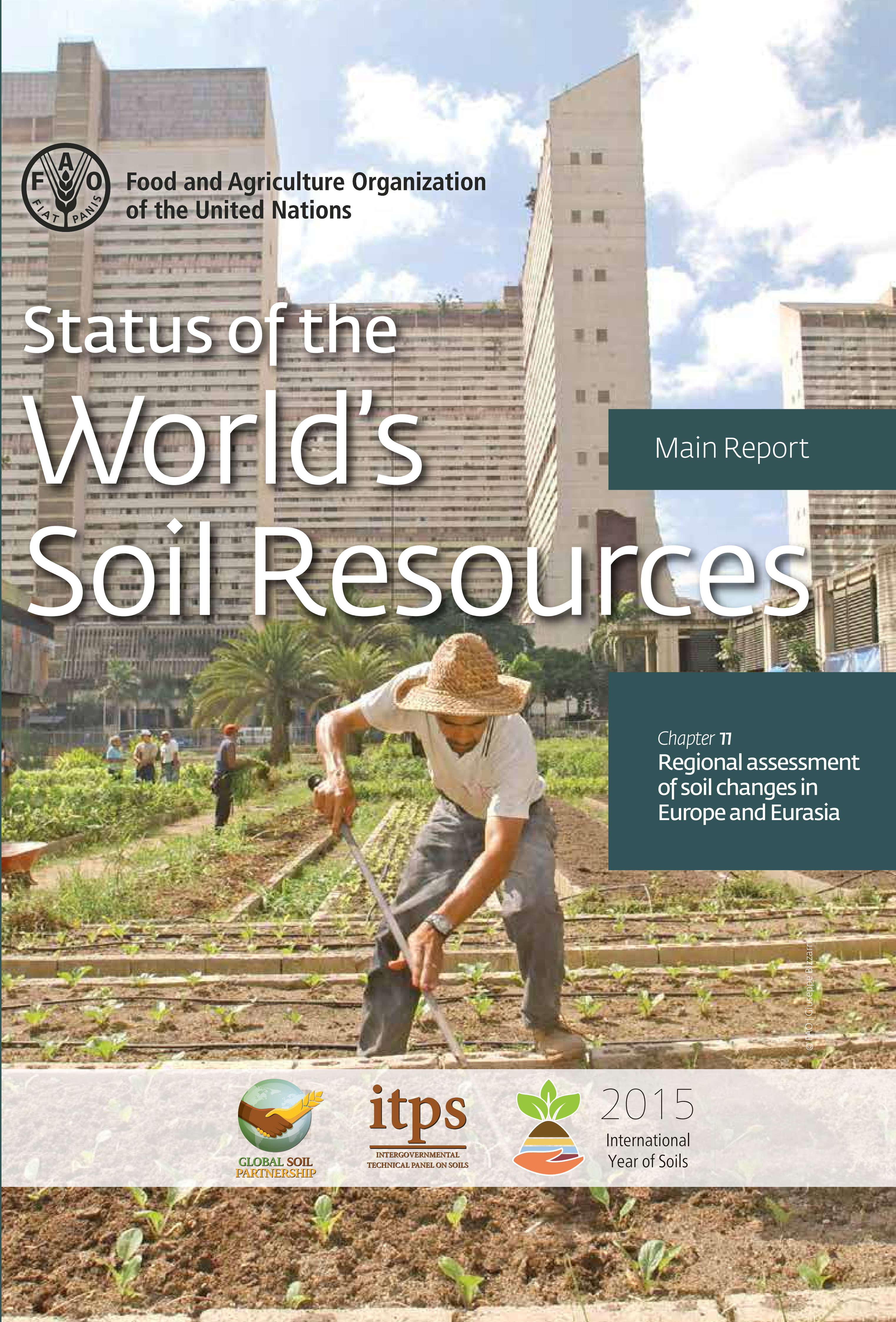
Food and Agriculture Organization of the United Nations

Status of the World's Soil Resources

Main Report

Chapter 11
Regional assessment of soil changes in Europe and Eurasia



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11 | Regional assessment of soil changes in Europe and Eurasia

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11.1 | Introduction

The majority of reports on the global state of soil degradation regard the European region as less disturbed compared with the situation in other regions. According to an ISRIC estimation (Oldeman, 1998), the average cumulative loss of productivity during the post-Second World War period due to human-induced soil degradation was estimated as 7.9 percent while in Africa it was 25 percent, and in Central America it was as high as 36.8 percent. However, the extent of soil degradation in Europe appears to be underestimated, because soil degradation on the territory of the European region has many facets, not all considered in previous estimates.

The processes of human-induced soil degradation started in many parts of the region in ancient times, because many centres of agrarian civilization emerged in Europe and Eurasia several millennia ago: Greece, Anatolia and the Amu Darya delta are just the most remarkable examples. Since that time the pressure on the land has increased because of growing populations and the intensive migration of people due to a decline in natural resources and climatic fluctuations. The western part of the European region in comparison to other regions of the world has a history of over 200 years of industrialization which have placed additional pressures on the soil.

Soil changes can occur naturally but are now under increasing threat from a wide range of anthropogenic pressures. Today these pressures represent the main reason for soil degradation in many parts of Europe. Soil resources are being over-exploited, degraded and irreversibly lost due to poor management practices, industrial activities and land-use changes. These issues in the region threaten soil's key role as the basis for provision of food, feed, fibre and energy as well as for ecosystem services and mitigation of climate change.

Knowledge on the state of soil resources in the region is good because of the generally high development of soil science and soil monitoring in the countries of the region. Nonetheless, an overview of the state of soil resources and of the development of land degradation for the whole region remains difficult because of the lack of harmonization of data, which were often obtained at different times using different methodologies (Jones and Montanarella, 2003; Morvan *et al.*, 2008).

In this chapter, we focus on anthropogenic degradation, e.g. alteration of soil properties induced by human activities that leads to declines in soil productivity and ecosystem services. The human activities in question include improper agricultural use, and soil disturbance and contamination due to urbanization, industrial and mining activities.

11.2 | Stratification of the region

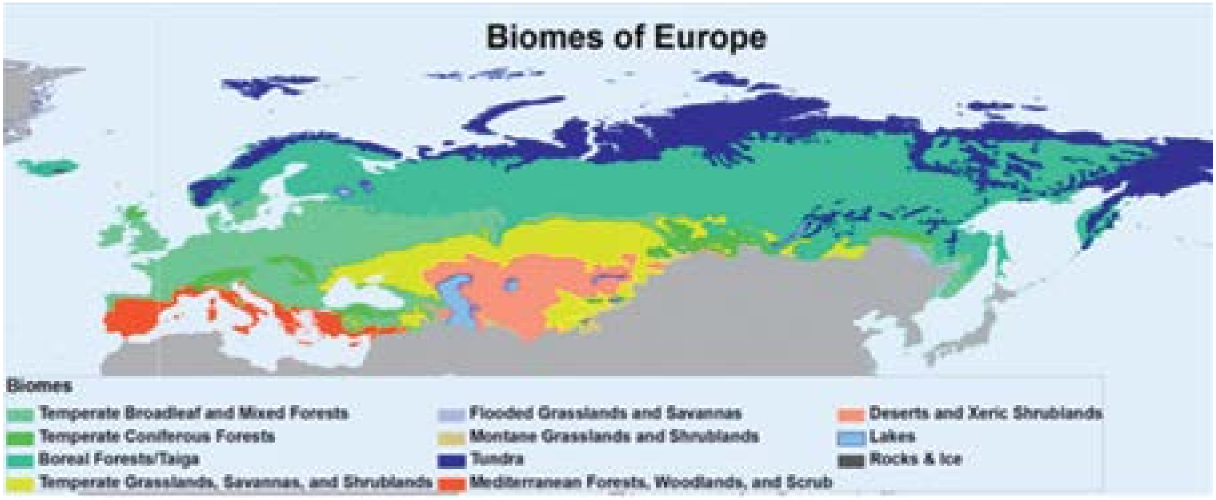
The European region as considered in this report includes Europe *sensu stricto* plus Turkey and Eurasia. This larger definition extending beyond Europe proper entails consideration of a wider diversity of bioclimatic and soil resources and consequently of land use. The importance of agriculture varies among the countries of the region (Table 11.1). In terms of percentage area under agricultural use, the five leaders are Kazakhstan, Moldova, United Kingdom, Ukraine and Turkmenistan and the five least agricultural countries are Greenland, Norway, Finland, Sweden, and the Russian Federation. For the countries with the largest agricultural area, it should be noted that the figures require interpretation. For example, the high percentage of agricultural lands in Kazakhstan does not mean that the country has the highest pressure on natural ecosystems, because almost 90 percent of its agricultural area is in fact occupied by rangelands. The countries with the least percentage of agricultural lands are the coldest countries of the region, where bioclimatic condition do not allow the extension of agricultural activities.

Table 11.1 | The percentage of agricultural land area of total land area in the countries of the European region
Source: FAO, 2015.

Area name	Agricultural area of total land area, percent
Kazakhstan	77.00
Republic of Moldova	76.05
United Kingdom	71.35
Ukraine	71.32
Turkmenistan	69.29
Hungary	64.41
Uzbekistan	63.04
Denmark	62.82
Ireland	62.79
Romania	61.67
Serbia	57.81
Azerbaijan	57.54
Spain	57.44
Netherlands	57.12
Armenia	56.21
Kyrgyzstan	55.96
Greece	55.38
Czech Republic	55.09
Serbia and Montenegro	54.81
France	53.81
Poland	53.17
Turkey	52.27
Luxembourg	49.95
Italy	49.76
Germany	48.59
Bulgaria	47.95
The former Yugoslav Republic of Macedonia	46.78
Belgium	45.57
Belarus	44.20
Lithuania	43.69
Liechtenstein	42.44
Slovakia	42.17
Bosnia and Herzegovina	42.07
Andorra	41.81
Albania	41.69
Channel Islands	41.34
Portugal	41.17
Austria	39.59
Georgia	38.34
Montenegro	38.19
Switzerland	38.11
Tajikistan	33.47
Malta	30.34
Latvia	27.80
Slovenia	24.62
Croatia	21.98
Estonia	20.45
Iceland	18.43
San Marino	16.67
Cyprus	15.38
Russian Federation	13.17
Sweden	7.66
Finland	7.47
Norway	3.39
Greenland	0.57

The internal stratification within the region and within countries, including the extent of agricultural lands, depends mainly on bioclimatic conditions which determine agro-ecological zones. According to standard agro-ecological zoning (Fischer *et al.*, 2002), the European region lies in the following agro-ecological zones: Arctic (only Greenland and Russia); Boreal continental (Eastern Russia); Boreal sub-continental (Russia, Scandinavian countries, Greenland); Boreal oceanic (Iceland and Greenland); Temperate continental (Russian and Kazakhstan); Temperate sub-continental (Eastern and Central Europe, Turkey, South Caucasian countries, Russia, Central Asian Countries); Temperate oceanic (Western, Central and Northern Europe); Sub-tropical with winter rainfall (Southern Europe, Turkey, South Caucasus); and Sub-tropical with summer rainfall (only small areas in Spain and southern France).

