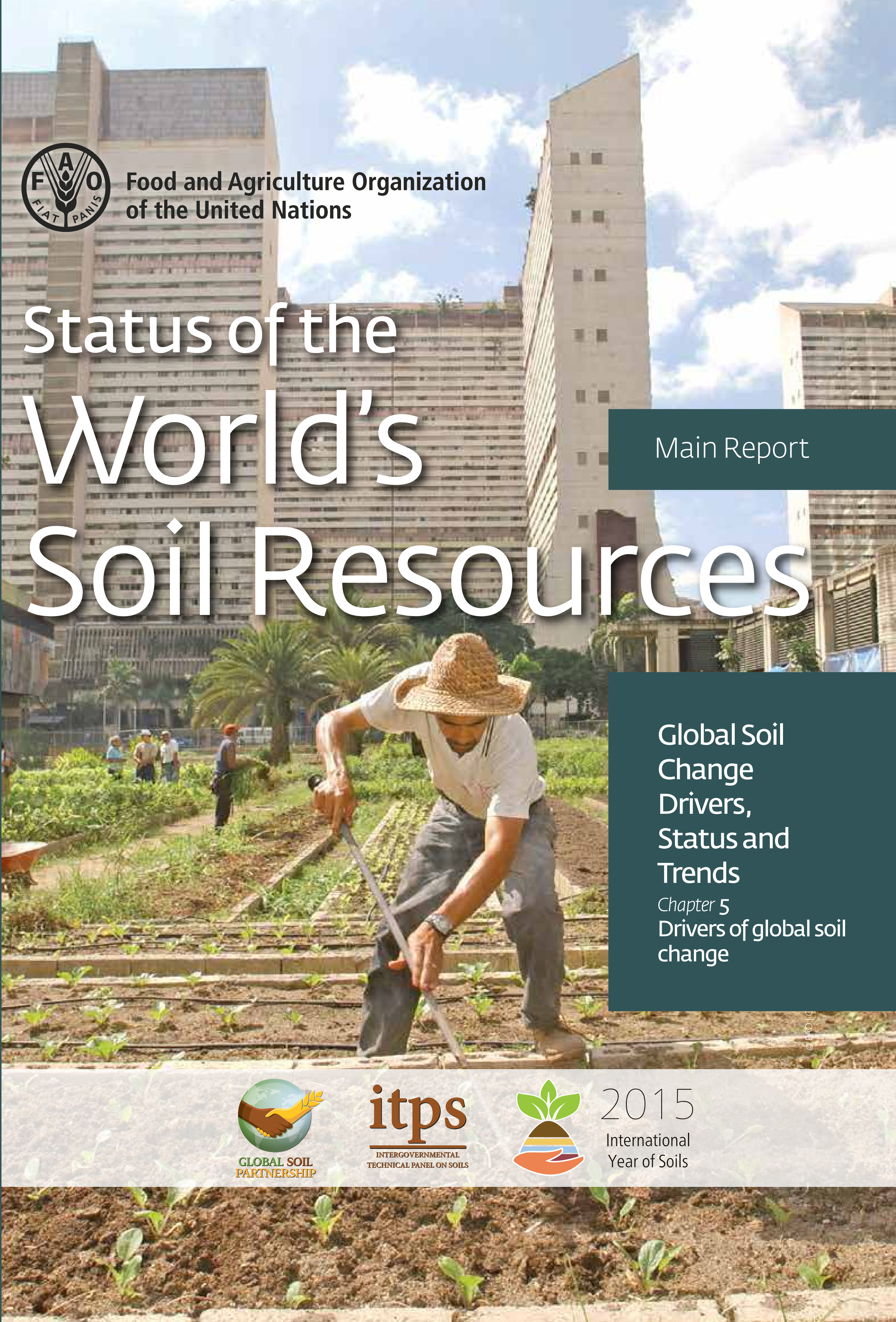

Food and Agriculture Organization of the United Nations

Status of the World's Soil Resources

Main Report

Global Soil Change Drivers, Status and Trends

Chapter 5
Drivers of global soil change

GLOBAL SOIL PARTNERSHIP

itps
INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

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Global Soil Change

Drivers, Status and Trends

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5 | Drivers of global soil change

