated. Results from the LADA national- and local-level land degradation assessments are used in support of policy formulation and interventions for natural resources management, as well as in countries reporting to the UNCCD (Box 3.4).

An operational methodology for applying the FAO-LADA framework to the integrative analysis of global datasets (GLADIS: Global Land Degradation Information System) is in final stages of development by FAO (LADA, 2010a). GLADIS assesses the status, trends and impacts of land degradation on local populations using a set of indicators spanning the social, economic and environmental dimensions of

BOX 3.3: THE MAIN CHARACTERISTICS OF THE FAO-LADA FRAMEWORK

- The key role of **stakeholder evaluation** of the status and trends of **multiple ecosystem benefits** spanning three dimensions – social, economic and environmental – widely recognized as the three pillars of 'sustainability'.
- Degradation is deemed to be occurring whenever pressures exerted upon an ecosystem trigger a continual declining trend (over a period of approximately ten years or more) in the value of one or more benefits to levels **below that which is considered acceptable by the community of stakeholders** that, directly or indirectly, is responsible for the 'management' of the ecosystems. The underlying rationale is that stakeholders will continually make trade-offs among various benefits in order to 'manage' the ecosystem towards the attainment of acceptable levels on all three 'sustainability' criteria.
- Degradation can be considered to be permanent when the cost of rehabilitating degraded land using currently available technologies would be judged unacceptable by stakeholders, from economic and or social standpoints.
- The 'state of land degradation' (equated to the condition of ecosystem benefits at a point in time) as well as 'trends' in land degradation can only be evaluated against a reference year. Both 'state' and 'trend' are important considerations in evaluating the urgency for remedial actions. Critical situations occur when low 'state' occurs simultaneously with a rapidly declining 'trend' in ecosystem services. Areas with low to moderate 'state' and declining 'trend' should be highlighted for preventative actions, for greater cost-effectiveness.
- Data collection methodologies used to measure various aspects of degradation evolve over time. The FAO-LADA framework can be applied independently of specific methodologies and at various scales. Either measured variables or related indicators can be used.
- Drivers and impacts of land degradation are assessed at different scales. This allows comprehensive understanding of the behaviours and strategies of various land users, and facilitates coherent actions at different levels of decision-making.

ecosystem services. In GLADIS, the condition of multiple ecosystem benefits is represented in the form of radar diagrams that allow rapid assessment of the status and trends in six main dimensions of land- and water-related ecosystem services: biomass, soil, water, biodiversity, economic and social (Figure 3.1).

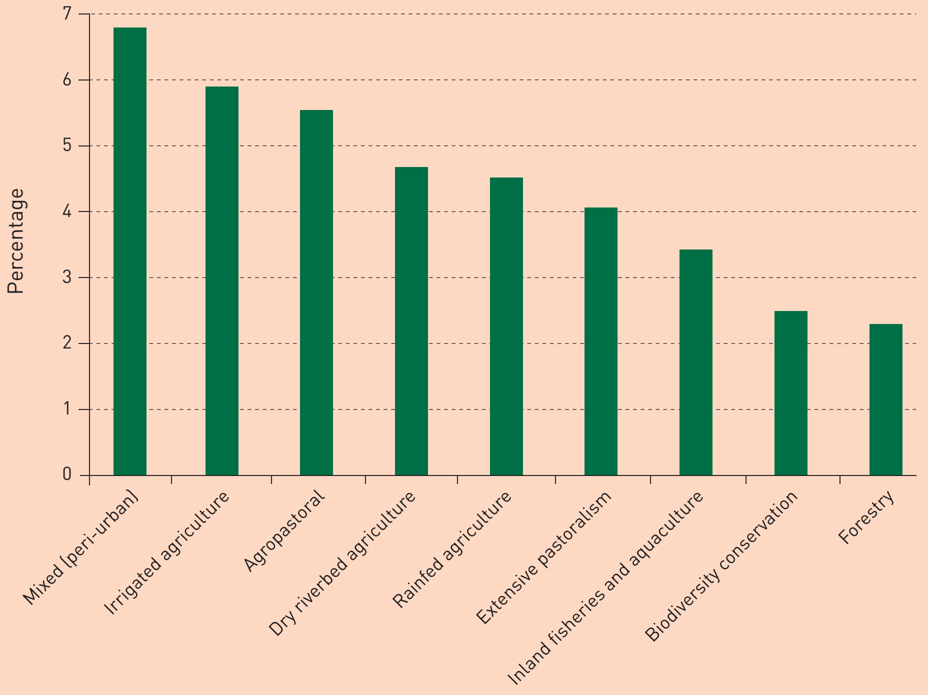
The GLADIS assessment shows that land use and management are the most important causes of degradation. For example, conversion of forest to cropland causes loss of a range of ecosystem services, and the resulting cultivated lands – often as a result of soil tillage – are more susceptible to degradation. Forests have high capacity to produce biomass, soil health and biodiversity. When forests are converted to cultivation, many of these services are lost and the subsequently cultivated lands are more likely to degrade.

Trends are an important element in the assessment of ecosystem services. GLADIS assesses changes in ecosystems services over 1990–2005 in order to monitor

BOX 3.4: NATIONAL LAND DEGRADATION ASSESSMENT, SENEGAL

Following the LADA national assessment methodology, expert estimates were made on the spatial extents of selected types, degree and rate of biophysical degradation, as well as their causes and impacts on ecosystem services, within all major land-use systems. Types of degradation include soil erosion (wind, water) and soil deterioration (chemical, physical, water, biological). Their causes include soil management, crop management, deforestation, over-exploitation of vegetation for domestic use and overgrazing (LADA, 2010b).

Extent of degradation (percentage area of land-use system)

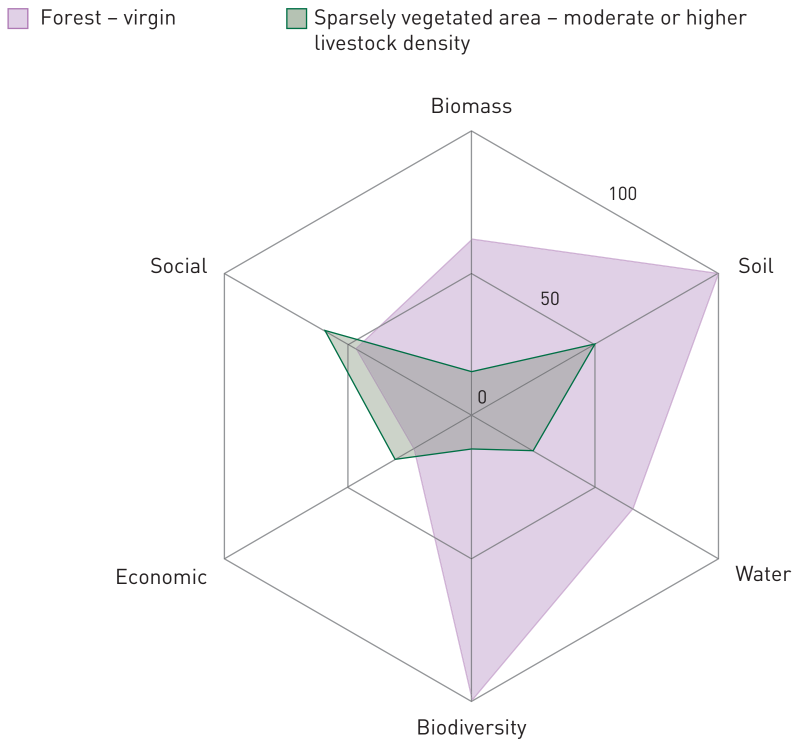


improvement or further deterioration. Large parts of all continents are experiencing degradation, with particularly high incidence of degradation down the west coast of the Americas, across Southern Europe and North Africa, across the Sahel and the Horn of Africa, and throughout Asia. The greatest threat is the loss of soil quality, followed by biodiversity loss and water depletion (Molden, 2007).