The other approach for characterizing the internal stratification of the region is its division according to the major biomes. The digital map of terrestrial eco-regions presented below (Figure 11.1) delineates the major biomes found in the European region, based on the World Wildlife Fund's eco-regions (The Nature Conservancy, 2009).



Prepared by EU JRC

Figure 11.1 | Terrestrial eco-regions of the European region.
Source: Olson et al., 2001.

In brief, the relation of these major zones to agricultural development and soil degradation processes is the following:

Polar and tundra, and taiga zone

This zone represents a treeless polar ecosystem located in high latitudes in the European region in Russia and Scandinavia. The climate is characterized by long winters with months of total darkness and extremely frigid temperatures. Vegetation is mainly scattered, although sometimes it can be patchy, reflecting changes in soil and moisture gradients. Most precipitation falls in the form of snow during winter time. Soils tend to be acidic and saturated with water where not frozen. The region is sparsely populated, with agriculture in the tundra limited to reindeer grazing. Thus agricultural pressure on soils is not very strong; however huge areas are affected by mining and petroleum extraction. Some land degradation processes are triggered by humans indirectly. For example, in Siberia the processes of permafrost melting due to climatic change is resulting in the alteration of topography and causing severe damage to roads and buildings. Waterlogging is also a challenge in many areas.

Boreal forest/taiga

These ecosystems cover extensive areas in northerly latitudes and with low annual temperatures. There are large expanses in central and eastern Russia, with medium precipitation of 40-100 cm yr^{-1}, partly in the form of snow. Predominant tree species are coniferous including *Abies*, *Picea*, *Larix* and *Pinus* as well as deciduous such as *Betula spp*. And *Populus spp*. The ground cover is mainly dominated by mosses and lichens. These biomes are known for slow regeneration of mature forests, due to the challenging climate and soil conditions. Forests are sensitive to acid rain and other forms of pollutant. Agriculture in the taiga is restricted to relatively small areas used for livestock and production of such crops as rye, flax, millet and vegetables. Some two decades ago, soil acidification induced by industrial contamination of the atmosphere, so called 'acid rain', was an important menace to soil quality in these areas. However, today the pressure of technogenic acid precipitation is considerably reduced (Jones *et al.*, 2011).

Broad-leaf and mixed forest zone

This zone stretches across the European region from the British Isles to Western Siberia, and most of this territory is actually under cultivation. In the temperate climate, forests experience a wide variability in temperature and precipitation. Species such as oak (*Quercus* spp.), beech (*Fagus* spp.), birch (*Betula* spp.) and maple (*Acer* spp.) typify the composition of this biome. Structurally, these forests are characterized by four layers: a canopy composed of mature full-sized dominant species; a slightly lower layer of mature trees; a shrub layer; and an understory layer of grasses and other herbaceous plants. In contrast to tropical rain forests, most biodiversity is concentrated much closer to the forest floor. The zone has a favorable humid climate and soils with a relatively high natural productivity. Anthropogenic pressure is, however, strong due both to the intensive practice of agriculture and to high population density. The main threats to soils in this zone are water erosion favoured by intensive deforestation, and soil sealing and capping due to the high urbanization rate and dense infrastructure. In addition, the high degree of industrialization in this biome results in extensive contamination of the soils.

Temperate coniferous forest

This ecosystem is also known as 'temperate evergreen forest'. It sustains the highest levels of biomass of any terrestrial ecosystem after tropical rainforest. The area has warm summers and cool winters, resulting in a high variation of the vegetation, e.g. needle leaf trees, broadleaf evergreen trees or a mix of both types. Temperate evergreen forests are common in the coastal areas of regions with mild winters and heavy rainfall, or inland in drier climates or hilly areas. Predominant tree species include pine, cedar, fir and redwood. This biome is mostly located in mountainous regions and the use of these areas is not very intensive.

Temperate grassland zone

This zone possesses the soils with the highest natural productivity such as Chernozems and Kastanozems. This high potential results in an intensive use of the land for agriculture which in places occupies up to 90-95 percent of the total land area. The main threats to soils in this zone are water and wind erosion. These processes are the main reasons for the loss of organic carbon in soils; however, the loss of carbon by mineralization from arable lands is also a common process. Since the population density and the development of industry are high in this zone, soil sealing and capping and contamination are also threats. In places, especially in endorheic valleys, soil salinization may be observed.

Mediterranean zone

This zone by definition is typical of the regions around the Mediterranean Sea. The ecosystems are characterized by hot and dry summers with cool and moist winters, with precipitation mostly during the winter months. Plant species are uniquely adapted to the stresses caused long, hot and dry summers. Most of the vegetation is adapted to fire and in fact depends on this disturbance for its sustainability. Some wildlife species undertake seasonal migration according to resource availability. The natural communities in this biome are highly sensitive to habitat fragmentation, grazing, and alteration of fire regimes (over-burning or fire suppression). Native species are also at risk from exotic species that easily establish and spread. To maintain the natural communities fire regimes need to be managed and exotic species controlled (WWF, 2014). The ecosystems and soils are vulnerable due to the dryness of climate and to the abundance of shallow limestone soils. In many countries, transformation of pastures represents a serious problem. Erosion, organic carbon loss and decline in biodiversity are the main challenges for areas with Mediterranean climate. In places soil salinity may also limit the agricultural use of soils.

Sub-arid and arid zone

This zone includes deserts and semi- deserts, mostly located in Central Asia but also in some areas of Anatolia (Camci Çetin *et al.*, 2007) and in the Iberian Peninsula. The vegetation in this zone is sparse, and all the ecosystems are subject to desertification. The main threats to soils in the zone are salinization, sodification, and wind erosion. Salinization is a natural process in many areas, also favored by initially saline parent material of marine origin. However, the most menacing process is irrigation-induced soil salinization, which leads to a drastic decline in soil fertility.

11.3 | General threats to soils in the region

Soil threats in the European region are complex, and although they are unevenly spread in the region, their dimension is continental and they are frequently inter-linked. If not managed, soil threats will lead to soil degradation, and the capacity of the soil to carry out its vital ecosystem functions will be lost. When many threats occur simultaneously, the combined effect tends to aggravate soil degradation (Jones *et al.*, 2005). Climate change is likely to affect soil quality and cause land degradation through changes in soil moisture content (Calanca *et al.*, 2006; Wong *et al.*, 2011; García-Ruiz *et al.* 2011). For example, throughout central and northern Europe, evapotranspiration has increased by about 0.3 mm day^{-1} and this has the potential to deplete the normally adequate soil water store and limit plant growth. More frequent and severe droughts may cause plant cover to reduce leading to the onset of erosion and desertification (Jones *et al.*, 2011). However, the precise impacts of climate change on soil degradation in Europe are still uncertain (Kovats *et al.*, 2014). General threats to soils in the European region include the following.

(1) Erosion by wind and water

A recent report (Jones *et al.*, 2011) estimated that in the 1990s 105 million ha, or 16 percent of Europe's total land area (excluding Russia), were affected by water erosion, and that 42 million ha were affected by wind erosion. A new model of soil erosion by water constructed by the JRC has estimated the surface area affected in EU-27 at 1.3 million km^2, with almost 20 percent subject to soil loss in excess of 10 tonnes ha^{-1} yr^{-1}. In Russia the area affected by medium and strong water erosion is 51 million ha, 26 percent of the agricultural land area and about 3.5 percent of the total land area (Ministry of Natural Resources, 2006). In Ukraine the area affected by water and wind erosion is about one third of all agricultural land, or 14.4 million ha. In Moldova the area affected by water erosion is about 840 thousand ha, one third (33.6 percent) of the total area of arable lands in the republic (Leah, 2012). In Belorussia the area affected by water erosion is 467 thousand ha, and by wind erosion 89 thousand ha; totally eroded lands cover about 10 percent of the territory of the country. In Turkey, where 80 percent of soils are located on slopes steeper than 15 percent, the area affected by moderate, severe and very severe erosion is 61.3 million ha, or 78.7 percent of the total area of the country; wind erosion is active on about 500 thousand ha (Senol and Bayramin, 2013). The area of eroded soils in South Caucasus varies between 35 and 43 percent of total agricultural lands, aggravated by the mountainous topography of the region. In Central Asia as a whole, the total area affected by water erosion is over 30 million ha, and by wind erosion about 67 million ha: in Uzbekistan up to 80 percent of agricultural land is affected by water erosion, and in Tajikistan the area of agricultural lands affected by water erosion is estimated by different sources at between 60 and 97 percent (CACILM, 2006). Long-term observations in Russia show that soil erosion on average decreases the yield of leguminous crops by 15 percent, of wheat by 32 percent, of potatoes by 45 percent, and of perennial grasses by 25 percent (State Committee of Russian Federation on Land Resources and Land Planning, 1999).

(2) Soil organic carbon change

Organic matter is a key component of soil, controlling many vital functions (Jones *et al.*, 2011). The loss of organic matter in soils is due both to erosion and to the increased rate of mineralization of organic carbon in arable soils. Methodologically, it is difficult to separate erosion and mineralization-driven loss of humus in soils. However, soils with negligible erosion loss commonly also lose organic carbon under cultivation. The rate of soil organic matter loss differs between mineral and peat soils. In the latter group, soil degradation after drainage may be fairly quick, producing an intensive flux of carbon dioxide to the atmosphere and in places leading to complete mineralization of the organic layer and exposure of infertile underlying sediments. This threat is discussed in detail in Section 11.4.3 below.

(3) Soil contamination

Due to more than 200 years of industrialization, soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. The number of sites where potentially polluting activities have taken place now stands at approximately three million. The issue is discussed in detail below in Section 11.4.1.

(4) Soil acidification

Acidification involves the loss of base cations (e.g. calcium, magnesium, potassium, sodium) through leaching and their replacement by acidic compounds, mainly soluble aluminum and iron complexes. Acidification is always accompanied by a decrease in a soil's capacity to neutralize acid, a process which is irreversible in nature except over very long periods. Regulatory controls initiated in recent decades to mitigate global warming have had a significant impact on the emissions of pollutants that cause acidification, mainly by decreasing SO_2 emissions. By 2020, it is expected that the risk of ecosystem acidification will only be an issue in some hot spots, in particular in the border area between the Netherlands and Germany (EEA, 2010a). Recovery from acid deposition is characterised by decreased concentrations of sulphate, nitrate and aluminium in soils. An increase in pH and acid-neutralising capacity (ANC) coupled with higher concentrations of base cations would, in turn, improve the potential for biological recovery. However, given the delay in the response of soil to decreases in acid deposition, many decades are likely to be required for affected sites to recover fully. Additional information on trends in acidification is presented in the SOER 2010 Air Pollution Assessment (EEA, 2010a).

(5) Salinization and sodification

In Europe, salinization is generally the result of the accumulation of salts from irrigation water and fertilizers. High levels of salt eventually make soils unsuitable for plant growth. Improper irrigation and the use of highly mineralized irrigation water lead to rapid accumulation of soluble salts in soil profiles. This form of salinization affects approximately 3.8 million ha in Europe. Though a number of practices of saline soil reclamation exist, most of them are expensive and not very effective, and all of them are site-specific. This makes salinity control a challenging task. Geographically this threat is localized in the drier parts of the region, mostly in central Asia, in southern Russia, in Turkey, Azerbaijan, Greece, Hungary, and Spain. This threat is discussed in more detail in Section 11.4.4 below.