Drivers in general comprise the factors that bring about socio-economic and environmental changes. They operate at various spatial and temporal levels in society. They differ from one region to another, and within and between nations. Drivers are diverse in nature and they include: demographics; economic factors; scientific and technological innovation; markets and trade; wealth distribution; institutional and socio-political frameworks; value systems; and climate and climate change (UNEP, 2007; IAASTD, 2009). Drivers have an impact on natural resources including soil services and functions, with impacts on biodiversity, environmental health and ultimately human well-being. Globalization has particularly affected these drivers, leading to an increase in human mobility with social, economic and environmental implications. Patterns of settlement and consumption result in pressures on ecosystem services, including those provided by soils. Rural-urban migration and associated livelihood changes contribute to changing patterns of energy use and shifts in diet – for example, towards meat – which can intensify pressures on land and soils in producing areas (UNEP, 2012). In addition, climate change may have significant impacts on soil resources through changes in water availability and soil moisture, as well as through sea level rise (IPCC, 2014b).

5.1 | Population growth and urbanization

5.1.1 | Population dynamics

Changing global population trends

The world population of 7.2 billion in mid-2013 is projected to increase by almost one billion by 2025. By 2050 it is expected to reach 9.6 billion, and to rise to 10.9 billion by 2100 (UN, 2014). The principal factor in this continual rise is the rapid increase in the population of developing countries, in particular in Africa, where the population is projected to increase from the current 1.1 billion to reach 2.4 billion by 2050 (Table 5.1). Many countries of Sub-Saharan Africa are still experiencing fast population growth with high fertility rates. Other countries with similar trends include India, Indonesia, Pakistan, the Philippines and the United States. By 2030

India's population is expected to surpass China's, to become the most populous country in the world. Nigeria's population is expected to surpass the United States population in 2045 to become the world's third most populous country. Nigeria's population is likely to rival that of China by the end of the century (Table 5.2). Over the period 2013–2100, eight countries are expected to account for over half of the world's projected population increase: Nigeria, India, the United Republic of Tanzania, the Democratic Republic of Congo, Niger, Uganda, Ethiopia and the United States of America. On the other hand, Europe's population is projected to decline, since fertility rates are far below the level for replacement of population in the long run. As fertility decreases and life expectancy rises, population ageing is a challenge for Europe (UN, 2014). Other developing countries with young populations but lower fertility (e.g. China, Brazil and India) are also likely to face challenges of an ageing society by the end of this century (Gerland *et al.*, 2014).

Table 5.1 | World population by region

Region	Area (millions of km²)	2013 Population (millions)	Percent of world population	Density (p/km²)	2050 population. (projected)	% of world pop.	% Change 2013-2050
Asia	31.9	4 298	60.0	135	5 164	54.1	20
Africa	31.0	1 110	15.5	36	2 393	25.1	115
Europe	23.0	742	10.4	32	709	7.4	-4
LAC	20.5	617	8.6	30	782	8.2	27
North America	21.8	355	5.0	16	446	4.7	26
Oceania	8.6	38	0.5	4	57	0.6	48
World	**136.8**	**7 162**	**100.0**	**52**	**9 551**	**100**	**33**

Table 5.2 | The ten most populous countries 1950, 2013, 2050 and 2100 (population in millions). Source: United Nations, 2014.