Global extent of degraded area – preliminary results from GLADIS

In GLADIS (LADA, 2010a), global datasets covering environmental, economic and social dimensions were input to models, which produced indices that are indicative of the current status (i.e. the 'baseline' condition) of ecosystem benefits as well as trends (i.e. the overall long-term tendency of changes in the flow of such benefits, whether improving or not). Status and trends were determined for eleven globally impor-

FIGURE 3.1: SCHEMATIC REPRESENTATION OF A LIKELY CHANGE IN CONDITION OF SIX SELECTED ECOSYSTEM SERVICES ASSOCIATED WITH A MAJOR CHANGE IN LAND USE (FROM FOREST TO EXTENSIVE LIVESTOCK PRODUCTION)



Source: this study

tant land-use classes, as defined in GLADIS, which allowed the identification of four different typologies of degradation (Figure 3.2) . These typologies facilitate geographic targeting and priority-setting of remedial strategies and interventions.

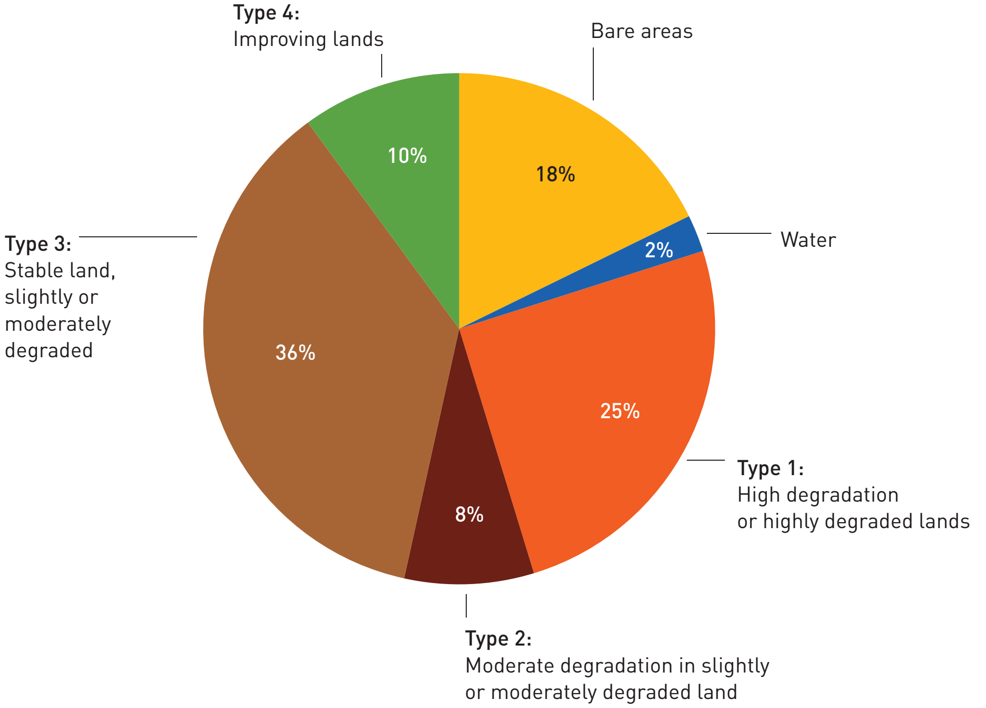
The relative extents of the different typologies of degradation vary depending on land use. Highest values for Type 1 were associated with *sparsely vegetated areas with moderate or high livestock density* (68 percent of the global extent of this land use class). The highest shares of improving lands (i.e. Type 4) are mostly associated with *cropping with little to no livestock* (24 percent). Globally, approximately 25 percent of all land is of the critical Type 1 category, while about 46 percent are stable (neither significantly increasing nor decreasing trends) and are slightly to moderately degraded (Type 3). Only 10 percent is associated with improving conditions (Figure 3.2).

Negative on-farm impacts of agriculture

The current 1600 Mha of cultivated land represent the better and more productive part of global land resources. However, parts of this land are degrading through farming practices that result in water and wind erosion, nutrient mining, topsoil

FIGURE 3.2: STATUS AND TRENDS IN GLOBAL LAND DEGRADATION

Typology of degradation of ecosystem benefits	Intervention options
Type 1 – High degradation trend or highly degraded lands	Rehabilitate if economically feasible; mitigate where degrading trends are high
Type 2 – Moderate degradation trend in slightly or moderately degraded land	Introduce measure to mitigate degradation
Type 3 – Stable land, slightly or moderately degraded	Preventive interventions
Type 4 – Improving lands	Reinforcement of enabling conditions which foster SLM



Source: this study

compaction, salinization and soil pollution. As a result, the productivity of the land resource base has declined. Land degradation also leads to off-site problems, such as sedimentation of reservoirs, reduced watershed system functioning and carbon dioxide emissions.

Deterioration of land productivity can occur in several ways. First, there may be loss of organic matter and physical degradation of the soil, such as when forests are cleared and soil structure declines rapidly. Second, nutrient depletion and chemical degradation of the soil may occur. Globally, only half the nutrients that crops take from the soil are replaced, with nutrient depletion in many Asian countries equivalent to 50 kg / ha annually. In some Eastern and Southern African countries, annual depletion is estimated at 47 kg / ha of nitrogen, 6 kg / ha of phosphorus, and 37 kg / ha of potassium. When farming systems do not include fertilization or nitrogen fixation, losses from nutrient mining and related erosion are even higher (Sheldrick *et al*., 2002).

A third aspect of deterioration is on-site soil erosion caused by poor land management. Many studies have demonstrated the effect on yields of loss of nutrients and organic matter and the related deterioration of the water-holding capacity of the soil. Loss of soil quality and its protective cover also affects broader ecosystem services by causing hydrological disturbance, loss of above- and below-ground biological diversity, and reduced soil carbon stocks and associated increases in carbon dioxide emissions.

Soil health is declining in many cropping systems both in developed and developing countries. The worst situations occur in highland rainfed cropping systems in the Himalayas, Andes, Rockies and the Alps, in low-input, low-husbandry systems such as the rainfed cropping systems in the sub-Saharan Africa savannahs (Box 3.5) and agro-pastoral systems in the Sahel, Horn of Africa and Western India, and in intensive systems where nutrients and pesticides can lead to soil and water pollution if not properly managed.

Irrigation development has played a vital function in raising agricultural production worldwide, but the negative side-effects of intensive irrigated farming on soil and water have also been substantial. On-farm, salinization and waterlogging are the main problems. Few plants can tolerate much salt, as it prevents the uptake of moisture, with a consequent rapid decline in yields. Salinization may come about when irrigation releases salts already in the soil, or when irrigation water or mineral fertilization brings new salts to the land. Waterlogging is a related problem. It curtails plant growth by eliminating air from the soil, effectively stifling the plant. Waterlogging also often leads to salinization of soils. Worldwide, FAO estimates that 34 Mha (11 percent of the irrigated area) are affected by some level of salinity (Map 3.1); Pakistan, China, the United States and India represent more than 60 percent of the total (21 Mha). An additional 60–80 Mha are affected to some extent by waterlogging and related salinity.

Off-farm impacts and externalities

In addition to the on-site impacts of land and water management, there are also extensive off-site and downstream impacts, including changes in river hydrology and groundwater recharge rates, the pollution of downstream water bodies and of groundwater, downstream effects of siltation due to runoff from farms, and the overall impact on water-related ecosystems.