(6) Waterlogging

Waterlogging occurs in many soils affected either by a high groundwater table or by rainwater stagnation due to poor permeability. Most waterlogged soils have excessive moisture due to natural causes, but waterlogging may also be caused by improper irrigation practices or through disturbance of landscape hydrology by construction, mining and traffic activities. The Russian Federation is the country that has the most extensive area of waterlogged soils in the world. Excessively moist soils, both mineral and organic, occupy 360 million ha (21 percent of the total area of the country). Among the agricultural lands of Russia 23.9 million ha or 10.1 percent are waterlogged. Unlike Russia, where the distribution of waterlogging is mostly due to natural reasons, in Central Asia excessive moisture is caused by irrigation. In Uzbekistan, the groundwater table is less than 2 meters below the surface in about one-third of irrigated lands. The area of waterlogged land varies from 40 percent in the Fergana Valley to 80 percent in downstream Amu Darya. In dry areas, waterlogging is commonly associated with salinization.

(7) Nutrient imbalance

The situation with the balance of nutrients in soils is much better in the European region than in most other parts of the world. However, there is considerable heterogeneity in the distribution of nutrients in soils. In Western Europe, the concentration of nutrients in soils is high due to application of high doses of fertilizer (Grizzetti, Bouraoui and Aloe, 2007). The absolute leader in the use of nitrogen fertilizers is the Netherlands, where in places the dose exceeds 170 kg of N per ha. Germany, France and the United Kingdom also apply nitrogen fertilizers intensively. The highest doses of phosphorus fertilizers – in doses higher than 21 kg P per ha – are used in some regions of Italy, Spain, France and Greece. These regions are running a risk of contaminating the ecosystem with excessive fertilizers (e.g. for France: Lemercier *et al.*, 2008, Follain *et al.*, 2009). In Eurasia, by contrast, the use of fertilizers is much lower, although Russia and Belorussia are major exporters of mineral fertilizers. The restricted use of fertilizers in these countries is in part due to the high natural productivity of their soils, but is also due in part to economic reasons. Underutilization of fertilizers in Central Asia is caused by the fact that small farmers cannot afford them or make money out of them.

(8) Compaction

Compaction can be induced by the use of heavy machinery in agriculture. Compaction reduces the capacity of soil to store and conduct water, makes it less permeable for plant roots and increases the risk of soil loss by water erosion. Estimates of areas of Europe at risk of soil compaction vary. Some authors estimate that 36 percent of European subsoil has a high or very high susceptibility to compaction (Jones *et al.*, 2011). Other sources report 32 percent of soils as being highly susceptible and 18 percent as being moderately affected (Jones *et al.*, 2011). In Russia and Central Asia, soil compaction is also a challenge, especially where soils are naturally susceptible to compression, for example, in soils with *vertic* or *natric* properties, or in heavy textured soils. These kinds of soils are located mainly in the southern part of the Russian Federation, and in many places in Kazakhstan, Uzbekistan, Kyrgyzstan and Tajikistan.

(9) Sealing and capping

Sealing occurs when agricultural or non-developed land is lost to urban sprawl, industrial development or transport infrastructure. It normally includes the removal of topsoil layers and leads to the loss of important soil functions, such as food production, water storage or temperature regulation. The population of the Europe is approximately 11 percent of the world population (740 million) and it has grown at a rate of 0.15 percent a year during the last decade. The urbanization rate is high, particularly in the small and highly developed countries of Western Europe. It is the rapid and intensive expansion of urban and industrial development onto soils that makes soil sealing an important challenge for Europe. The issue is discussed in more detail in Section 11.4.2 below.

11.4. Major threats to soils in Europe and Eurasia

11.4.1 | Soil contamination

Local contamination of soils is generally associated with intensive industrial activities, inadequate waste disposal, mining, military activities or accidents. Management of these contaminated sites is a tiered process starting with a preliminary survey (searching for sites that are likely to be contaminated), followed by site investigations where the actual extent of contamination and its environmental impacts are defined, and finally remedial and after-care measures.

As discussed above (11.3.3), the number of sites where potentially polluting activities have taken place in Europe now stands at approximately three million. Due to improvements in data collection, the number of recorded sites is expected to grow as investigations continue. If current trends continue and no changes in legislation are made, the numbers reported above are expected to increase by 50 percent by 2025 (Jones *et al.*, 2011; EEA, 2014). There is some evidence of progress in remediation of contaminated sites, although the rate is slow. In recent years, around 17 000 sites have already been treated while many industrial plants have attempted to change their production processes to generate less waste. In addition, most countries now have legislation to control industrial wastes and prevent accidents. In theory, this should limit the introduction of pollutants into the environment. However, recent events – such as the flooding of industrial sites in Germany during extreme weather events which led to the dispersal of organic pollutants, and the collapse of a dam at an aluminium plant in Hungary in October 2010 – show that soil contamination can still occur from potentially polluting sites. Trends in the deposition of heavy metals from industrial emissions are discussed in the SOER 2010 Assessment on Air Pollution (EEA, 2010b).

Diffuse soil contamination is one of the specific threats to soils in European region. Even though this form of pollution may be only barely apparent or may not even be directly apparent at all, it can cover very large areas. The contaminants include inorganic compounds such as metallic trace-elements and radionuclide, and organic compounds like natural and xenobiotic molecules. Radionuclides originate from nuclear accidents and nuclear tests, but there are also other sources such as fertilizer application (P). The most common xenobiotic chemicals include PAH, PCB and many pesticides still in use or inherited from the past (e.g. DDT and its metabolites).

The economic feasibility of soil surveys is hindered by the diversity of contaminants – particularly of persistent organic pollutants (POPs), which are in constant evolution due to agrochemical developments – and by the transformation of organic compounds in soils by biological activity into diverse metabolites. The most widespread metallic trace elements in European soils comprise notably As, Cd, Cr, Cu, Hg, Ni, Pb, Zn, which are mobilized in one place but may then be transported to distant areas.

The real extent of diffuse soil contamination by metallic trace elements is not clearly known. Even though some EU member states and other countries have already implemented long-term soil surveys, they lack a harmonized soil monitoring system.

The case study of Austria (Section 11.5.1) includes the description of: (I) local and diffuse pollution affecting Austrian soils; (II) the effect of regulation on contamination trends; and (III) the remediation activities being carried out.

11.4.2 | Sealing and capping

Soil sealing is especially intensive in Western Europe. On average, built-up and other manmade areas account for around 4 percent of the total area in EEA countries (data exclude Greece, Switzerland and the United Kingdom), but not all of this is actually sealed (EEA, 2009). EU member States with high sealing rates exceeding 5 percent of the national territory are Malta, the Netherlands, Belgium, Germany and Luxembourg (EC, 2011).The EEA has produced a high resolution soil sealing layer map for the whole of Europe for the year 2006 based on the analysis of satellite images. Much more detail can be found in the SOER Assessments on the Urban Environment (EEA, 2010c) and Land Use (EEA, 2010d), as well as in EC (2011).

Productive soil continues to be lost to urban sprawl and transport infrastructure. Between 1990 and 2000, the sealed area in the EU-15 increased by 6 percent and at least 275 ha of soil were lost per day in the EU, amounting to 1 000 km² per year. Between 2000 and 2006, the EU average loss increased by 3 percent, but by 14 percent in Ireland and Cyprus, and by 15 percent in Spain (EC, 2011). A study by Huber *et al*. (2008) provides an interesting insight into the development of baselines and thresholds to monitor soil sealing. See also the SOER 2010 Assessment on Land Use (EEA, 2010b) for additional details on urbanisation.

Soil sealing causes adverse effects on soil functions, or even their complete loss, and it prevents soil from fulfilling important ecological functions. Fluxes of gas, water and energy are reduced which affects, for example, soil biodiversity. The water retention capacity and groundwater recharge function of soil are reduced, resulting in several negative impacts such as a higher risk of floods. The reduction in the ability of soil to absorb rainfall leads to rapid flow of water from sealed surfaces to river channels, resulting in damaging flood peaks. Above-ground biodiversity is affected through fragmentation of habitats and the disruption of ecological corridors. These indirect impacts affect areas much larger than the sealed areas themselves. Built-up land is lost for other uses such as agriculture and forestry, as the soils which are sealed are often fertile and high value soils. Soil sealing appears to be almost irreversible and may result in an unnecessary loss of good quality soil. Soil sealing can lead to the contamination of soil and groundwater sources because of higher volumes of unfiltered runoff water from housing, roads and industrial sites. This is exacerbated during major flood events, as was demonstrated by the 2002 floods on the Elbe which deposited levels of dioxins, PCBs and mercury from industrial storage areas onto the soils of floodplains, well in excess of national health thresholds (Umlauf *et al*., 2005).

In the Russian Federation the density of population is low and the area of settlements constitutes only 0.3 percent of the national territory. However, the vicinities of megacities suffer intensive urban sprawl which takes land out of agriculture.

11.4.3 | Soil organic matter decline

Soil organic matter is essentially derived from residual plant and animal material, transformed (humified) by microbes and decomposed under the influence of temperature, moisture and ambient soil conditions. The stable fraction of organic substances in soil is known as complexed organic matter (previously referred as humus). Soil organic matter (SOM) plays a major role in maintaining soil functions because of its influence on soil structure and stability, water retention and soil biodiversity, and because it is a source of plant nutrients.

The primary constituent of SOM is soil organic carbon. Some 45 percent of soils in Europe have low or very low organic matter content (0–2 percent organic carbon). This is particularly evident in the soils of many southern European countries, but is also the case in parts of France, the United Kingdom, Germany, Norway and Belgium. A key driver is the conversion of woodland and grassland to arable crops.

The soils of EU-27 Member States are estimated to store between 73 and 79 billion tonnes of carbon, which is equivalent to almost 50 times annual greenhouse gas emissions from the EU. However, intensive and continuous arable production may lead to a decline of soil organic matter. In 2009, European cropland emitted an average of 0.45 tonnes of CO_2 per hectare, much of which resulted from land conversion (EEA, 2011).

The conversion of peatlands and their use is particularly worrying. For instance, although only 8 percent of the farmland in Germany is on peatland, it is responsible for about 30 percent of the total greenhouse gas emissions of its whole farming sector (EC DG Environment and JRC, 2010). However, with appropriate management practices, soil organic matter can be maintained and even increased. Apart from peatlands, particular attention should be paid to the preservation of permanent pastures and the management of forests soils, as carbon age in the latter can be as high as 400-1 000 years (EC DG Environment and JRC, 2010). Maintaining carbon stocks is essential for the fulfilment of the present and future emission reduction commitments of the EU.