Country	Population in 1950	Country	Population in 2013	Country	Projected Population in 2050	Country	Proj. Popul. 2100
China	544	China	1 386	India	1 620	India	1 547
India	376	India	1 252	China	1 385	China	1 086
United States	158	United States	320	Nigeria	440	Nigeria	914
Russian Federation	103	Indonesia	250	United States	401	United States	462
Japan	82	Brazil	200	Indonesia	321	Indonesia	315
Indonesia	73	Pakistan	182	Pakistan	271	Tanzania	276
Germany	70	Nigeria	174	Brazil	231	Pakistan	263
Brazil	54	Bangladesh	157	Bangladesh	202	Dem. Rep of Congo	262
United Kingdom	51	Russian Federation	143	Ethiopia	188	Ethiopia	243
Italy	46	Japan	127	Philippines	157	Uganda	205

5.1.2 | Urbanization

In tandem with the rate of population increase is the rising rate of urbanization. According to the United Nations, by 2014 more people were living in urban areas (54 percent) than in rural areas. The urbanization trend is expected to continue in all regions, and by 2050, 66 percent of the world's population is projected to be urban. Today some of the most urbanized regions are Northern America (82 percent), Latin America and the Caribbean (80 percent) and Europe (73 percent). However, Africa and Asia are now the fastest urbanizing regions, with the share of the population urbanized expected to rise from today's 40 and 48 percent respectively to 56 and 64 percent by 2050. Three countries together are expected to account for 37 percent of the growth of the world's urban population between 2014 and 2050: India (adding 404 million), China (adding 292 million) and Nigeria (adding 212 million). Whereas in the past mega-cities were located in more developed regions, today's large cities are principally found in lower income countries. Since 1990 the number of these mega-cities has nearly tripled globally; and by 2030, the world is projected to have 41 global agglomerations, housing more than 10 million inhabitants each. In developing countries, the competition between demand for agricultural land and the needs of growing cities is a mounting challenge (Jones *et al.*, 2013).

The rural population globally is now close to 3.4 billion but is expected to decline to 3.2 billion by 2050. Africa and Asia are home to nearly 90 percent of the world's rural population. India has the world's largest rural population (857 million), followed by China (635 million). Rural/urban migration continues to feed urban growth, causing environmental changes including effects on land use and soils. Policy and poverty also drive the threats to land and soils. Many rural poor live under regimes of weak land policy and insecure tenure systems. They often farm marginal lands of low agricultural productivity, typically employing traditional farming methods. This may aggravate soil degradation and biodiversity decline, with resulting yield losses and food insecurity (Jones *et al.*, 2013; Barbier, 2013). In addition, land grabs may lead to eviction of farming families, for whom rural to urban migration may be the only option, so accelerating the pace of urbanization (Holdinghausen, 2015).

5.2 | Education, cultural values and social equity

Education influences decisions regarding land use and land management. Farmers' decisions result from many factors, including incentives, access to capital and risk management, but also from knowledge and level of education, all of which may affect land use and management practices (MA, 2005). Land use and management is dependent on the sum total of all decisions taken by individual farmers of different education and gender groups in a community (IAASTD, 2009).

Women play a key role in agriculture. They represent 43 percent of the agricultural labour force world-wide, ranging from around 20 percent in Latin America to 50 percent in parts of Africa and Asia (FAO, 2011b). Women are responsible for half of the world's food production, providing between 60 and 80 percent of the food in most developing countries (World Bank/FAO/IFAD, 2009). However, evidence shows that women still own less land and have smaller landholdings with generally poor soil quality. Improving women's access to land and secure tenure can have direct impacts on farm productivity and in the long run improve household welfare (FAO, 2013). FAO's *Gender and Land Rights Database* (2010) suggests that less than one quarter of agricultural land holdings in developing countries are operated by women. Latin America and the Caribbean have the largest mean share of female agricultural land holders, exceeding 25 percent in Chile, Ecuador and Panama. In North Africa and West Asia, female landholders represent fewer than five percent of the owners. In sub-Saharan Africa the average rate is 15 percent, although there are wide variations within the region, from less than five percent in Mali to over 30 percent in Botswana, Cape Verde and Malawi (Figure 5.1).