BOX 3.5: NUTRIENT DEPLETION IN SMALL-SCALE CROPPING SYSTEMS IN SUB-SAHARAN AFRICA

Traditionally cultivated, unfertilized fields with high spatial variability in plant growth, Senegal

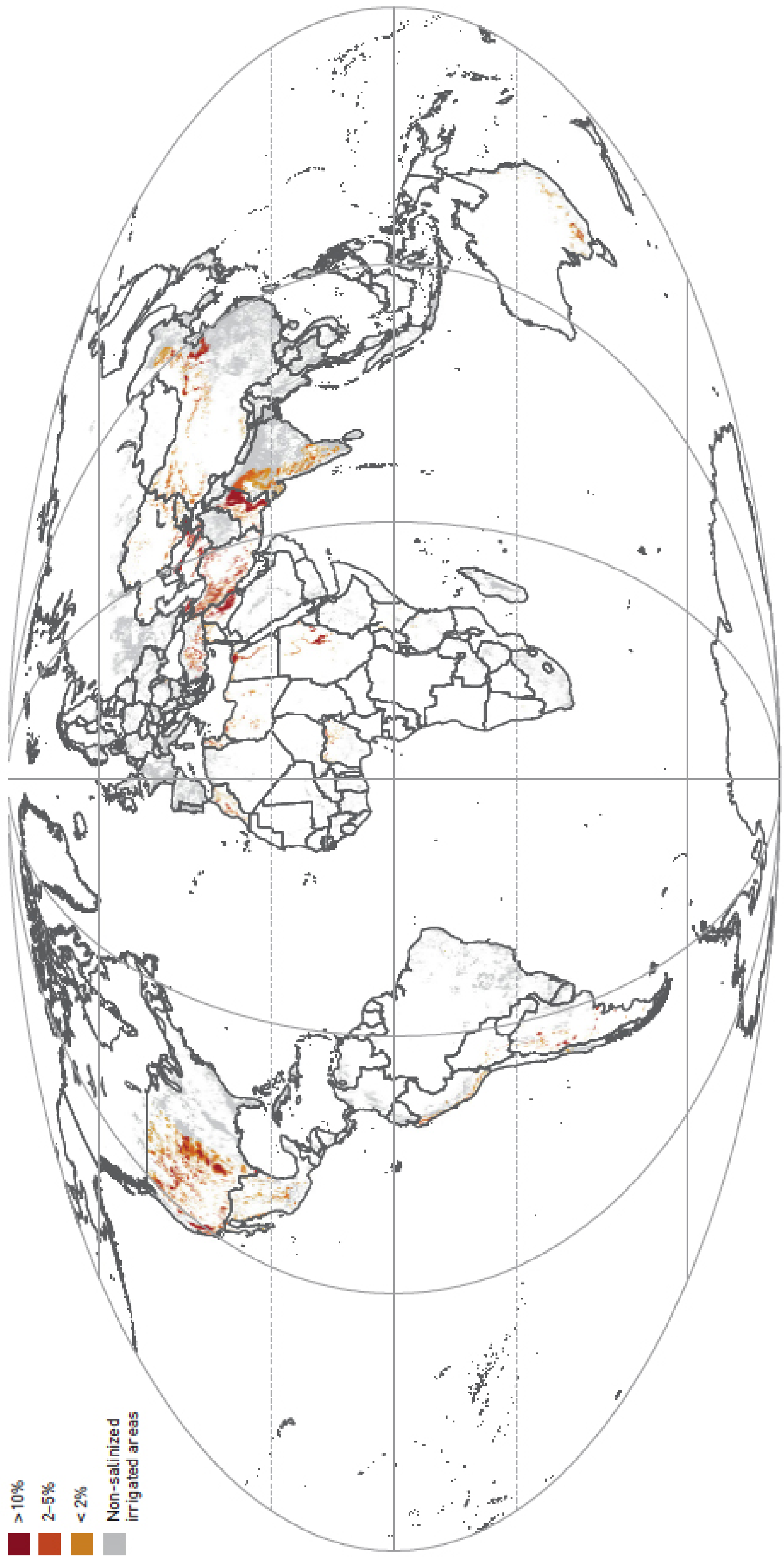
Only 7 percent of sub-Saharan Africa is under cropland. Crop productivity is low. Soil fertility depletion is reaching a critical level in the region, especially under small-scale land use. It results from a negative nutrient balance, with at least four times more nutrients removed in harvested products compared with nutrients returned in the form of manure and mineral fertilizer.

Source: CDE (2010) Photo: USGS

Impacts on the hydrological regime due to irrigation water withdrawals

Irrigated agriculture has had a profound impact on water-related ecosystems. The flow regimes of rivers have changed, sometimes with substantial negative effects on water availability downstream and on downstream aquatic ecosystems, and with substantial reduction in discharge to the ocean. Many rivers heavily used for irrigation no longer have sufficient levels of flow to keep river systems 'open'. In some heavily populated basins in China and India, rivers no longer discharge to the sea, with resulting saline advance upstream, and loss of coastal habitat and economic activity. But there may be positive impacts through improved flood control and aquifer recharge (Charalambous and Garratt, 2009), although this may also reduce the transportation of beneficial sediments (Molden, 2007). Irrigation withdrawals have also contributed to the shrinkage of vast lakes: Lake Chapala in Mexico lost 80 percent of its volume between 1979 and 2001, and the Aral Sea all but disappeared at the end of the 20th century as irrigation withdrawals for cotton reduced inflows.

MAP 3.1: PROPORTION OF LAND SALINIZED DUE TO IRRIGATION



Source: this study

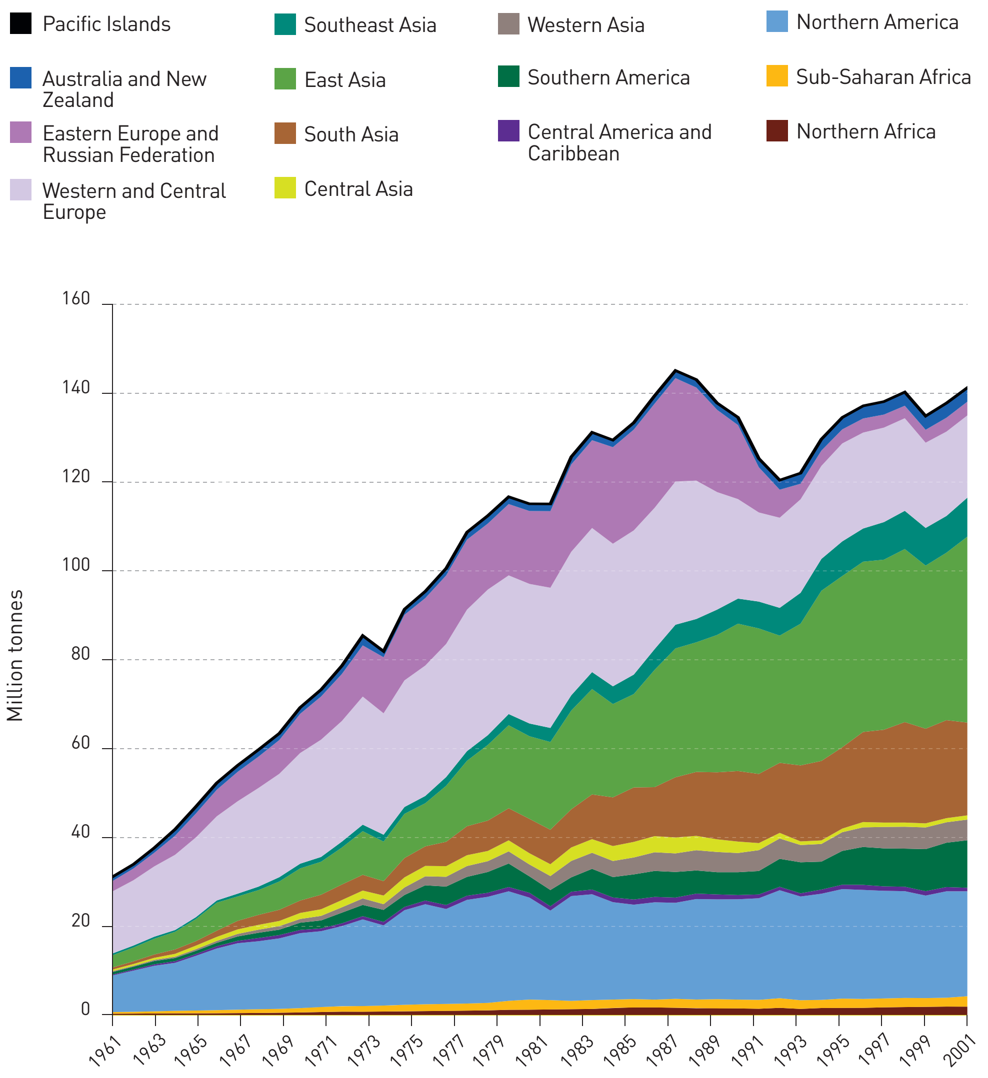
Wetlands have also been drained. In Europe and North America, more than half of wetlands have been drained for agriculture, leading to loss of biodiversity, risk of flooding and downstream eutrophication (FAO, 2008c; Molden, 2007: 249).