In Russia more than 56 million ha of mineral soils on agricultural land are characterized by the loss of organic matter (Shoba *et al.*, 2010), in Ukraine, the area subject to loss of SOM is 18.4 million ha (Laktionova *et al.*, 2010), and in Moldova more than 1 million ha (Leah, 2012). Turkey was reported to be losing SOM from about 70 percent of its agricultural soils (Senol and Bayramin, 2013), but the rate and extent of dehumification are unknown yet. In the South Caucasus republics, the loss of soil organic matter is not well documented, largely because in mountainous countries it is hard to separate out erosion and mineralization-driven loss of humus. A similar situation exists in the data reported for Central Asia: the cultivation of virgin lands in Kazakhstan resulted in the loss of approximately 570 million tonnes of carbon from soils, but a significant part has been transported by the wind.

Several factors are responsible for a decline in SOM and many of them relate to human activity: conversion of grassland, forests and natural vegetation to arable land; deep ploughing of arable soils; drainage; fertiliser use; tillage of peat soils; crop rotations with reduced proportion of grasses; soil erosion; and wild fires (Kibblewhite *et al.*, 2005). High soil temperatures and moist conditions accelerate soil respiration and thus increase CO_2 emissions (Brito *et al.*, 2005). Excess nitrogen in the soil from high fertiliser application rates and/or low plant uptake can cause an increase in mineralisation of organic carbon which, in turn, leads to an increased loss of carbon from soils. Maximum nitrogen values are reached in areas with high livestock populations, intensive fruit and vegetable cropping, or cereal production with imbalanced fertilisation practices. While in extreme situations, the surplus soil nitrogen can be as high as 300 kg N ha^{-1} (EC, 2002), estimates show that 15 percent of land in the EU-27 exhibits a surplus in excess of 40 kg N ha^{-1}. For reference, while rates vary from crop to crop, the IRENA Mineral Fertiliser Consumption Indicator (EEA, 2005a) estimates that average application rates of nitrogen fertiliser for EU-15 in 2000 ranged from 8 to 179 kg N ha^{-1}.

There is growing realisation of the role of soil, in particular peat, as a store of carbon and recognition of soil's role in managing terrestrial fluxes of atmospheric carbon dioxide (CO_2). Other than in tropical ecosystems, soil contains about twice as much organic carbon as above-ground vegetation. Soil organic carbon stocks in the EU-27 are estimated to be between 73 to 79 billion tonnes, of which about 50 percent is to be found in the peatlands and forest soils of Sweden, Finland and the United Kingdom (Schils *et al.*, 2008). Peat soils contain the highest concentration of organic matter in all soils. Peatlands are currently under threat from unsustainable practices such as drainage, clearance for agriculture, fires, climate change and extraction. The current area of peatland in the EU is estimated at more than 318 000 km^2, mainly in the northern latitudes.

While there is no harmonised exhaustive inventory of peat stocks in Europe, the CLIMSOIL report (Schils *et al.*, 2008) estimated that more than 20 percent (65 000 km^2) of all peatlands have been drained for agriculture, 28 percent (almost 90 000 km^2) for forestry and 0.7 percent (2 273 km^2) for peat extraction. The degradation of organic soils is especially pronounced in Belorussia, where about 190 thousand ha of peat soils are strongly degraded: the peat layer was completely mineralized, and infertile sands were exposed on an area of 18.2 thousand ha. In the Russian Federation, the mineralization of peat has occurred on extensive drained areas with Histosols located mainly in the north of the European part of the country. The total area of drained peatland in Russia was estimated as 3.86 million ha (Inisheva, 2005), but the area of deeply degraded drained peat soils is unknown. Extensive areas of previously drained peatland have been abandoned as agriculture has shifted to more climatically favorable regions closer to markets. These dry peatlands are subject to fires in dry summer periods; in 2010 peat fires in Central European Russia caused an ecological catastrophe, driving millions of people from their homes and disrupting air transportation because of dense smoke over thousands of square kilometers. Another common practice in Russia is forest drainage, designed to improve forest productivity in waterlogged areas. Currently about 3 million ha of forested organic soils are drained in Russia, mainly in the European part. Though productivity has increased, the loss of organic carbon from soils is also evident. In Ireland, peatlands are widely used for energy production. Annual production of peat in the country peaked in 1995 at 8.0 million tonnes (Devlin and Talbot, 2014).

11.4.4 | Salinization and sodification

While naturally saline soils exist in certain parts of Europe, the main concern is the increase in salt content in soils resulting from human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water and/or poor drainage conditions. Locally, the use of salt for de-icing can also be a contributing factor. The primary method of controlling soil salinity is to use excess water to flush the salts from the soil. In most cases where salinization is a problem, this must inevitably be done with high quality irrigation water.

Thresholds to define saline soils are highly specific and depend on the type of salt and land use practices (Huber *et al.*, 2008). Excess levels of salts are believed to affect around 3.8 million ha in Europe (EEA, 1995). While naturally saline soils occur in Spain, Hungary, Greece and Bulgaria, artificially induced salinization is affecting significant parts of Sicily and the Ebro Valley in Spain and more locally in other parts of Italy, Hungary, Greece, Portugal, France and Slovakia (Figure 11.2).

In the post-Soviet countries, saline soils cover the most extensive areas in Kazakhstan, Russia, Uzbekistan, Turkmenistan, Ukraine, and Azerbaijan (Figure 11.3). In other countries saline soils are present only locally, either on marine marsh deposits or in areas of salt mining. In Belorus, salt-affected soils occupy less than 1 thousand hectares around the potassium fertilizer mines in Solikamsk region. The area occupied by saline soils in different countries is shown in Table 11.2.

Table 11.2 | The areas of saline soils in the countries with major extent of soil salinization in the European region

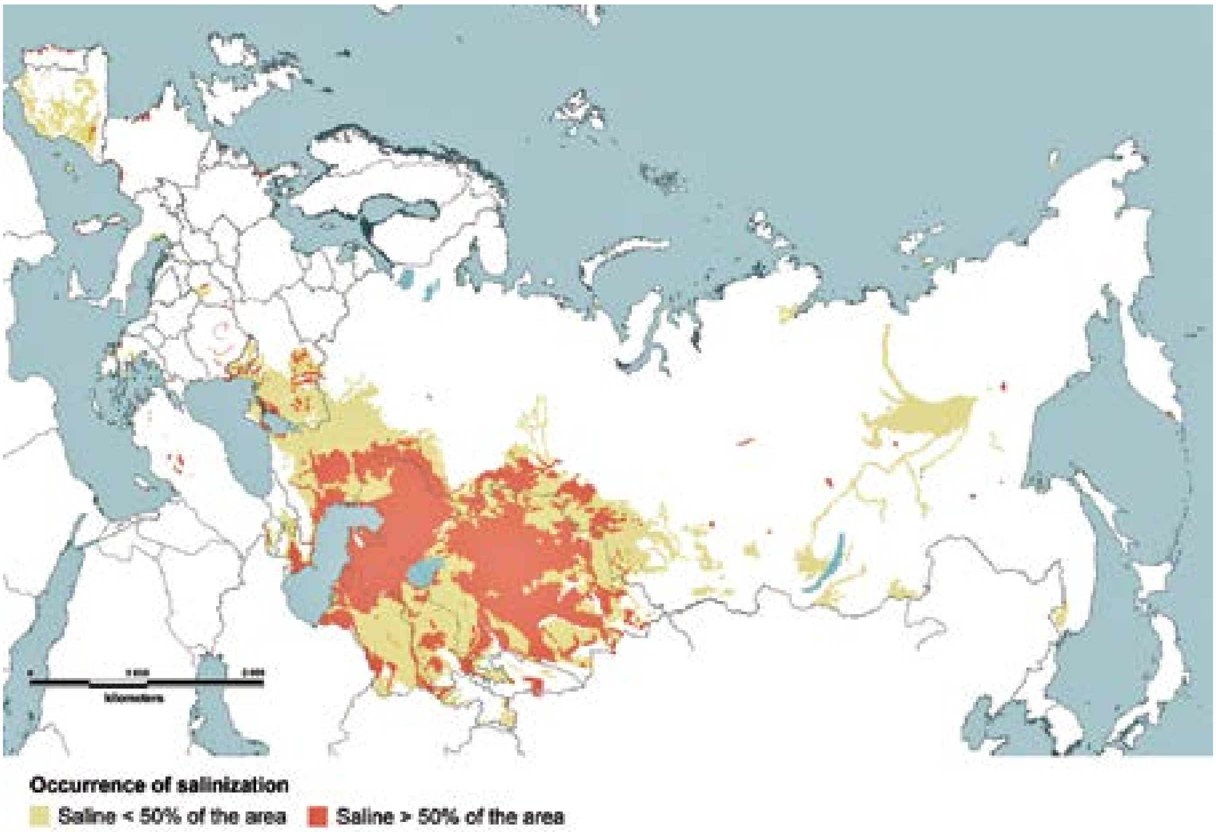
Country	Area of salt-affected soil (million ha)	Data source
Kazakhstan	111.5	Borovskii, 1982
Russia	54.0	Shishov and Pankova, 2006
Uzbekistan	20.8	Kuziev and Sektimenko, 2009
Turkmenistan	14.1	Pankova, 1992
Ukraine	4.0	Novikova, 2009
Turkey	1.5	Senol and Bayramin, 2013
Spain	0.63	Tóth *et al.*, 2008
Hungary	0.56	Tóth and Szendrei, 2006
Azerbaijan	0.51	Ismayilov, 2013

Kazakhstan

The area of saline soils in Kazakhstan, including Solonetz, alkaline soils, and complexes of Solonetz with other soils, is 111.55 million ha, or 41 percent of the national territory (Borovskii, 1982). Saline soils are present everywhere in the country except in mountainous areas. They are common in the steppe zone, where they cover about 30 percent of the area. In dry steppe, semi-desert and desert zones these soils occupy up to 50 percent of the area. Salt-affected soils are represented mainly by Solonetz and alkaline soils. Solonchaks cover only 1–3 percent of the area of salt-affected soils in the steppe zone, and 7–13 percent of the area of salt-affected soils in the semi-desert and desert zones.

Russian Federation

The area of salt-affected soils in Russia, including Solonetz, alkaline soils and combinations of salt-affected soils with other soil groups, is 54 million ha or 3.3 percent of the total area of the country. The category of salt-affected soils includes all the soils with a salic horizon starting within the first 1 meter. Salt-affected soils in Russia are located in the European part of the country and in Eastern Siberia within the steppe, dry steppe and semi-desert zones. The major part of the area is occupied by Solonetz and alkaline soils. In Eastern Siberia and in the Far East, salt-affected soils are localized in closed inter-mountain basins with dry steppe landscapes and semiarid to arid climate. In Yakutia (Sakha), salt-affected soils form over permafrost in thermo-karst depressions (so-called alases) in taiga larch forest. Sporadically saline soils are present along the northern and eastern shores of the country, but their area is insignificant (Shishov and Pankova, 2006).



Prepared by I. Alyabina

Figure 11.2 | Soil salinization on the territory of the European region.
Source: Afonin et al., 2008; Toth et al., 2008; GDRS, 1987.