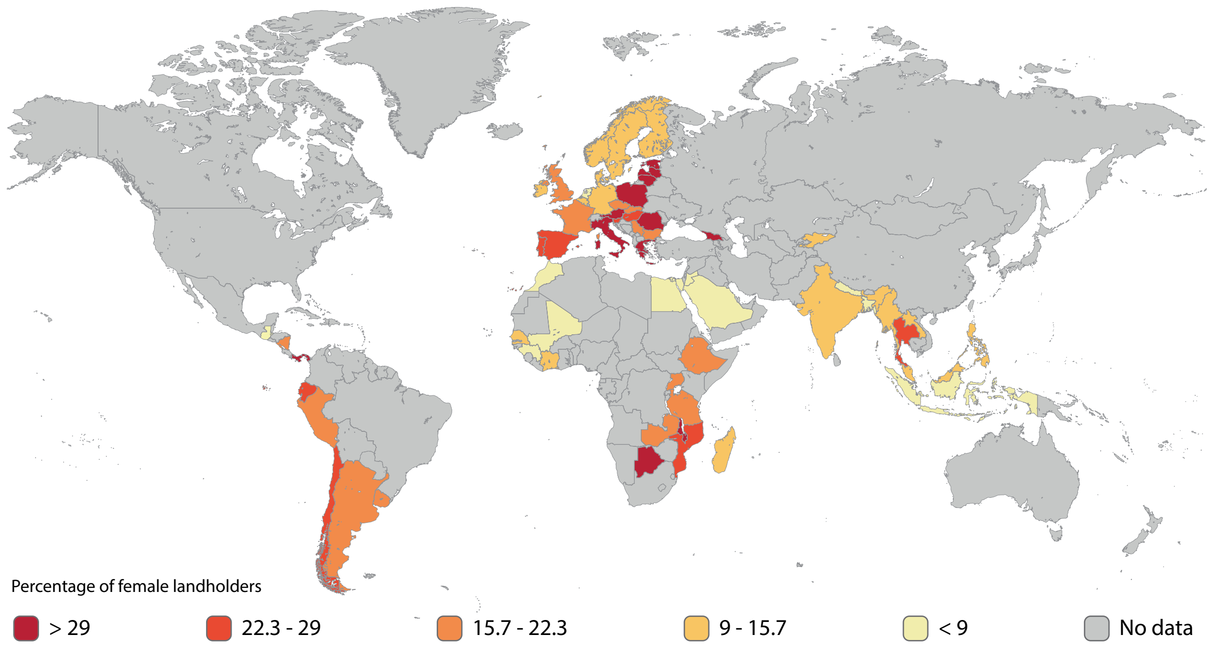

Figure 5.1 | Percentage of female landholders around the world.
Source: FAO, 2010.

5.3 | Marketing land

Today land is used more intensively than ever. The expansion of markets, rising population, and economic development and higher incomes have pushed up demand for land for both agriculture and for settlements and so driven unprecedented land use change (Section 4.1, this volume). The most dramatic changes have been in reduction in forest cover, in expansion and intensification of cropland, and in urbanization (UNEP, 2007). In agriculture, production of crops and livestock products for markets is fundamental to the economies of many countries. One new segment of market-driven production is biofuels, where incentives have strengthened as a result of higher and volatile oil prices and because a number of countries have introduced renewable energy promotion policies (Rulli *et al.*, 2013). North America is leading global biofuel production, with 48 percent of the global market. The second largest producer of biofuels is Brazil, producing 24 percent of the world's biofuels (OECD/FAO, 2011). The growth of biofuels production is driving an increase in deforestation and other land use changes.

It is widely accepted by economists that when land markets function in an efficient manner, the resulting land use patterns provide the highest possible benefits to the society. However, empirical research findings reveal that the functioning of land markets in many developing countries is inefficient and the resulting land use patterns are sub-optimal (Pinstrup-Anderson and Watson II, 2011). Amongst the causes of inefficiencies the following have been cited: lack of well-defined property rights (Allen, 1991; Alston, Libecap and Schneider, 1995; Besley, 1995); higher bargaining power exercised by different groups of buyers (Sengupta, 1997; Ghebru and Holden, 2012); non-existence or under-functioning of insurance markets to absorb risk and uncertainties in the natural environment (such as climate change) (Dayton-Johnson, 2006; Auffret, 2003); and environmental externalities like soil erosion.