Water pollution from agriculture

The most important water pollution problems related to agriculture are excess nutrients accumulating in surface and coastal waters, nitrate accumulating in groundwater, and pesticides accumulating in groundwater and surface-water bodies.

Water pollution by excessive application of nutrients (particularly nitrate and phosphate) has increased with the intensification of agriculture together with significant inputs from urban sewage. Increased use of mineral fertilizers (Figure 3.3) and higher concentrations of livestock are the main causes. The increase in the load of

FIGURE 3.3: TRENDS IN MINERAL FERTILIZER USE (NPK)



Data source: FAO (2010b)

nutrients in croplands has increased the transport and accumulation of nitrates in water systems through run-off and drainage. Agrochemical pollution is currently a serious and widespread problem, including much of East and Southeast Asia, Europe, parts of the USA and Central Asian countries, as well as on some plantations in Central and Latin America.

Nutrients in surface waters can cause eutrophication, hypoxia (depletion of dissolved oxygen supporting aquatic life), and algal blooms and other infestations, such as of water hyacinth. Coastal areas of Australia, Europe and the USA, and many inland waters, are affected (Mateo-Sagasta and Burke, 2010). Life in some seas, including parts of the Baltic and Adriatic, is often stifled. Wetlands and lakes receiving influxes of nutrients may cross eutrophication thresholds. It has been suggested that the planetary boundary, or upper tolerable limit, for changes to the global nitrogen cycle (Rockström *et al.*, 2011) and for freshwater eutrophication, has already been crossed (Carpenter and Bennet, 2011). It is estimated that there are 12 000 km^3 of polluted freshwater in the world, equivalent to six years of irrigation use.

A further problem is related to the use of some pesticides (Turral and Burke, 2010). Pest management has been a recurrent issue in irrigated agriculture since the emergence of modern large-scale rice and wheat farming. In monocultures, pests and diseases can spread rapidly and result in epidemics when conditions are favourable to a particular pathogen or pest. Some high-yielding varieties of rice have proved to be susceptible to particular pests (e.g. IR64 to brown plant hopper). Early pesticides, such as organochlorines, proved to be persistent, and accumulated in food chains. Although many were banned in the 1970s, their use continued in some parts of the world. They were replaced by more apparently benign formulations, such as organophosphates, which then also became largely banned or restricted. The risks of pollution are linked to the solubility and mobility of different chemical compounds. For example, the herbicide atrazine, widely used in maize production in the USA, has been held responsible for considerable groundwater contamination. Agricultural run-off and drainage readily transport these pollutants to water bodies.

Greenhouse gases

Agriculture also contributes substantially to the release of greenhouse gases. Its emissions amount to about 5–6 billion t CO_2eq per year. Together with deforestation activities, it is responsible for a third of total anthropogenic greenhouse gas emissions, or about 13–15 billion t CO_2eq per year (Table 3.1). It emits about 25 percent of total carbon dioxide (largely from deforestation), 50 percent of methane (rice, enteric fermentation, animal waste) and 75 percent of N_2O (fertilizer application, animal waste) emitted annually by anthropogenic activities. Although much of these emissions may be an unavoidable part of intensified agriculture, a number of mitigation strategies in the agriculture and forestry sectors have been identified as useful in

TABLE 3.1: ANNUAL ANTHROPOGENIC GREENHOUSE GAS EMISSIONS (2005)

	Billion tCO_2eq	Share %
Global	**50**	100 %
Agriculture	**5–6**	10–12 %
Methane	(3.3)	
N_2O	(2.8)	
Forestry	**8–10**	15–20 %
Deforestation	(5–6)	
Decay and peat	(3–4)	
Total agriculture and forestry	**13–15**	25–32 %

Source: FAO (2008a)

achieving the goal of stabilization of atmospheric concentrations. These options are discussed in Chapter 5.

Depletion of groundwater

The quantity of water available to agriculture is likely to be affected by dwindling of the groundwater resource in many areas. As discussed earlier, the boom in groundwater use fuelled by tubewell technology, cheap energy and profitable markets has led to widespread depletion of groundwater reserves, including irreversible mining of some aquifers (Shah, 2009; Llamas and Custodio, 2003; Morris *et al*., 2003). But while depletion has been a dominant impact, in some circumstances pumping can increase recharge (Shamsudduha *et al*., 2011).

Widespread and largely unregulated groundwater withdrawals by agriculture have resulted in depletion and degradation of some of the world's most accessible and high-quality aquifers. The depletion in the Central Valley of California or the Ogallala aquifer in the US Great Plains are well known. But other examples from key agriculture areas include the Punjab, North China Plain and the Souss basin in Morocco, where annual declines of up to 2 metres since 1980 have been recorded (Garduno & Foster, 2011). Pumping costs to individual farmers and public groundwater supply schemes rise as the water table drops. But in some cases the demand for groundwater to service high-value crops appears inelastic (Hellegers *et al*., 2011): in Yemen some pumping is from depths of over 1 km.

Groundwater depletion has also contributed to subsidence as aquifer structures collapse. The most notable example to date is the Central Valley of California, due to the continued exploitation of deeper groundwater for irrigation. In Iran, intensive withdrawal of groundwater is contributing to drying up of traditional *qanat* (springs and shallow wells) and has also led to subsidence of productive agricultural land due to compression of underlying aquifers as groundwater is withdrawn.

A further risk is salinization of groundwater resources. This may occur when saline irrigation drainage water percolates to an aquifer. But in many coastal zones and small islands, intensive pumping of groundwater for agricultural use has induced saline intrusion, rendering many economically important aquifers unfit for water supply. Some aquifers are already permanently salinized (for example, the coastal aquifers of Gaza, Gujarat (India), west Java and Mexico).

A global inventory of groundwater use in agriculture conducted by FAO (Siebert *et al.*, 2010) indicates that almost 40 percent of the global irrigated area is now reliant on groundwater (Table 3.2). Key food-producing regions are dependent on groundwater. Regions affected include some of the world's major grain-producing areas, such as the Punjab and the North China Plain. Four of the world's largest food producers depend on groundwater for a third or more of their irrigated area, and India (64 percent) and the USA (59 percent) for up to two-thirds of the irrigated area. Consequently, risks to global food supply from depletion and deterioration of aquifers are high.

Anticipated impacts of climate change

Worldwide, agricultural systems are also considered at risk from climate change (FAO, 2011d). Climate change and variability affect thermal and hydrological regimes, and this in turn influences the structure and functionality of ecosystems and human livelihoods. Expected changes in the mean and variability of temperature and precipitation, elevated CO_2, plus complex interactions among these, will

TABLE 3.2: MAJOR FOOD-PRODUCING COUNTRIES DEPENDENT ON GROUNDWATER

Country	Area equipped for irrigation (ha)	Groundwater (ha)	Surface Water (ha)	Dependence on groundwater (% of area equipped for irrigation)
Brazil	3 149 217	591 439	2 557 778	19%
China	62 392 392	18 794 951	43 597 440	30%
Egypt	3 422 178	331 927	3 090 251	10%
India	61 907 846	39 425 869	22 481 977	64%
Pakistan	16 725 843	5 172 552	11 553 291	31%
Thailand	5 279 860	481 063	4 798 797	9%
USA	27 913 872	16 576 243	11 337 629	59%

Source: Siebert et al. (2010)

have impacts on land and water resources, affecting crop productivity and the agricultural sector in the coming decades (Tubiello and van der Velde, 2010).