Uzbekistan

The area of salt-affected soils in Uzbekistan is 20.8 million ha, or 46.5 percent of the country's territory. Saline soils are everywhere in the country except in mountainous regions and well drained flood valleys. Salt-affected soils are represented by Solonchaks in closed depressions and the bottom of the largely dried-up Aral Sea, by Salic Calcisols in uplifted areas such as the Ustyurt plateau and the Kyzyl-Kum desert, by Takyric Salic Fluvisols in the alluvial and deltaic plains, and by extensive irrigated soils of various grades of human-induced salinization.

Turkmenistan

The area of salt-affected soils in Turkmenistan is 14.1 million ha or 28.7 percent of the total area of the country. These soils are distributed all over the country, but the major concentration is in the western part of the country close to the Caspian Sea. Most of these soils are not classified as Solonchaks and belong to the groups of Salic Calcisols and Takyric Salic Calcisols.

Ukraine

The area covered by salt-affected soils in Ukraine is about 4 million ha or 6.6 percent of the national territory (Novikova, 2009). Most of these lands are not used in agriculture; they are located largely in the southern and eastern parts of the country within the steppe and forested steppe zones. Most of these soils are classified as Solonetz and other soils with various grades of alkalinity.

Turkey

The major areas with salt-affected soils in Turkey are: Konya-Eregli, the Aksaray and Malya plains of Central Anatolia, and the alluvial plains of lower Seyhan, Igdır, Menemen, Bafra, Söke, Acıpayam and Salihli. The distribution of the salt-affected arable lands is: 60 percent slightly saline, 19.6 percent saline, 0.4 percent alkali and 8 percent saline-alkali. Although sodium salts are the main components of the salt-affected soils, there are also magnesium soils in Denizli-Acıpayam, potassium-nitrate-alkali soils in Nigde- Bor, Kayseri, and gypsiferous soils in Central Anatolia.

Spain

In Spain 3 percent of the 3.5 million ha of irrigated land is severely affected, reducing markedly its agricultural potential, while another 15 percent is at serious risk. Soil salinization is a frequent problem in arid and semiarid regions like Southeast Spain (Hernández Bastida, Vela de Oro and Ortiz Silla, 2004). In these areas, demand for water for agriculture and increasing frequency of drought events have led farmers to irrigate with poor quality water. This has caused processes of soil degradation and salinization, limiting crop growth and impairing productive capacity (Pérez-Sirvent *et al.*, 2003; Acosta *et al.*, 2011).

Hungary

In Hungary Solonchak soils, which are by definition saline soils, occupy a total area of only 4.7 thousand ha. They are mainly located in low-lying areas, typically along the shorelines of saline/sodic lakes in the region between the Danube and Tisza Rivers, but they also occur in patches east of the Tisza River. These soils are not cropped, but sustain native halophyte vegetation which is grazed. Solonchak-Solonetz soils with a total area of 65.9 thousand ha are also found largely between the Danube and Tisza Rivers, but above deeper groundwater levels of around one metre. These soils also sustain a native halophyte vegetation which is grazed. Mollic Gleyic Solonetz soils occupy a total area of 274.9 thousand ha and are characterized by large exchangeable sodium percent and a not very high salt content. Mollic Solonetz soils, with a total area 212.2 thousand ha, have only minor limitations for cultivation of crops and are typically under arable farming.

Azerbaijan

The area of salt-affected soils in Azerbaijan is estimated to be 510 thousand ha or 5.9 percent of the territory of the country. The saline soils are located mainly on the coastal plain of the Caspian Sea, in the Kura-Araksinskaya depression and in the Salyan, Mugansk, and Milsk plains. These soils are represented mainly by Solonchaks, Salic Gleysols and, in rare cases, by Salic Calcisols.

While several studies show that salinization levels in soils in countries such as Spain, Greece and Hungary are increasing (De Paz *et al.*, 2004), systematic data on trends across Europe are not available.

11.5 | Case studies

11.5.1 | Case study: Austria

Austria is a relatively small country that is land-locked in central Europe and shares borders with eight countries (Gentile *et al.*, 2009). Austria's location in the middle of Europe gives rise to specific environmental issues such as the pressures from intensive freight transit traffic (e.g. air emissions, habitat disruption) and the trans-boundary exchange of acidifying air pollutants and tropospheric ozone precursors (e.g. damage to forests and soil). In addition, only 37 percent of the national territory is suitable for permanent settlements.

This is due to the country's geo-morphological conditions with more than 60 percent of the territory occupied by mountains. As a consequence, urban sprawl and land consumption occurs in restricted areas, with resulting high pressures on the environment.

Overall, the Austrian soils are in a good condition, but their ecological functionality is at risk from diffuse and local accumulation of pollutants, intensive use of land, sealing and erosion. The more affected areas are located in the Alpine region, where forest soils are threatened by air deposition, and in urban areas, where sealing and contamination put urban soils under a growing pressure. Sealing is also present in rural areas due to the increasing urban sprawl and new road construction. In arable land, According environmental measures within Cross Compliance in arable land a treatment of the soil is prohibited, if the soil is water-satisfied. Soil erosion is higher on steeper slopes and land under permanent crops (vineyards, orchards), as well as on land cultivated with maize, sugar beet, potatoes and vegetables.

The use of heavy machinery, especially in case of wet soil conditions, often results in the compaction of the topsoil, which can reach in some cases the subsoil layer. Soil compaction mainly occurs in areas with intensive agriculture and, locally, in other areas due to forest management activities. According environmental measures within Cross Compliance in arable land a treatment of the soil is prohibited, if the soil is water-satisfied.

Floods happen occasionally in the floodplains of eastern Austria after extraordinary weather conditions (heavy rainfalls) whereas landslides occur quite often in the alpine regions with steep slopes. Adequate management measures for the protection of forests and afforestation, as well as technical engineering measures, are being implemented to prevent the consequences of such events and reduce the risks.

Salinization is found in the areas around the lake Neusiedl, which is located in the north-eastern part, at the Hungarian border. Salinization is causing problems only in small areas with intensively managed and irrigated agricultural soils. Information on decline of organic matter is scarce. Some areas of arable land show low organic matter content. The evaluation of the Austrian environment programme for agriculture (ÖPUL) concerning organic matter contents in soil showed positive trends.

Contamination from heavy metals is mainly due to long-range trans-boundary air pollution, especially in forest soils due to the high filter capacity of vegetation cover and the barrier effects of the Alps to air mass circulation. Contamination by heavy metals and persistent organic pollutants can also be found in restricted areas originating from different sources, e.g. local industrial sources, traffic especially near bigger population centres or agricultural sources.

The restructuring of the industrial sector and in particular the decline of the heavy industry in the 1990s did not have observable effects on environmental pressures. Despite the decrease of the overall production, the contribution of this sector to the overall emissions is still considerable. Adverse effects of soil degradation are still to be expected, despite the continuing improvement in the implementation of regulations and the reduction of pollutant emissions, since many pollutants (e.g. heavy metals) are accumulating in the soil. The major indirect impacts are on biodiversity and the quality of groundwater resources.

The threats to soil in Austria

Contamination

Diffuse contamination

Soil surveys targeted at the four most relevant heavy metals (mercury, lead, cadmium and copper) showed increased lead and cadmium concentrations in topsoil with respect to background values in the regions of the Northern and Southern Limestone Alps. This may be attributed both to local sources of pollution and to long-range trans-boundary air pollution. Lead enrichment is particularly high in grassland and forest soils – the latter due to the high filtering effect of the vegetation cover. The guidance values for lead established by the Austrian Standard (Önorm, 1975, 2004[1]) were exceeded in more than 5 percent of monitored grassland sites, and in more than 3 percent of forest sites. Cadmium concentrations exceeded the guidance value in 5 percent of the monitoring sites in forests and in 6 percent of the sites in grassland areas.

On the other hand, soil pollution with mercury and copper only occurs in restricted areas. In particular, copper contamination can be found mostly in the surroundings of industrial sites processing copper ore and in areas with intensive animal husbandry. The latter is due to the application of high amounts of pig manure with high copper content, of which the source is copper-enriched ready-made food. Other sources of copper inputs in soil are sewage sludge and compost as well as the application of pesticides containing copper. About 2 percent of the forest and grassland monitored sites exceeded the guidance value for copper.

Contamination from Persistent Organic Pollutants (POPs) was found in a limited number of sites, some of which required to be cleaned-up. POP pollution mainly occurs in urban areas and around industries. It can also derive from long-range trans-boundary air pollution. Emissions of POPs have been substantially reduced in the past years. This should have resulted in lower concentrations in the soil. However, a systematic survey targeted at organic pollutants in soil has not been carried out. For this and other reasons, such as the low mobility of these pollutants and the appearance on the market of new chemical products, the importance of POP pollution may be expected to increase in the future (Umweltbundesamt, 2004, 2007b).

Contamination from local sources

In Austria, soil contamination requiring clean up may be present at 2 500 sites. Potentially polluting activities are estimated to have occurred at 80 000 sites (including the 2 500 sites already mentioned) and investigation is needed to establish whether remediation is required. Approximately 70 heavily contaminated sites have been cleaned up in the past two decades. Industrial production and commercial services, municipal and industrial waste treatment, and oil storage are reported to be the most important sources of heavy contamination. National reports indicate that heavy metals, polycyclic aromatic hydrocarbons, cyanides and mineral oil are the most frequent soil contaminants at investigated sites. Nearly two-thirds of the remediation expenditure come from public budgets. Although considerable efforts have been made already, it will take decades to clean up the legacy of contamination. New contamination is not expected due to the implementation of prevention measures in place.

Salinization

In Austria, salinization is of little relevance as compared to other soil threats. According to an agricultural soil mapping survey carried out in the period 1958-1970, the areas where soil is affected by salts amounted to only 2 500 ha. Conditions for potential salinization do occur in small areas in Eastern Austria. These are areas with a negative water balance, salt-sensitive soils, a low groundwater table and salty groundwater.

1 An ÖNORM standard is a national standard published by the Austrian Standards Institute. ÖNORMs are voluntary standards drawn up in committees of the Austrian Standards Institute

Future changes in climate and land management practices could lead to the salinization of soils also in these areas. In addition, soda-containing soils are estimated to cover only 2 000 ha. In these areas, strict rules for agricultural production apply.

Erosion

Soil erosion in Austria is mainly increased by unsustainable agricultural practices, construction of buildings and roads, and the use of leisure infrastructures. National estimates report that about 13 percent of the agricultural land or more than 5 percent of the total territory is potentially under a high risk for water erosion. The spatial distribution of potential erosion risk is very heterogeneous. The most affected areas include the productive areas of the southeast and northeast plains and hills, the Alpine foreland and the Carinthian basin (Strauss and Klaghofer, 2006).

Except for the results of some scientific studies, Information on wind erosion is scarce. Loss of soil by wind has been observed in the lowlands of Eastern Austria. Areas at risk are sandy soils and, in the dry season, some areas covered with black soils (chernozems). In the past, some measures, such as reforestation of lowlands, were carried out to protect soil against wind. New windbreaks are planted annually, thus increasing the protected areas by several thousand hectares per year. The presence of wind erosion risk in sandy areas has been acknowledged since the 18th century. This early recognition of the problem and the measures adopted have resulted in the stabilisation of erosion in these areas (Strauss and Klaghofer, 2006).