Land grabbing - large scale land acquisitions - started initially in response to the 2007-2008 increase in food prices. Since then the phenomenon has intensified (IMF, 2008). Foreign states and companies and national investors, often with the support of the national government, see land as an attractive asset in order to meet the demands of food supply and energy. Experience in Africa, Eastern Europe, South America and South and Southeast Asia has shown that in an unregulated environment this 'land grab' can lead to the displacement of local farmers (Rulli *et al.*, 2013). Since fertile land is a limited resource, competition for it may lead to a rise in poverty, violence and social unrest in countries with weak regulatory systems or power imbalances (Nolte and Ostermeier, 2015).

Large areas of arable land have been bought or leased in recent years, mainly in developing countries (Figure 5.2). According to the Land Matrix Global Observatory database, since the year 2000 over 1 000 land deals involving foreign investors have been struck, covering 39 million ha, while another 200 deals cover 16 million ha. The main driver of large land-scale acquisitions continues to be agricultural production, with 40 percent of deals for food crop production and livestock farming, followed by agrofuels as the second most important driver with 190 deals, and forestry projects which have increased by 50 percent (Land Matrix Newsletter, 2014). Other acquisitions have been for urban expansion, mining, infrastructure projects and tourism (Nolte and Ostermeier, 2015).

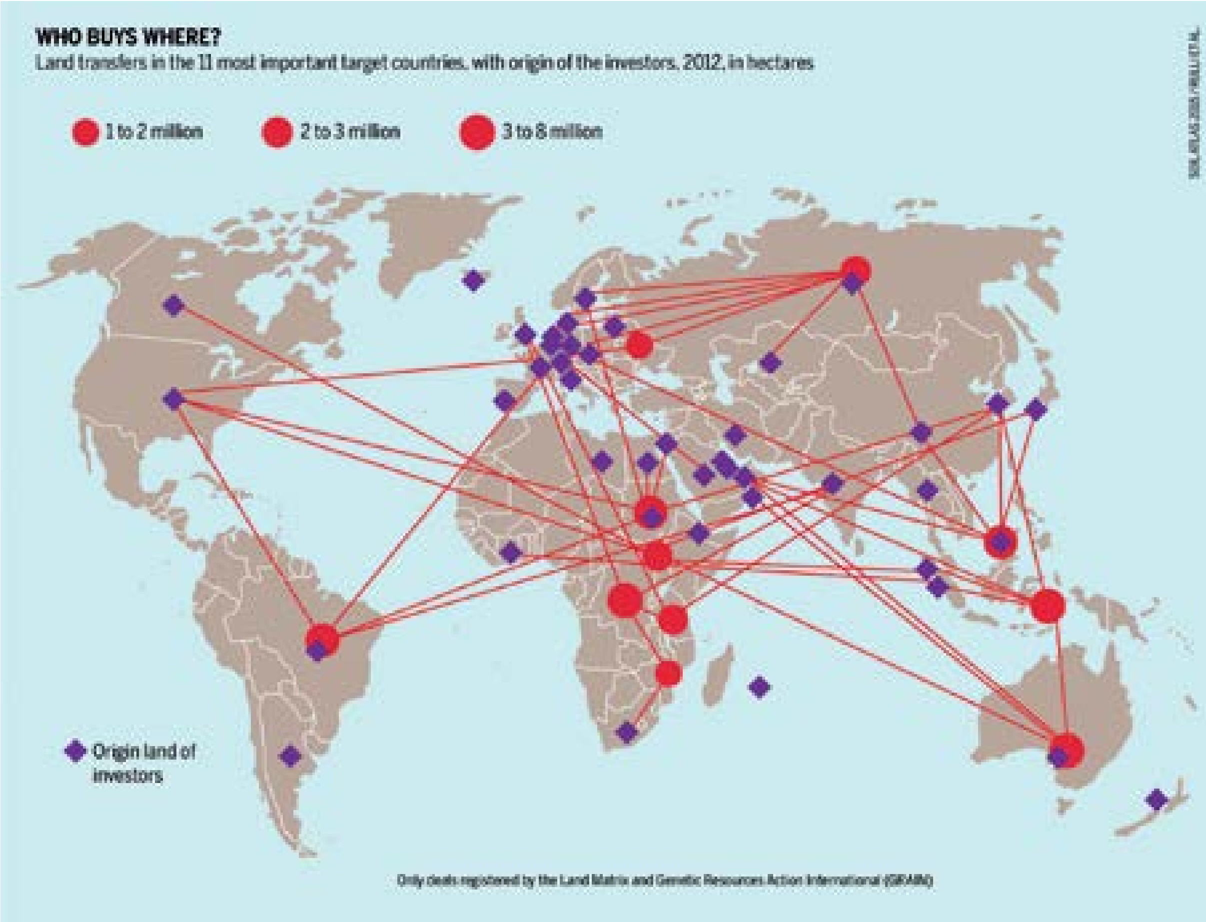

Figure 5.2 | Major land deals occurring between countries in 2012.
Source: Soil Atlas, 2015/Rulli et al., 2013.

In addition to these commercial land transactions, policy responses for climate change adaptation and mitigation have led to market-based approaches which attach a value to ecosystem services. In this context, there is the allocation of land for environmental ends, for example, offsetting emissions in the industrialized North by protecting forests in the South. These approaches in practice have sometimes required curtailment of customary or community access rights to forest and water. In other cases, these approaches have encouraged the shift of smallholder labour from subsistence farming and cash crop production to carbon sequestration (UNEP, 2012). A number of projects focusing on soil health and carbon sequestration in Africa have aimed to benefit individual farmers and at the same time to mitigate climate change. These pioneering projects have faced implementation challenges, including high unit costs, small land sizes, and weak land tenure rights. In addition, the incentive framework has been weakened by the small size of the cash payments the projects can offer for carbon sequestration, due to the low value of carbon credits and periodic market volatility in international voluntary carbon markets. Nevertheless, the non-carbon benefits gained from the projects, such as improved agricultural productivity through sustainable land management and soil health and strengthening of community solidarity, are important results to be prioritized in future projects (Shames, 2013).