These impacts will vary by region and over time. It is expected that up to 2050, moderate warming may benefit crop and pasture yields in temperate regions, while it will decrease yields in semi-arid and tropical regions. Global warming thus has the potential to boost food production in some parts of the world (e.g. Canada, Russia), and to limit it in others (e.g. Southern Africa). Changes in precipitation regimes are also expected. The associated changes in evapotranspiration to precipitation ratios will modify ecosystem productivity and function, particularly in marginal areas. There is likely to be an increased frequency of extreme events—such as heatwaves, hailstorms, excessive cold, heavy and prolonged precipitation, and droughts—with negative impacts on crop yields. Climate change will need to be taken into account in all considerations of future land and water management strategies (FAO, 2010c).

Possible climate change impacts at the global level

Climate change impacts are expected to combine to depress yields and increase production risks in many areas, with increasing aridity, more unpredictable weather patterns and more pronounced rainfall events. Increases in precipitation and temperature may lead to increased pest and disease pressure on crops and livestock. Impacts are expected to grow more negative and pronounced with time, especially in developing regions. There may be some benefits in certain parts of the world from warmer temperatures, more water and a longer growing season. Even increasing atmospheric CO_2 could have a beneficial effect on productivity, although this is uncertain.

The impacts of climate change on world aggregate cereal production, depending on the scenario considered, may vary between –5 percent and +3 percent (Box 3.6). If risks materialize, climate change may have serious consequences in developing countries, due to the vulnerability and food insecurity of the poorer parts of the population, scarcity of capital for adaptation measures, their warmer baseline climates and their heightened exposure to extreme events. It is estimated that climate change could increase the number of undernourished by between 10 and 150 million people.

Anticipated climate change impacts by zone

Although all climate change projections are subject to a wide range of uncertainty, projections indicate an increase in the percentage of current cultivated land falling into arid and semi-arid climatic zones in Africa, particularly in Northern Africa and Southern Africa. By 2080, arid and dry semi-arid areas in Africa may increase by 5–8 percent (60–90 Mha). Drier areas may become less productive, or go out of production altogether. In Asia, by contrast, aridity would decline in all subregions. In temperate zones, impacts may be more favourable, although offset by the likelihood of more extreme weather events. The expected changes in temperature and precipitation regimes, and associated soil moisture conditions, will modify the suitability of crop species and cultivars. This will lead to changing management require-

BOX 3.6: ANTICIPATED IMPACTS ON PRODUCTION POTENTIAL OF CEREALS

If impacts are unmitigated, scenario results show an overall decline in the production potential of rainfed cereals of about 5 percent (see table below). If adapted crop types are used or if increased CO_2 associated with climate change has a fertilization effect, then the decline in production potential would be lessened. If both adapted crop types and the CO_2 fertilization effect are assumed, then climate change could result in an overall global increase in production potential of 3 percent. Increases would be largest in East and Central Asia. Production would still decline in some regions, particularly in Western Africa. Within these projections, it is likely that poor rainfed areas and farmers will have the least access to adaptation, and so will suffer the most.

Impacts of climate change on the production potential of rain-fed cereals in current cultivated land

Region	Cultivated land	Percentage changes with respect to potential under current climate*			
		Without CO_2 fertilization; current crop types	Without CO_2 fertilization; adapted crop types	With CO_2 fertilization; current crop types	With CO_2 fertilization; adapted crop types
Northern Africa	19	–15	–13	–10	–8
Sub-Saharan Africa	225	–7	–3	–3	1
Northern America	258	–7	–6	–1	0
Central America and Caribbean	16	–15	–11	–11	–7
Southern America	129	–8	–3	–4	1
Western Asia	61	–6	–6	–1	–1
Central Asia	46	19	19	24	24
South Asia	201	–6	–2	–2	2
East Asia	151	2	6	7	10
Southeast Asia	99	–5	–2	–1	4
Western and Central Europe	132	–4	–4	2	3
Eastern Europe and Russian Federation	173	1	1	7	7
Australia and New Zealand	51	2	4	7	9
Pacific Islands	0	–7	–3	–2	2

* Using Hadley A2 scenario for year 2050 versus reference climate.

Source: adapted from Fischer et al. (2010)

ments, such as increased need for irrigation in many regions, new cropping calendars, and altered planting and harvesting operations (Fischer *et al*., 2010).

Effects of climate change on irrigation

Although there are many uncertainties about climate change, impacts on water resources are expected to be significant, with projected increases in water stress already pronounced by 2050 (FAO, 2011a). Regional water availability may change through shifts in snow-melt and river flows. Major precipitation changes may impact river flow in key irrigated regions, especially the Indian subcontinent (FAO, 2011a; De Fraiture *et al*., 2008). Although these impacts are difficult to quantify, a combination of reduced river base flows, increased flooding and rising sea levels is expected to impact highly productive irrigated systems that help maintain the stability of cereals production. The production risks will be amplified in alluvial plains dependent on glacier melt (e.g. Colorado, Punjab) and in lowland deltas (e.g. Ganges, Nile) (Frenken, 2010).

On the demand side, impacts of climate change on irrigation requirements will be felt through net changes in precipitation and evapotranspiration (Bates *et al*., 2008). Net crop irrigation requirements may increase 5 to 20 percent globally by 2080, with larger changes in some regions; Southeast Asia, for example, may see requirements rise by 15 percent. Larger impacts are foreseen in temperate regions, as a result of both increased evaporative demands and longer growing seasons under climate change (Fischer *et al*., 2007). The ratio of irrigation withdrawals to available renewable water resources may increase as a result of climate change, especially in the Middle East and Southeast Asia. Irrigation requirements may also increase in North Africa, but decrease in China (Bates *et al*., 2008). Increased frequency of droughts is expected to stress water reservoirs, as more water will be necessary to offset increased crop demand.

Systems at risk

SOLAW has identified nine major categories of systems at risk for which special attention is needed (further breakdown has led to a total of 14 subsystems presenting specific patterns of risk and development options). All these systems are expected to experience some negative impacts, as well as to impose negative externalities on other systems, unless corrective actions are taken. Key characteristics (status and trends) and options for addressing land and water issues in these systems are shown in Table 3.3. The incidence and severity of negative impacts anticipated are described, together with the main options needed to address risk, restore sustainability, and improve contribution to local and global food needs.

TABLE 3.3: MAJOR LAND AND WATER SYSTEMS AT RISK (A BROAD TYPOLOGY)

Global production systems	Cases or locations where systems are at risk	Risks
RAINFED CROPPING Highlands	Densely populated highlands in poor areas: Himalayas, Andes, Central American highlands, Rift Valley, Ethiopian plateau, Southern Africa.	Erosion, land degradation, reduced productivity of soil and water, increased intensity of flood events, accelerated out-migration, high prevalence of poverty and food insecurity.
RAINFED CROPPING Semi-arid tropics	Smallholder farming in Western, Eastern and Southern Africa savannah region and in Southern India; agro-pastoral systems in the Sahel, Horn of Africa and Western India.	Desertification, reduction of production potential, increased crop failures due to climate variability and temperatures, increased conflicts, high prevalence of poverty and food insecurity, out-migration.
RAINFED CROPPING Subtropical	Densely populated and intensively cultivated areas, concentrated mainly around the Mediterranean basin.	Desertification, reduction of production potential, increased crop failures, high prevalence of poverty and food insecurity, further land fragmentation, accelerated out-migration. Climate change is expected to affect these areas through reduced rainfall and river runoff, and increased occurrence of droughts and floods.
RAINFED CROPPING Temperate	Highly intensive agriculture in Western Europe.	Pollution of soils and aquifers leading to de-pollution costs, loss of biodiversity, degradation of freshwater ecosystems.
	Intensive farming in United States, Eastern China, Turkey, New Zealand, parts of India, Southern Africa, Brazil.	Pollution of soils and aquifers, loss of biodiversity, degradation of freshwater ecosystems, increased crop failure due to increased climate variability in places.
IRRIGATED Rice-based systems	Southeast and Eastern Asia.	Land abandonment, loss of buffer role of paddy land, increasing cost of land conservation, health hazards due to pollution, loss of cultural values of land.
	Sub-Saharan Africa, Madagascar, Western Africa, Eastern Africa.	Need for frequent rehabilitations, poor return on investment, stagnating productivity, large-scale land acquisition, land degradation.
IRRIGATED Other crops	RIVER BASINS Large contiguous irrigation systems from rivers in dry areas, including Colorado river, Murray-Darling, Krishna, Indo-Gangetic plains, Northern China, Central Asia, Northern Africa and Middle East.	Increased water scarcity, loss of biodiversity and environmental services, desertification, expected reduction in water availability and shift in seasonal flows due to climate change in several places.
	AQUIFERS Groundwater-dependent irrigation systems in interior arid plains: India, China, central USA, Australia, North Africa, Middle East and others.	Loss of buffer role of aquifers, loss of agriculture land, desertification, reduced recharge due to climate change in places.