Soil erosion is not expected to increase in the future due to the implementation of prevention and reduction measures such as the measures included in the national Agri-Environmental Programme. In 2008 these measures reduced the soil erosion rate by 3 to 18% depending on the region, in average by 10 percent (AGES, 2011). However, major pressures may come from future climate and land use changes (conversion of grassland into arable land) or significant changes in crop rotation, although these are not very likely to occur.

Decline in soil organic matter

According to the results of a recent monitoring programme that measured the content of organic carbon in topsoil, more than half of all grassland and forest sites in Austria have a content of organic matter in topsoil of over 8 percent, which is comparatively high by global standards. On the other hand, in arable land, most of the monitored sites show an organic matter content ranging from 2 percent to 4 percent (medium by global standards), while a low or very low content (< 2 percent) is found in a quarter of the sites. In the areas with low organic matter content, the natural soil functions will be at risk in the long run (Umweltbundesamt, 2004). Measurements of organic matter content in topsoil also provide an indication of the content in soil organic carbon.

Overall, the organic carbon stock in Austrian soils is not expected to decline in the future, due to the implementation of soil organic matter preservation measures in agriculture. Such measures of the national Agri-Environmental Programme have increased the humus content of arable soils from 1991-1995 until 2006-2009 by 0.1 up to 0.4 percent depending on region (AGES, 2011).

Sealing

Following the general trend in Europe, the sealing of the soil due to the increase of built-up areas and transport infrastructure has shown a growing trend in Austria in the past decades, although population has increased only slowly.

In total, about 7 percent (or around 5 500 km²) of the country area is occupied by buildings or transport infrastructures, and about 56 percent of this area is sealed. About half of the new residential buildings in 2001 were single family dwellings or semi-detached houses which, in comparison to multi-family residences or other high-density structures, occupy a considerably larger surface area (Umweltbundesamt, 2006). In the period 2012-2014, the average increase in built-up areas was about 19 ha day^{-1}. This resulted in a daily increment of soil actually sealed of 10 ha in 2012 and 2014. This figure still exceeds by a factor eight the relevant policy target (Umweltbundesamt, 2007a). These high rates may lead to the saturation of the available space in some regions. In Vorarlberg, for example, 29 percent of the permanent settlement area is already built-up.

These increases are due to changes in the standard of living and in lifestyles and to the development of associated settlement and transport activities, rather than to population growth. This is particularly evident in rural regions where the built-up area continues to grow despite a net decrease in population.

Hydro-geological risks

Erosion and erosion control have been a major issue for a long time in Austria, due to the country's specific geo-morphological configuration. More than 60 percent of the territory is occupied by mountains. The focus of past and current activities is on the control of torrents and avalanches, as these are major threats to human life in alpine environments (Strauss and Klaghofer, 2006).

According to BMLFUW (Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Managemen[2]), about 67 percent of the territory may be classified as either part of a torrent watershed, avalanche watershed or a general risk area. The regional coverage ranges from 16 percent in Burgenland to 91 percent in Tyrol. The amount of budget available for measures against these risks increased from 70 million EUR in 2001 to 148 million EUR in 2009.

In case of extraordinary weather conditions (heavy rainfalls), floods happen occasionally in the floodplains of eastern Austria. The flood events in August 2002 affected large parts of the national territory. Particularly Upper Austria and Lower Austria suffered heavy damage, as floods reached areas that were previously considered as safe. More details on this event can be found in the special chapter on floods of the 7th national State of Environment report (Umweltbundesamt, 2004).

Cross-cutting issues

Brownfields

In general, the remediation of contaminated sites based on fit-for-use remediation goals should be seen not only as bringing an improvement to the status of the environment through the restoration of soil functions but also as bringing benefits to economy and society. In Austria, there is a potential for brownfield redevelopment. The average consumption of green-field areas for housing and traffic was 7 ha day^{-1} in 2014. On the other hand, only 37 percent of the national territory is suitable for permanent settlements.

According to an unofficial definition, brownfields are sites of formerly industrial or commercial land, now derelict or underused, or sites that have been affected by former uses of the site or surrounding land. The latter may require intervention before they can be returned to beneficial use, particularly where there are contamination problems. The number of brownfield sites in Austria is in the range of 3 000-6 000, covering an area between 8 000 and 13 000 ha. According to estimates based on their previous use, about 85 percent of the industrial brownfield sites may present no or little contamination problem and could be revitalised and reused without public funding for remediation.

2 http://www.bmlfuw.gv.at/en.html

Considering an increase of industrial brownfield sites of about 3 ha per day, about a quarter of the annual land requirement for housing and economic activities could be saved by reconverting brownfields to a productive use. Some measures have been proposed to this end. These include policy measures, sustainable and innovative land management, and mechanisms for the involvement of stakeholder groups. However, redevelopment activities are yet to be started. For more details see (Umweltbundesamt, 2007b).

Soil services

The main soil services in Austria include:

- protection of groundwater and spring water in mountain areas, resulting in the availability of water in sufficient quality and quantities (about 99 percent of drinking water supplies originate from groundwater and spring water)
- high diversity and mosaic distribution of geology and soils, which enables a high level of diversity of landscapes and biodiversity
- availability of highly productive soils for agricultural and forestry production
- availability of soils for building purposes, although this function is limited due to the relatively small permanent settlement area available (37 percent of the total area of the country)
- The main impacts of soil degradation in Austria are:
- biodiversity decline from soil sealing and contamination
- impairment of groundwater quality from diffuse pollution and local contamination - there may be 2 500 sites in Austria needing remediation, of which less 3 percent have been cleaned up since 1989
- destruction of natural landscapes from soil sealing and unsustainable agricultural practices

Hot spots

The Alpine region is an environmentally sensitive area with a high level of diversity of landscapes, soils, flora and fauna. This region is under threat of acidification and contamination from deposition of air-borne pollutants on the one hand, and from erosion and landslides because of its steep slopes on the other hand.

Some industrial areas are seriously contaminated from diffuse sources. These include, in particular, the city of Linz, the Inn valley in the Tyrol, and Arnoldstein in Carinthia. In addition, a high concentration of sites which are potentially contaminated can be found in the most urbanised and industrialised regions, in particular the cities of Vienna, Linz and Salzburg, the Inn valley in the Tyrol and the Mur and Mürz valley in Styria.

Outlook

Soil resources in Austria are on average in a good condition; however soil functions are still being threatened by the deposition of airborne pollutants, by a legacy of contamination in industrial and urban areas, and by the continuing increase in the built-up area.

There are some uncertainties on future trends of soil contamination due to the lack of data on the presence of organic pollutants in soil and the appearance on the market of new chemical products whose effects on the environment are not fully understood (Umweltbundesamt, 2004 and 2007b). However, the inputs of pollutants (in particular lead, cadmium and POPs) in the soil are expected to decrease, since emissions and thus depositions are diminishing due to the implementation of regulations and preventive measures in place. On the other hand, acidifying substances, in particular NO_x from traffic sources, are expected to increase. Moreover, soil contamination and its adverse effects are still to be expected in the long run since many pollutants (e.g. heavy metals and POPs) have low mobility and high persistence and accumulate in the soil. In addition, the increase of the emissions of acidifying substances may result in an increase of the pressures on forests and forest soils. The major indirect impacts will be in terms of the loss of biodiversity and the quality of groundwater resources.

In urban and industrial areas, no new contamination is expected due to prevention measures in place. Nevertheless, the clean-up of historical contamination will continue to pose a challenge. In fact, although considerable efforts have been made already, in particular in the investigation and monitoring of contamination, a slow progress is made in the implementation of remedial measures. According to the national vision for contaminated sites the identification of all historically contaminated sites and the remediation measures at heavily contaminated sites shall be completed until 2050 (BMLFUW, 2008).

The amount of soil actually sealed through the construction of buildings and infrastructures is currently increasing at a rate of 10 ha day^{-1}. This figure exceeds ten times the national 2010 sustainability target. As in Austria only 37 percent of the territory is suitable for permanent settlements, high increases of built-up areas may also lead to the saturation of the available space. This is more likely to occur in some regions currently registering the highest rates, especially in rural areas. On the other hand, the redevelopment of brownfields and the clean-up of historical contamination are expected to provide opportunities for the reduction of the consumption of green-land, as well as opportunities for economic and technological development, and job creation. Brownfields in Austria could cover about one quarter of the current needs for land.

Soil degradation in agricultural areas, especially erosion, compaction and decline in organic matter content is not expected to increase in the future due to the implementation of prevention and reduction measures such as notably those measures included in the national Agri-Environmental Programme. For the same reasons, the organic carbon stock in Austrian soils is expected to remain stable on average.

Climate change and the development of the tourist sector may result in increased hydro-geological risks.

Investigations and monitoring of historical contamination are quite advanced. More is known on contaminated sites but remediation activities are progressing slowly. If current trends are maintained, it will take decades to clean-up a legacy of contamination. In Austria, remediation is aimed at removing the source of contamination and restoring the soil functions to a certain extent. The objective is to make the soil again fit for specific uses, in particular for the protection of groundwater resources (ultimately, the source for about 50 percent of drinking water supplies). Further progress with the clean-up of historical contamination and brownfield redevelopment will also provide opportunities for the reduction of land consumption, economic and technological development, and job creation.

11.5.2 | Case study: Ukraine

About 60 percent of the soils of Ukraine are Chernozems – soils known for their unique structure, chemical properties and inherent fertility. These soils are distinguished by a very deep (more than 1 m) humus-enriched layer, perfectly expressed granular structure, almost optimal bulk density, and a good and satisfactory stock of nutrients. However, these favourable soil properties are only present in soils under virgin ecosystems. Chernozems are the best soils in the world (the 'tsar of soil') according to Vasiliy Dokuchaev, the founder of modern soil science. However, are very sensitive to anthropogenic intervention. In particular, when intensively tilled, they rapidly degrade. As a result, in recent years these soils have been characterized in Ukraine by a significant decline of their potential productivity, equal to 80-90 million tonnes of grain annually, or up to 2 tonnes per head of the population. It has proved almost impossible to maintain good ecological conditions for these soils.

The fragility of the soils of Ukraine is well known and has been the subject of many studies. Nevertheless, this has not deterred intensive development which has led to their severe degradation. About a third of arable land is eroded, 30 percent of organic matter has been lost, approximately 40 percent of soils have a compacted layer, and stocks of nutrients have noticeably decreased. Where soils have been improved, numerous problems have also been observed (Balyuk and Medvedev, 2012).