5.4 | Economic growth

Economic growth and urbanization generate immense benefits to humankind but also contribute to unsustainable consumption patterns. They may lead to increased levels of emissions from mining, manufacturing, sewage, energy and transport and to the consequent release of persistent pollutants to land, air and water (UNEP, 2012). By 2050 the population around the globe is expected to be generally wealthier and more urbanized, resulting in an increase and shift in consumption and food demand and consequently in a rise in pollution risk. In developing economies, livestock production is already increasing at a rapid rate as a result of structural change in diets and consumption. FAO predicts that the total demand for animal products will increase at more than double the rate of increase in demand for food of vegetable origin, such as cereals (FAO, 2011a). This will lead to the expansion of land dedicated to livestock, both pasture and feed production. The largest expansion is predicted in the tropics, particularly in South America and Africa where vast areas of tropical forests, semi-arid lands, savannah, grassland and wetland ecosystems could be exploited for livestock - with potentially devastating environmental results (Laurance, Sayer and Cassman, 2014). In developing countries, difficult decisions on the trade-offs between preserving natural ecosystems and economic development will be required. In any case, it is likely that agricultural expansion and biofuel production will continue to trigger deforestation, and consequently soil degradation, pollution of land and water and increase in greenhouse gas emissions (FAO, 2003; Alexandratos and Bruinsma, 2012).

Despite improvements in income growth in many countries, poverty and access to food remain problematic. According to FAO (2014), an estimated 842 million people around the world are currently undernourished. The 2007-2008, 2010 and 2012 price hikes in commodity markets evidenced how price shocks can trigger prolonged crises leading to food insecurity amongst the most vulnerable (FAO, 2011b). Global agendas such as those stated in the Sustainable Development Goals and the Post-2015 Agenda argue that environmental stewardship and sustainable management of natural resources provide opportunities to decrease inequality while increasing production of goods and services. However, this is a complicated agenda, as links between human well-being and natural resources, including soils, are influenced by a host of factors, including economic wealth, trade, technology, gender, education etc. Turning these lofty themes into real policies and programs to reduce poverty equitably and sustainably remains the key development challenge for the coming decades (UNEP, 2007).