Global production systems	Cases or locations where systems are at risk	Risks
RANGELANDS	Pastoral and grazing lands, including on fragile soils in Western Africa (Sahel), North Africa, parts of Asia.	Desertification, out-migration, land abandonment, food insecurity, extreme poverty, intensification of conflicts.
FORESTS	Tropical forest-cropland interface in Southeast Asia, the Amazon basin, Central Africa, and Himalayan forests.	Cropland encroachment, slash-and-burn, leading to loss of ecosystems services of forests, land degradation.
Other locally important subsystems	DELTAS AND COASTAL AREAS: Nile delta, Red River delta, Ganges/ Brahmaputra, Mekong, etc. and coastal alluvial plains: Arabian Peninsula, Eastern China, Bight of Benin, Gulf of Mexico.	Loss of agricultural land and groundwater, health-related problems, sea-level rise, higher frequency of cyclones (Eastern and Southeast Asia), increased incidence of floods and low flows.
	SMALL ISLANDS Including Caribbean, Pacific islands.	Total loss of freshwater aquifers, increased cost of freshwater production, increased climate-change related damages (hurricanes, sea-level rise, floods.
	PERI-URBAN agriculture	Pollution, health-related problems for consumers and producers, competition for land.

Source: this study

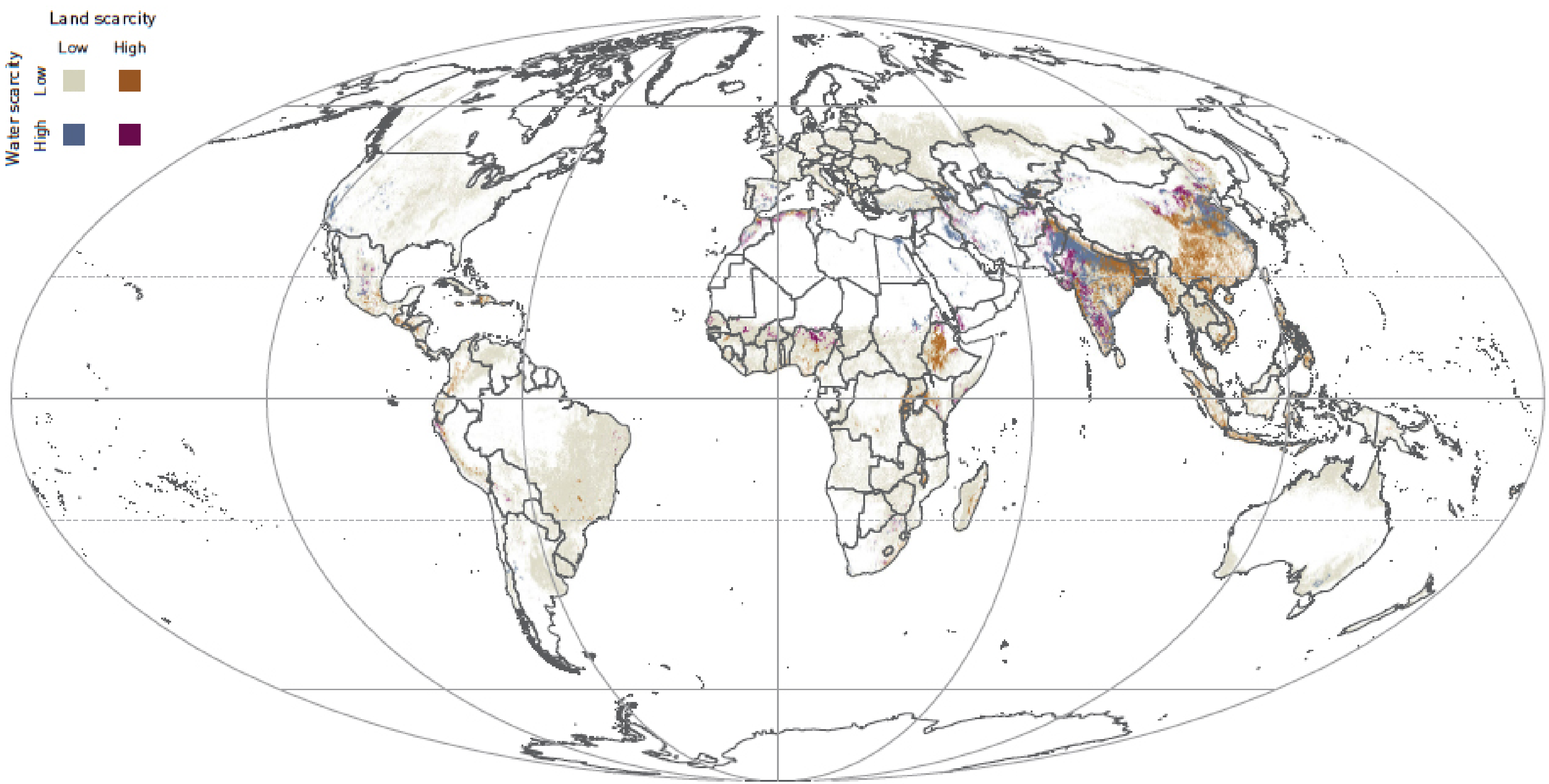
Map 3.2 highlights areas within agricultural systems where the rural population exceeds the capacity of land or water resources to provide food. This map shows where rural population density presents a challenge to agricultural systems, and where responses need to be crafted in combinations of sustainable intensification practices and reduction of demographic pressure on the environment.

Densely populated highlands in poor areas

These systems, which include areas such as the Himalayas, the Andes and highland areas of sub-Saharan Africa (including the Rift Valley, the Ethiopian plateau and Great Lakes area), are characterized by extreme population pressure on fragile ecosystems. Expansion into marginal lands leads to high rates of erosion, increased risk of landslides and changes in patterns of runoff, with consequent degradation of water resources downstream. Negative impacts of erosion and desertification lead to declining productivity, and are expected to be exacerbated by climate change.

In these systems, there is almost no possibility of expanding the cultivated area. The scope for intensification is limited to non-marginal lands and requires heavy investments in soil and water conservation measures. Better land husbandry and

MAP 3.2: AGRICULTURAL SYSTEMS AT RISK: HUMAN PRESSURE ON LAND AND WATER



Source: this study

efforts to reduce pressure on fragile lands are needed, otherwise impoverishment and out-migration are likely to occur. Response options in such fragile ecosystems include soil and water conservation, watershed management practices, terracing, flood protection, and reforestation in most fragile areas. PES in watersheds, promotion of agri-tourism, planned out-migration and provision of basic services and infrastructure are among the non-agricultural options that need to be developed.

Rainfed systems in the semi-arid tropics

These include smallholder farming in sub-Saharan African savannahs and some agro-pastoral systems in Asia (western India) and Africa. They are currently characterized in many places by overexploitation of natural resources and fuelwood, and by expansion into more marginal lands. With low cropping potential and unimproved agricultural practices, productivity is low (and sometimes declining) due to depletion of soil organic matter and fertility, soil acidification, poor soil moisture-holding capacity, and wind and water erosion. Ecosystems are degrading, with biomass and biodiversity decline, frequent occurrence of fires and water shortages. Institutional failings contribute to problems of land tenure and access, and to agriculture–livestock conflicts. Many of these areas are characterized by widespread poverty and vulnerability to climate shocks, with highly variable production subject to climate variability. Issues of access to land and conflicts between agriculture and livestock are widespread.