Comparison of cultivated soils with virgin analogues shows that for the last 40-50 years the most typical processes were (Bulygin, Breus and Seminozenko, 1998; Grekov *et al*., 2011; Medvedev, 2012):

- Loss of humus in arable soils: at the end of the 1980s, 0.5-1.5 tonnes per ha were being lost annually. Between 2005 and 2009 the rate of organic matter loss was 0.42-0.51 tonnes per ha annually.
- Increasing deficiency of labile nutrients, especially nitrogen (declining from -41.4 kg per ha in 2001 to – 56.4 kg per ha in 2009) and potassium (declining from -32.9 to – 64.2 kg per ha between 2001 and 2009).
- Acidification of Chernozems, especially in the Cherkassy and Sumy regions, where the drop in pH was 0.3-0.5 units.
- Compaction, particularly in the western forested steppe but widespread on 40 percent of arable land nationwide. Compaction is characterized by a destruction of structure, lumpiness and crusting.
- Reduction of the depth of upper layer of the soil due to erosion, reaching several centimeters in Chernozems according to modelled data, and also in the drained soils of Polissiya.
- Secondary alkalinization and salinization of irrigated soils, accompanied by a reduction of peat depth.

Among other negative processes of local importance are: contamination with radionuclides and heavy metals; waterlogging; flooding; iron, calcium carbonate and aluminum accumulation; desertification; and alkalinization and soda formation.

The types and extent of degradation of arable soils in Ukraine are shown in Table 11.3 and Figure 11.3. The estimation of soil degradation has been carried out using the technique proposed by van Lynden (1997). The sources of data have been: (I) the results of the agrichemical certification of fields conducted every five years since 1965; and (II) the database of the National Scientific Center (the 'O.N. Sokolovsky Institute for Soil Science and Agrochemistry Research'). The database has provided information on the morphological, physical, physicochemical and chemical properties of more than 2 500 soil profiles, and also information from long field experience on tillage and application of fertilizers (Laktionova *et al.*, 2010; Grekov *et al.*, 2011).

Soil degradation in Ukraine is mainly the result of the use of inappropriate farming technology. Chernozems are vulnerable to mechanical deformation due to their low bulk density before tillage in the spring, and also to the influence of moisture owing to the low stability of the swelling smectite minerals which predominate in their mineralogical composition.

The problem has been aggravated because state and regional programmes of soil protection slowed down significantly after 1991. These programmes had obtained important results in protecting and restoring soils up to the end of the 1980s but during the last two decades measures aimed at improving soil fertility have been significantly reduced.

Soil degradation is a major problem in Ukraine. There is little realization of the threat it represents for the present and especially future generations. Issues include the absence of effective mechanisms to enforce laws on soil protection, and unbalanced and insecure land tenure. Combating soil degradation requires raising awareness at all levels of society, wide educational activity, active dissemination of knowledge, and gradual formation of a new attitude to soil resources.

Table 11.3 | Types and extent of soil degradation in Ukraine

Type of degradation	Extent, percent of arable land
Fertility decline and reduced humus content	43.2
Compaction	38.2
Sealing and crusting	37.5
Water erosion, surface wash	16.8
Soil acidification	14.1
Waterlogging	12.9
Soil pollution by radionuclides	10.9
Wind erosion: loss of topsoil	10.5
Soil contamination with pesticides and other organic contaminants	9.2
Soil contamination with heavy metals	8.0
Salinization / alkalinization	4.3
Water erosion: terrain deformation by gullying	2.6
Off-site effects of water erosion	2.5
Lowering of the soil surface	0.4
Wind erosion: terrain deformation	0.4
Desertification	0.2

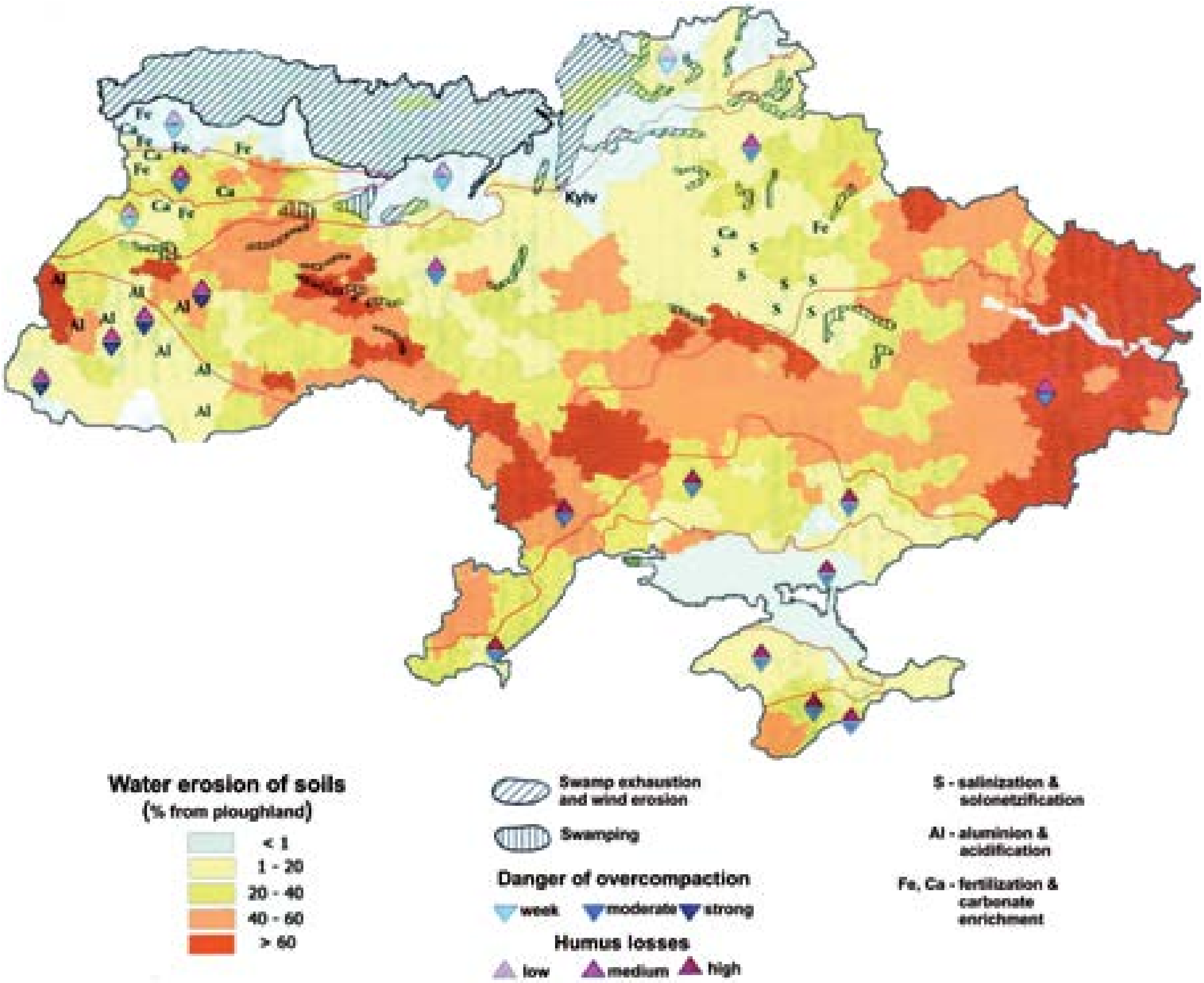


Figure 11.3 | Some types and extent of soil degradation in Ukraine.
Source: Medvedev, 2012.

11.5.3 | Case study: Uzbekistan

Uzbekistan is one of the flattest countries of Central Asia. About 80 percent of the national territory consists of plains, with mountains located in the extreme east of the republic. The climate of Uzbekistan is 'continental dry', with significant daily and seasonal fluctuations in air temperature. The summer is long and hot, the autumn is relatively wet, and the weather in winter is variable. The arid climate favors desertification and maintains relict accumulations of soluble salts in soils and sediments.

The entire area of the country is 44.9 million ha, and agricultural lands constitute 46.1 percent of the national territory. The distribution of soils in Uzbekistan reflects a complex system of pedo-geographical regularities (Figure 11.4). The westernmost part of the republic is occupied by a desert zone that can be subdivided into a sub-boreal desert (Central Kazakhstan) and a subtropical desert (Turan) desert. The boundary between the two types of desert corresponds to the northern limit of possible cotton cultivation. In the lower belt of the piedmont subtropical semi-desert there occur mainly Calcisols which are replaced as elevation increases by mountainous Cambisols under steppe and forest vegetation. Anthropogenic factors strongly modify the morphology and pedogenesis of the soils. Irrigated soils are mainly transformed into Anthrosols - some of the soils in the Amu Darya delta have been cultivated and irrigated for more than three thousand years. The country is vulnerable to negative environmental impacts due to its natural climatic conditions. Irrigated agriculture is localized in the plain and piedmont parts of the republic and is characterized by varying levels of technology and intensity and by the varying quality of the land.

The natural drivers of land degradation and desertification are the following:

- Climatic characteristics, such as aridity, continentality, wind action etc., which cause such phenomena as drought, hot winds, deflation, and atmospheric transportation of sand, salts and dust;
- Topography, with slopes favouring the development of water erosion and landslides, and flat areas with depressions creating conditions for waterlogging and salt accumulation. Topography also favours the formation of specific intensive winds which play an important role in wind erosion;
- Parent material, whose peculiarities are reflected in the soil profile (texture, gypsum and salts content) and which also determine the susceptibility of soils to wind erosion, karst phenomena, and the soil buffering capacity; and
- Extreme natural phenomena, such as forest and grassland fires, floods etc. which affect the development of soils.

Anthropogenic factors affect land resources and trigger degradation processes in the following ways:

- Irrigation without a proper drainage system and inappropriate regulation of the collector-drainage water lead to salinization and waterlogging;
- Inappropriate use of pastures leads to overgrazing, formation of exposed soil surface and destruction of the soil structure and, as a result, to the development of deflation under the effect of wind and high temperature; and
- Forestry strategy allows excessive logging which causes soil erosion on the slopes in mountainous areas, soil deflation and the expansion of sands on the fertile lands on the plains (Arabov, 2014).

Other economic activities such as industry, municipal and domestic wastes, transport emissions, and unreclaimed mining spoil also contribute to land degradation. The natural processes of land degradation and desertification are slow; their effect becomes evident only after decades or centuries. However, human activities accelerate these natural processes, and the results of anthropogenic degradation processes appear in a short period of time.

Box 1 | The catastrophe of the Aral Sea

An illustrative example of the menacing scale of ecological and socioeconomic disasters caused by inappropriate use of natural resources is the catastrophe of the Aral Sea. Its volume has been reduced more than 13 times, and its area by more than seven times. The primary cause being the diversion of inflowing rivers for irrigation projects. The shoreline has moved hundreds of kilometers. Salt concentrations have reached 120 g per liter in the western part and 280 g per liter in the eastern part of the sea (Arabov, 2014). The sea has split and is now on the verge of extinction: only two small components separated by a dam are left, the deeper western part, and the 'Small Aral' in Kazakhstan, Most of the shore is surrounded by a rind of salt cover over marshy clays and sands.