5.5 | War and civil strife

In the course of history, many conflicts over fertile land have occurred. Until the twentieth century, most of these conflicts were local and had relatively little impact on the soils themselves. However, modern warfare makes use of non-degradable weapons of destruction and of chemicals that may remain in the affected soils for centuries after the conflict. The impacts of war and civil strife on the environment in general, and on soils in particular, are both direct physical impacts and indirect socio-economic impacts.

Direct *physical impacts* of war on the soil resource include weapons and bombs remaining in the soil, the destruction of structures with consequent terrain deformation, heavy military transport that results in compaction, and chemical spraying that leads to contamination of both soils and groundwater. *Socioeconomic impacts* of war include local desertification and displacement of large populations of refugees towards safe regions, resulting in pressure on the environment and soils in the receiving sites (Owona, 2008).

Extensive areas in the world are still affected by remnants of past and present war events. Especially affected are zones where land mines have been buried (Box 5.1), making these soils unsuitable for any exploitation and provisioning of services. There are approximately 110 million mines and other unexploded ordnance (UXO) scattered in sixty-four countries on all continents, remnants of wars from the early twentieth century to the present (Kobayashi, 2013). Africa alone has 37 million landmines in at least 19 countries. Angola is by far the most affected zone with 15 million landmines and an amputee population of 70 000, the highest rate in the world. The problem persists despite campaigns to raise awareness, including the *International Campaign to Ban Landmines* (ICBL), which was awarded the 1997 Nobel Peace Prize. Removal of mines is proceeding, but at a glacial pace due to the danger, the cost (US$300 to US$1 000 per mine removed), and lack of international agreement on priorities.

Box 5.1 | Minefields

Minefields are one of the main constraints to the development of rural areas in Bosnia and Herzegovina (BIH), where large tracts (ca. 4 000 km²) of agricultural land and forest areas cannot be used because they remain mined after the war that ended two decades ago (ICBL, 2002). BIH is the most mine-affected country in Europe with an estimated one million mines (mostly antipersonnel) remaining in the soil, and only 60 percent of which are located (Bolton 2003; Mitchell, 2004). This affects about 1.3 million people, roughly one third of the population. At current rates of de-mining, it will take several generations before rural areas are again safe.

The displacement of people as a result of wars and conflicts has also created severe environmental and soil problems (Box 5.2).

Box 5.2 | Migration/Refugee Camps

Acholiland in northern Uganda has suffered from persistent insecurity since the mid-1980s. The massive disruption, dislocation and displacement and suffering of the people in the region are well-known. As a way of protecting the local people, the government placed most inhabitants of those districts in camps popularly referred to as Internally Displaced Peoples (IDP) camps. As a result, land has been abandoned and farming and other socio-economic activities are only possible near the protected camps in a restricted radius not exceeding seven kilometres. War creates refugees, leaves government and environmental agencies impaired or destroyed, and substitutes short-term survival for longer-term environmental considerations. This means that ecosystems continue to suffer even after the fighting has stopped (Owona, 2008). The Uganda analysis shows that the creation of 157 IDP camps has significantly affected the environment in terms of deforestation (140 km²), soil erosion, habitat destruction and pollution (Owona, 2008).

Often war results in a combination of negative effects on soils. These may include soil compaction, soil contamination, soil sealing and enhanced wind erosion and dust fall out (Box 5.3).

Box 5.3 | Combined effects of war and strife on soils.