The potential for expansion is low to medium, with some possibilities where lands are not too fragile and irrigation water is available. Potential for intensification varies, and depends on scarce water resources, presence of fragile lands and population density. Options for improvement include enhanced land tenure security, land reform and consolidation where possible, better integration of agriculture and livestock, investments in irrigation and water harvesting where possible, crop insurance, integrated plant nutrition, plant breeding adapted to semi-arid conditions, improved governance, and investments in infrastructure (markets, roads). These regions also offer potential for more systematic use of solar energy for agriculture and household consumption. In extremely pressurised systems, planned out-migration may be needed.

Subtropical systems

Subtropical systems include those found in the densely populated and intensively cultivated areas around the Mediterranean basin and in Asia. They suffer from overexploitation of land and water, leading to erosion, low soil fertility, vegetation and biodiversity decline, water shortage and fires. Socio-economic problems include land fragmentation and high rates of out-migration, in particular by male family members.

These systems have very little potential for expansion, as most agriculturally suitable land is already in use. Instead, reduction in cultivated areas is likely to happen, under the combined pressure on land and on water resources by other sectors. The potential for intensification is relatively low and likely to be constrained by further land fragmentation. Out-migration and progressive marginalization of agriculture are likely to continue. The pace of degradation and its impact on the livelihoods of rural populations will depend on agricultural policies and the effective implementation of better conservation programmes.

Response options will need to include plant breeding adapted to semi-arid conditions, improved soil and water conservation and integrated plant nutrition. On the institutional side, a combination of land reforms and consolidation and climate change adaptation planning, setting up of viable crop insurance systems, investments in rural infrastructure and services and planned out-migration will be necessary. These systems must be considered in the overall context of social development, where the necessary transition towards a more urbanized society will need to be anticipated and accompanied in order to ensure good balance and integration between urban and rural environment.

Intensive temperate agriculture systems

Most temperate systems are in high-income countries. Agricultural systems in Western Europe are characterized by the highest level of productivity, associated with high levels of intensification. Intensive farming also occurs in the United States, Eastern China, Turkey, New Zealand, parts of India, Southern Africa and Brazil. These systems are well integrated into global markets and include some of the most active food-exporting areas in the world. Some receive the highest levels of agricultural subsidies in the world.

Some systems do have potential for further expansion: set-aside land in Europe could be put into agricultural use again, and expansion is also possible in both Northern and Southern America. Potential for intensification is very limited in Europe, but still possible elsewhere. However, yield gaps are reducing rapidly in several regions, including Eastern China. Climate change may provide a warming effect in Europe, shifting agro-ecological zones further north and expanding the areas suitable for agriculture. However, less reliable rainfall patterns and more extreme events may cancel out any benefits.

These systems are productive, but often associated with environmental problems. Soil health degradation (compaction, organic matter decline, sealing), pollution of soils and aquifers (leading to health hazards and de-pollution costs), loss of biodiversity and the degradation of freshwater ecosystems are among the main challenges these systems face. The negative environmental impacts associated with such levels of intensification are likely to increase unless they are more carefully managed.

Response options include pollution control and mitigation, conservation agriculture, integrated plant nutrition and integrated pest management. Expansion and intensification will probably happen in response to market pulls, but they need to be carefully planned and monitored to avoid further negative impact on the environment.

Rice-based systems

Rice-based systems are concentrated mostly in Southeast and Eastern Asia, and to a lesser extent in sub-Saharan Africa (Madagascar, Western Africa, Eastern Africa). These regions show distinct characteristics and face quite different types of challenges. In Asia, rice-based systems have high but level productivity and suffer from fragile ecosystems, growing occurrence of droughts and floods, and soil and water pollution. Competition for land, water and labour, and a dynamic economic transition in most of the countries, are placing new stresses on these systems.

Irrigated systems in Asia are at high risk from many drivers. In the already intensive rice-based systems, there is little opportunity for further intensification or expansion, and stresses will grow due to strong competition for land, water and labour from urban settlements and industry. Increased demand for diversified production to serve urban populations, increased rainfall variability, and occurrence of droughts and floods are further challenges faced by these systems, together with land abandonment, loss of buffer role of paddy land, increasing cost of land conservation, health hazards due to pollution, and loss of cultural values of land. Improved water storage, mechanization, diversification (introduction of fish and vegetables), pollution control and PES are among the options that may help these systems respond to a rapidly changing economic environment and climate change.

Rice-based systems in sub-Saharan Africa are, by contrast, low in productivity, mainly due to institutional problems of poor management and governance (in particular in relation to irrigation and water user associations, rapid degradation of irrigation infrastructure and poor market development). These systems show a high potential for both intensification and expansion, but this would require solutions to the institutional and economic problems that have plagued operations up to now. These solutions need to consider market and technologies, better incentives to farmers, access to inputs and improved varieties, and improved governance, management and infrastructure. Several systems would benefit from adapted agronomic packages such as the system of rice intensification, where local systems of water control and topography are suitable. (Uphoff *et al.*, 2011)

Large contiguous surface irrigation systems in dry areas

Large contiguous systems found in the basins of Asia, Northern America, Northern China, Central Asia, Northern Africa and the Middle East suffer from water resource problems of scarcity, overexploitation and competition, and have major negative externalities, including sediment and salinity transport, and impacts on water-related ecosystems. For the large contiguous irrigation systems in dry areas, mostly in Asia, demographic pressure and urbanization will increase pressure on land and water. Very little expansion is expected. Further intensification and diversification are possible through modernization of irrigation service delivery and better soil and water management, but the negative impacts on the ecosystems are likely to deteriorate further with intensification unless corrective action is taken. Climate change is likely to modify the volume and patterns of river flows and increase crop water requirements, with possible imbalance between water availability and demand.

The scope for expansion is very low in many places that have already reached their limits in terms of land or water availability. Where it is still possible, irrigation schemes must be carefully planned, and environmental and social concerns incorporated. Modernization of irrigation schemes (both infrastructure and governance) is needed to improve water service and increase flexibility and reliability in water supply to support diversification. It will also be necessary to develop incentives for efficient use of water, as well as prepare and implement climate change adaptation plans.

Groundwater-dependent irrigation systems

Groundwater-dependent irrigation systems in interior arid plains are found in India, China, central USA, Australia, Northern Africa, the Middle East and elsewhere. They are characterized by the continuing depletion of high-quality groundwater, pollution and salinization in places, leading to the loss of the buffer role of aquifers, loss of agriculture land and desertification. They face competition from cities and industries for a source of good-quality water. Climate change is expected to affect the pattern and style of recharge of these aquifers.

In the places where aquifer depletion is already occurring, there is limited scope for expansion, and it is likely that the extent of agricultural land served by intensive aquifers will progressively shrink as water levels fall, while groundwater use in supplementary irrigation may increase in other areas. Regulatory measures for groundwater withdrawal, more effective water allocation and use, and enhanced water productivity in irrigation are the only options to avoid losing excessive production capacity.

Rangelands

Pastoral and grazing lands are found in all continents. In areas at risk, including West Africa (Sahel), North Africa and parts of Asia, these systems are characterized by decreases in traditional grazing and food use, livestock pressure on land, development of invasive species, fires, fragmentation, sedentarization, conflicts, extreme poverty, food insecurity and out-migration. Such systems are extremely vulnerable to climate variability, which affects the productivity of land. Climate change, through increased temperature and rainfall variability, is likely to accentuate this trend.

Possibilities for expansion are very limited because land is already near or beyond the limit of use, particularly in fragile lands in poor countries. Scope for better land husbandry, while limited, is possible, and depends on economic and climatic conditions and the adoption of better practices, which may include lowering or control of stocking rates, improved rangeland management, controlled grazing practices and better integration with agriculture.