The processes of environmental change in the region have combined with global climatic changes and resulted in the intensification of seasonal droughts. The Aral catastrophe has aggravated the continentality of climate, increasing dryness and temperature in summer and prolonging cold and severe winters. In the Aral region, the number of days with the temperature over 40°C doubled, while in the rest of Uzbekistan it has gone up by about 1.5 times. According to expert evaluation, by 2035-2050 the air temperature in the region may increase by a further 1.5-3.0°C. On the dried surface of the sea bottom, there are extensive white salt crusts, covered in places by wind-blown sand. This territory forms a new desert called 'Aral Kum' that covers 5 million ha. This Aral Kum desert, which is still growing, has already absorbed 2 million ha of arable lands and led to degradation of pastures, riparian forest and other vegetation. Satellite images illustrate the penetration of plumes of salts and dust from the Aral Kum for 8 001 000 km, deep into densely populated zones.

The plains in the basins of Amu Darya and Syr Darya are lowlands with no natural drainage. Due to the dry climate, the low precipitation and the strong evaporation, these plains act as accumulators of easily soluble salts in the topsoil. For this reason, the development of irrigated agriculture, starting from the piedmont areas, requires careful attention to current or historic salt accumulation in the sediments. Farmers also have to be aware of the danger of secondary salinization. Salt-affected soils currently constitute more than 46 percent of the total irrigated area in Uzbekistan, including moderately saline soils (25 percent of the total area), and strongly saline soils (over 6 percent). The worst affected areas are the regions of Karakalpakstan, Bukhara, Khorezm, Dzhizak, Syrdarya, Andijan, Kashkadarya, Navoi, Samarkand, Surkhandarya. Some districts in Tashkent and Fergana regions are also affected. In the Samarkand region, the prevailing type of salinity is magnesium-carbonate salts accumulation. Salinization of some newly irrigated lands is followed by the formation of gypsum-enriched soils that are difficult to reclaim. Gypsum layers and horizons impede water infiltration and decrease the efficiency of leaching doses designed to wash salts from the soil profile. The total area of gypsum-containing soils is about 350 000 ha.

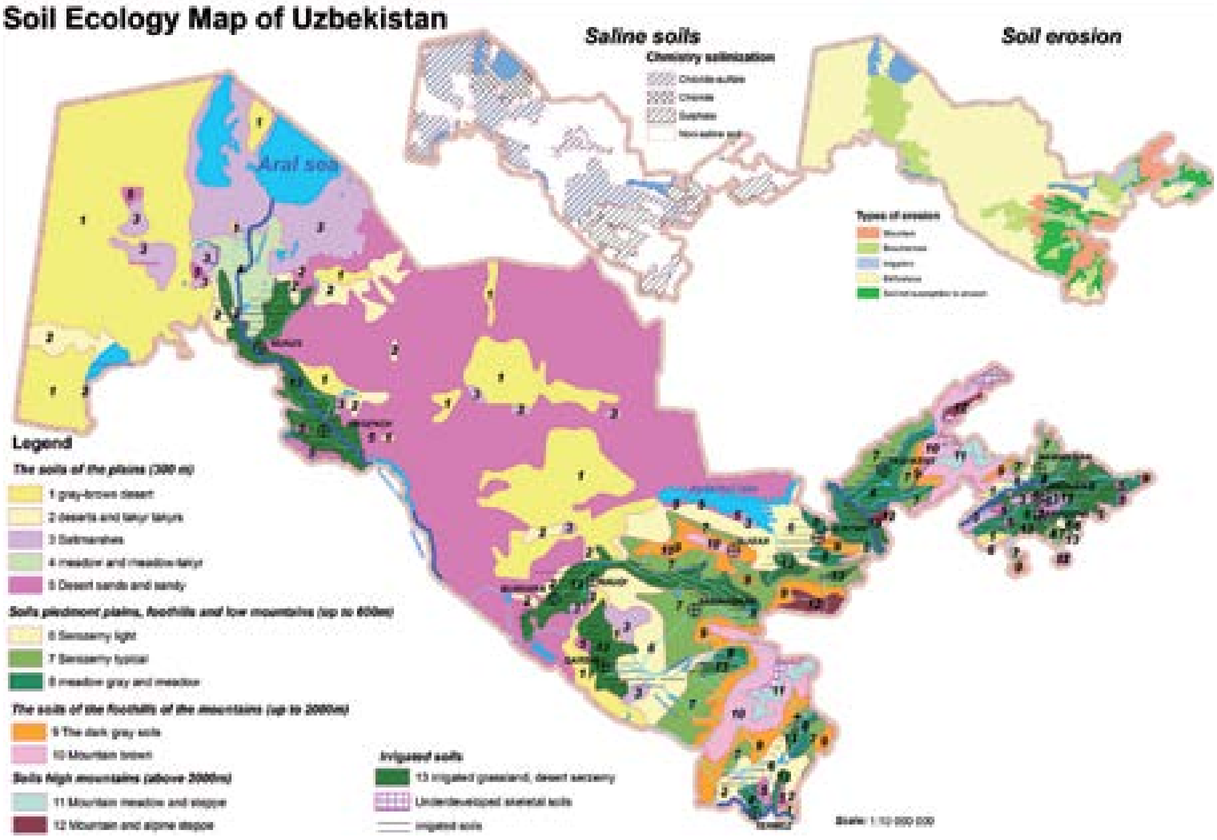


Figure 11.4 | Soil map and soil degradation extent in Uzbekistan.
Source: Arabov, 2010.

Across Uzbekistan, all types of erosion can be found: surface runoff and irrigation erosion, destructive mudflows, wind erosion, and direct negative effects of wind on plants. Wind erosion and negative wind effect on plants affect 21.4 million ha or 80 percent of all agricultural lands (Figure 11.5). Of the 3.7 million ha of irrigated lands, three quarters – 2.8 million ha – are eroded to various extents. Agricultural lands also suffer from water and irrigation erosion. Moderately and strongly eroded soils constitute 12 percent of the agricultural land pool and about 5 percent of the irrigated land pool (Kurbanov, 2001).

The major part of the country is occupied by pastures that cover an area of 20.6 million ha and serve as the main source of fodder for livestock (Arabov, 2014). Rational use and protection of the soils of pastures are issues in natural resources conservation and use. The state of pastures is currently endangered. During the last 70-80 years, the soils of pastures suffered a drastic decrease in humus and nutrient content and they have been affected by salinization and by water and wind erosion. Other negative processes include soil compaction, alkalinization, and decline in biological activity and resulting loss of soil

Thus, the key challenges in soil degradation in Uzbekistan are: (I) secondary salinization of irrigated lands; (II) waterlogging of irrigated agricultural lands; (III) depletion of soils, including the loss of humus and nutrients; (IV) compaction; (V) surface runoff and irrigation erosion in mountainous and piedmont areas; (VI) deflation and pasture degradation in desert regions where transhumance is practiced; (VII) deforestation and loss of biological diversity; (VIII) soil contamination with agrochemicals and industrial waste; (IX) desertification in the regions bordering the bottom of the dried-up Aral Sea; (X) inappropriate methods of land management; (XI) poor crop management (lacking or wrong crop rotation, in places insufficient or excessive use of fertilizers); (XII) insufficient irrigation; and (XIII) breakdown of the rules governing sustainable management of pastures (Gafurova *et al.*, 2012).

Clearly the protection of land and soils and their sustainable economic use are huge challenges for Uzbekistan. Article 55 of the Constitution reads: "The earth, minerals, water, flora and fauna, and other natural resources are national wealth, requiring their rational use and protection of the State". In order to provide comprehensive rehabilitation, conservation, protection and improvement of soils and their fertility, and to improve overall environmental conditions, the following steps are required:

- develop agricultural techniques aimed at restoring and enhancing soil fertility, including approaches to land reclamation and the promotion of farming practices which improve the physical, chemical and ecological status of the soil
- develop rapid methods of large scale soil mapping and automate the process of compiling maps and soil assessments, using remote sensing and GIS technologies
- develop techniques for preventing the processes of surface, gully and wind erosion, for predicting soil erodibility, and for recovering and improving the fertility of eroded soils
- develop approaches to stopping processes of soil salinization and introduce more effective and innovative ways of desalinization and reclamation of saline soils
- conduct targeted research to establish the levels and pathways of soil contamination by various toxicants, including fluorine, heavy metals, pesticides and others, and develop measures to prevent soil pollution by these substances
- develop integrated science-based recommendations for the assessment of soil fertility of both arable lands and pastures to promote sustainable economic land use in the republic

11.6 | Conclusion

The inherent complexity and spatial variability of soil makes the evaluation of the impact of any change difficult. Transformations of features such as texture and mineralogical composition will only occur over geological time spans while properties such as pH, organic matter content or microbial activity will show a more rapid reaction. In addition, the response of a particular soil type may be both positive and negative depending on the function in question. For example, rising temperatures and precipitation may support increased agricultural productivity on soils previously deemed marginal, but such a transformation can lead to a deterioration of soil biological diversity and an increased risk of erosion. Quantitative assessments of future trends in soil characteristics and properties are limited. As a consequence, this chapter provides an outlook only for a selected number of issues. Considerably more effort is required to model changes in the state of soil conditions in relation to drivers such as changes in land use and climate.

Based on the above finding, an assessment is made of the status and trend of the ten soil threats in order of importance for the region. At the same time an indication is given of the reliability of these estimates (Table 11.4).

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

Table 11.4 | Summary of soil threats status, trends and uncertainties in Europe and Eurasia

Threat to soil function	Summary	Condition and Trend					Confidence	
		Very poor	Poor	Fair	Good	Very good	In condition	In trend
Soil sealing and land take	In densely populated Western Europe soil sealing is one of the most threatening phenomena.		↙				Adequate	Adequate
Salinization and sodification	Salinization is a widespread threat in Central Asia, and it is challenging in some areas in Spain, Hungary, Turkey, and Russia.		↙				Adequate	Adequate
Contamination	Soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. The situation is improving in most regions.		↗				Adequate	Limited
Organic carbon change	The loss of organic carbon is evident in most agricultural soils. Peatland drainage in northern countries also leads to rapid organic carbon loss. In Russia, extensive areas of agricultural lands were abandoned that resulted in quick organic mater accumulation; however, some of these areas are now again used for agriculture.		↗↙				Limited	Limited
Nutrient imbalance	In the western part of the region the loss of nutrients is compensated by application of high doses of fertilizers. In the eastern part the use of fertilizers is insufficient, and in most soils nutrient mining results in intensive mineral weathering.		↗↙				Limited	Limited
Soil erosion	Water erosion is active in all the cultivated mountainous and rolling areas; the worst situation is observed in Turkey, Tajikistan and Kyrgyzstan. Due to the attention paid to this threat it is controlled in most areas, especially in the EU.			↗			Adequate	Limited

Loss of soil biodiversity	Loss of biodiversity is expected in the most urbanized and contaminated areas of the region. However, there are almost no qualitative estimations of the biodiversity loss in soils.			↙				
Soil acidification	Acidification due to acid rain was a challenge in Northern and Western Europe. The situation is now improving, though several decades will be needed for complete soil recovery.			↗				
Waterlogging	Waterlogging is mostly associated with irrigation in Central Asian countries. Most cultivated irrigated soils there are waterlogged. This phenomena in Central Asia is commonly associated with salinization.			↗↙				
Compaction	The use of heavy machinery and overgrazing are threatening in almost all the agricultural areas.			↗↙				

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