During the 1991 Gulf War in Iraq and Kuwait, there were massive impacts on the environment, resulting from heavy vehicle movements, hundreds of oil well fires, numerous oil lakes and spill-outs (Stephens and Matson, 1993; El-Baz and Makharita, 1994; El-Gamily, 2007). The desert ecosystem was severely damaged by the war: the rate of sand dune movement increased while in addition, new sand sheets and sand dunes were formed in several areas where there had been no sheets or dunes previously (Misak *et al.*, 2002; Misak, Al-Ajmi and Al-Enezi, 2009). The building of many fortifications exposed huge amounts of fine particles to wind erosion Off-site impacts included an increase in the rates of sand transport and dust fallout (Misak, Al-Ajmi and Al-Enezi, 2009). The damage remains years afterwards below the surface.

5.6 | Climate change

The IPCC Fifth Assessment Report reveals that the globally-averaged combined land and ocean surface temperature data show a linear trend of global warming due to increases in anthropogenic emissions of greenhouse gases of 0.85°C (90 percent uncertainty intervals of 0.65 to 1.06°C). Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems (IPCC, 2014a).

Climate change will have significant impacts on soil resources and food production in both irrigated and rainfed agriculture across the globe. Changes in water availability due to changes in the quantity and pattern of precipitation will be a critical factor (Turral, Burke and Faurès, 2011). Also, higher temperatures, particularly in arid conditions, entail a higher evaporative demand. Where there is sufficient soil moisture, for example in irrigated areas, this could lead to soil salinization if land or farm water management, or irrigation scheduling or drainage are inadequate. The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff. Soil moisture contents directly simulated by global climate models give an indication of possible directions of change (IPCC, 2014b). For example, using the $HadCM_2$ climate model, Gregory, Mitchell and Brady (1997) show that a rise in greenhouse gas concentrations is associated with reduced soil moisture in Northern Hemisphere mid-latitude summers. This results from higher winter and spring evaporation caused by higher temperatures and reduced snow cover, and from lower rainfall inputs during summer.

The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics (IPCC, 2014b). The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate change. Climate change also may affect soil characteristics, perhaps through changes in waterlogging or cracking, which in turn may affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing. Boix-Fayos *et al*. (1998), for example, show that infiltration and water-holding capacity of soils on limestone are greater with increased frost activity. From this, they infer that increased temperatures could lead to increased surface or shallow runoff. Komescu, Erkan and Oz (1998) assess the implications of climate change for soil moisture availability in southeast Turkey, finding substantial reductions in availability during summer.

The probable effects on soil characteristics of a gradual eustatic rise in sea-level will vary from place to place depending on a number of local and external factors, and interactions between them (Brammer and Brinkman, 1990). In principle, a rising sea level would tend to erode and move back existing coastlines. In coastal lowlands which are insufficiently defended by sediment supply or embankments, tidal flooding by saline water will tend to penetrate further inland than at present, extending the area of perennially or seasonally saline soils.

Climate change such as uncharacteristic droughts or rainfall and flooding have detrimental influences on soil microorganisms, changing the natural growing conditions for a region (Gschwendtner, 2014).

Soil formation is strongly dependent on environmental conditions of both the atmosphere and the lithosphere. Soil temperature is an important factor in this physical, chemical and biological process. Soil temperature is also an important parameter for plant growth. For example, excessive high temperature is harmful to roots and causes lesions of stems, while extreme low temperatures impede intake of nutrients. Extreme low and high soil temperatures also influence the soil microbial population and the rate of organic matter decomposition. Recent studies have shown that soil temperature is one of the main climate factors that influence CO_2 emission. High soil temperatures accelerate soil respiration and thus increase CO_2 emission

(Brito *et al.*, 2005). This has implications for the landscape and for land use. On convex slopes and hilltops, emission is greater than in foothills, where temperatures are normally lower. Soil surface wetness and canopy cover strongly influence the soil's energy balance and soil temperature, whereas variation in soil porosity and soil thermal conductivity have little effect on soil temperature (Luo, Loomis and Hsiao, 1992). The various ways to calculate soil temperature and its trends are discussed in Alavipanah (2006) and Alavipanah *et al.* (2007).

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