Forest–cropland interface

Forest–cropland interface systems are found mostly in tropical areas (Southeast Asia, the Amazon basin, Central Africa) and in the Himalayas. The main risks are associated with encroachment of agriculture on tropical forests, include loss of biodiversity and forest ecosystem services, introduction of invasive species, pests and diseases, fires, erosion, sedimentation and soil degradation. It is also well established that conversion of forest to cropland represents a net positive contribution to global GHG emissions.

Expansion of cropland encroachment into forests is not desirable in most cases. Possibilities for intensification exist through improved management of forest resources, agroforestry and the establishment of incentives such as PES.

Deltas, coastal alluvial plains and small islands

Deltas, coastal areas and small islands share the characteristics of high population density and vulnerable coastal ecosystems. They are vital for regional food production. Highly populated deltas include the Nile, the Red River, the Ganges / Brahmaputra and the Mekong. Coastal alluvial plains include those in the Arabian Peninsula and Eastern China, Bight of Benin and the Gulf of Mexico. These systems are under heavy demographic pressure and have seen important losses of biodiversity, particularly mangroves. Competition for land and water from industry and urban settlements is growing. They are increasingly polluted (notably by arsenic), and suffer from alkalinization and compaction of soil, and from contamination of shallow alluvial aquifers and underlying systems by industrial causes. Saline intrusion in groundwater and rivers is increasing under the twin effects of reduced flow of freshwater from the rivers and sea-level rise. Groundwater depletion is a common problem of many small islands and coastal areas.

Climate change is expected to affect these systems by sea-level rise, higher frequency of cyclones (Eastern and Southeast Asia), increased incidence of floods and low flows. Risks include loss of agricultural land and groundwater (with possible total loss of freshwater aquifers in small islands) and health-related problems. There is generally no scope for expansion, as competition for land is already strong, and expansion is determined by physiographic considerations and sea-level rise.

The scope for intensification depends on existing levels of productivity, which are, in many places, already very high. Response options include land-use planning, control of groundwater depletion, the establishment of climate change adaptation plans, flood and pollution control, mitigation of arsenic contamination through improved irrigation practices, and implementation of integrated water management strategies at the river basin level.

Peri-urban agriculture

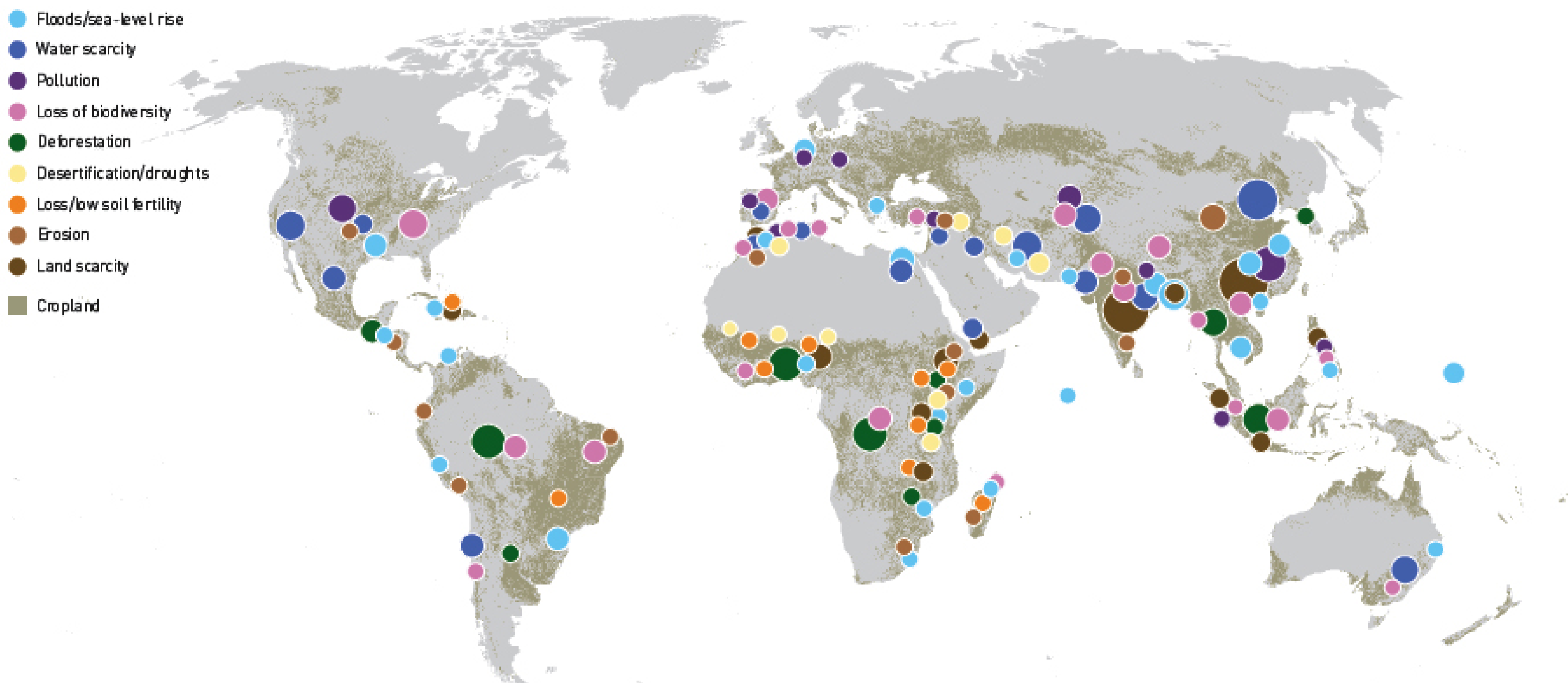
Peri-urban agriculture occurs all across all parts of the world, in response to increasing demand for agricultural products by urban centres. It suffers from scarcity of suitable land, poor land tenure security, limited access to clean water and pollution problems. Peri-urban agriculture will continue to expand where land and water are available, thus taking advantage of dynamic and fast-growing markets associated with urbanization. Health risks, both for producers and consumers, will need to be managed much more systematically than today, particularly where untreated waste-water is used. Better integration of urban and peri-urban agriculture in urban planning would allow such practices to efficiently and safely serve growing cities.

Conclusions

The world's agricultural systems, and the land and water resources on which they are based, have to respond to increasing demand for food and other agricultural products by a growing and richer population. Increase in production is likely to come primarily from sustainable intensification in temperate zones and in irrigated systems in large river basins; from extension of cultivated areas in parts of Latin America and Africa; from sustainable intensification in rainfed areas; and from progressive conversion of some rainfed land to irrigated production where it is economically and technically feasible. Groundwater-based supplemental irrigation will continue to serve an increasingly productive agriculture, where feasible.

Overall, the picture is also that of a world with increasing imbalance between availability and demand for land and water resources at local level: the number of regions reaching the limits of their production capacity is fast increasing. Food trade will compensate for some deficits, but this will have important implications for local

FIGURE 3.4: GLOBAL DISTRIBUTION OF RISKS ASSOCIATED WITH MAIN AGRICULTURAL PRODUCTION SYSTEMS – A SCHEMATIC OVERVIEW



Source: this study

and national food self-sufficiency, and for the livelihoods of rural communities. On the other hand, the intensive agricultural practices associated with past increases in productivity have been accompanied by severe degradation of ecosystems services. On-farm and downstream risks associated with demographic pressure and intensification will persist and worsen in several agricultural systems as long as corrective measures are not taken to reverse this trend. This represents a major challenge to the sustainability of land and water resource management.

Climate change will negatively affect farming systems, in the semi-arid and subtropical areas in particular, impacting water resources and irrigation systems in a number of ways, and requiring major adaptation efforts in most cases. Deltas and coastal areas will be doubly at risk of flooding from sea-level rise and more variable wet-season rainfall. Figure 3.4 gives a schematic overview of the global distribution of risks associated with main agricultural production systems.

In conclusion, a substantial share of the world's land and water resources, and their ecological integrity, are under stress from increasing demand and unsustainable agricultural practices. Further demand from agriculture and other sectors, taken with the anticipated aspects of climate change, will add stress and threaten their future production capacity.