CHAPTER 5

THE GLOBAL EXTENT OF SOIL DEGRADATION: CAUSES, CONSEQUENCES AND SOLUTIONS

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Soil degradation is a complex process driven by natural and human factors, characterised by the deterioration of soil properties, declining productivity and an impaired capacity to perform ecological functions. Under the Law of Ukraine «On Land Protection», soil degradation is defined as the deterioration of the beneficial properties and fertility of soils due to natural or human factors [4]. In the scientific literature, it is important to distinguish between soil degradation and land degradation. The former primarily concerns the deterioration of the physical, chemical and biological characteristics of the soil profile, whereas the latter is a broader concept encompassing changes in the condition, composition, functions and productivity of land resources as a whole.

From a geographical perspective, soil degradation has an uneven spatial distribution. Its intensity depends on climatic conditions, topography, geology, soil-forming processes, vegetation cover and land-use practices. In arid regions, moisture deficits, wind erosion and salinisation are particularly pressing problems. In areas with excessive moisture and dissected terrain, water erosion poses a significant threat. Intensively cultivated agricultural areas commonly experience organic matter loss, compaction, deterioration of topsoil structure and nutrient imbalances.

The global significance of the problem stems from the fact that soil resources regenerate far more slowly than they are degraded. The formation of a mature soil profile takes a long time, while the loss of the upper humus-rich horizon through erosion can cause a prolonged decline in land productivity. International research identifies land degradation as a major challenge to global environmental security. Publications of the United Nations Convention to Combat Desertification emphasise the links between land degradation and food security, water resources, climate change, biodiversity loss and socioeconomic stability [11].

The extent of soil degradation is determined not only by the area affected by adverse changes but also by the intensity of degradation processes, the depth of disturbance to the soil profile and the consequences for natural ecosystems and

economic activities. International comparisons draw on various indicators, including the proportion of degraded land, trends in vegetation productivity, changes in soil organic carbon stocks, the severity of erosion and salinisation, and contamination levels. According to the global data platform of the United Nations Convention to Combat Desertification, at least 100 million hectares of healthy and productive land were degraded annually between 2015 and 2019. These estimates also indicate that approximately 1.3 billion people are directly vulnerable to land degradation [6].

The report on the status of the world's soil resources published by the Food and Agriculture Organization of the United Nations provides an important synthesis of available evidence. International assessments identify the principal threats to soils as erosion, organic carbon loss, nutrient imbalances, salinisation, contamination, acidification, compaction, waterlogging and biodiversity loss [10].

Water erosion involves the detachment and transport of soil particles by raindrop impact and surface runoff. It is intensified on slopes and under conditions of insufficient vegetation cover, intensive tillage and disruption of the natural water regime. Its consequences include the loss of the most fertile part of the soil profile, declining humus and nutrient contents, and the formation of rills and gullies. The eroded material accumulates in watercourses and water bodies, contributing to siltation and declining water quality [7].

Wind erosion is particularly characteristic of arid and semi-arid regions, as well as open agricultural landscapes with insufficient soil surface protection. It intensifies during prolonged droughts and strong winds, especially where soil aggregates have broken down into fine particles and crop residues are absent from the surface.

Humus depletion, or the decline in humus and organic carbon stocks, is associated with rapid mineralisation of organic residues, insufficient organic matter inputs, losses through erosion and the deterioration of soil structure. Organic carbon loss adversely affects soil aggregate stability, water-holding capacity, cation echange capacity and biological activity.

Salinisation and sodification are particularly harmful in arid climates and under poorly managed irrigation. The accumulation of soluble salts in the root zone impedes water uptake by plants, disrupts their mineral nutrition and reduces crop yields. Sodification increases the proportion of exchangeable sodium, degrades soil structure, reduces water permeability and increases susceptibility to surface compaction.

Physical degradation encompasses compaction, structural breakdown, surface crust formation and deterioration of the soil water and air regime. Increasingly large areas are cultivated using heavy machinery, and machinery traffic on wet soils can compact both the plough layer and deeper horizons. This restricts root penetration, reduces water infiltration and increases surface runoff.

Chemical degradation and contamination are associated with the accumulation of heavy metals, pesticide residues, petroleum products, industrial compounds and other hazardous substances. Sources of contamination include industrial facilities, transport, mining, improper waste management and excessive agrochemical use.

Biological degradation is manifested in declining abundance, biomass and diversity of soil organisms. Reductions in populations of microorganisms, fungi, earthworms and other soil organisms disrupt organic residue decomposition, nutrient cycling and the formation of stable soil structure. Consequently, the soil's capacity for self-regulation and recovery from external disturbances declines.

Different forms of degradation reinforce one another: vegetation loss accelerates erosion, which depletes organic matter stocks and degrades soil structure. These interrelationships must therefore be considered when analysing degradation processes.

The causes of soil degradation should be viewed as a system of interconnected natural and human factors. In many regions of the world, natural processes create conditions conducive to soil deterioration; however, the intensity and extent of degradation depend largely on land-use practices. The *Global Land Outlook* report

published by the United Nations Convention to Combat Desertification identifies deforestation, overgrazing, wetland drainage, unsustainable land use and the expansion of agricultural, industrial and urban areas as major drivers of land degradation [11].

Agriculture plays an important role in ensuring food security. However, agricultural intensification that fails to account adequately for local environmental conditions can cause substantial soil degradation. Excessive conversion of land to arable use, monoculture, insufficient application of organic fertilisers, failure to follow crop rotations and tillage under unsuitable conditions lead to structural deterioration, declining humus content and increased erosion.

Climate change increases soil vulnerability through rising temperatures, changing precipitation patterns, more frequent and prolonged droughts in certain regions, and increasingly intense rainfall. Prolonged moisture deficits dry out the upper soil horizon, reduce vegetation cover and intensify wind erosion. Conversely, heavy rainfall on bare or compacted surfaces increases surface runoff and the risk of water erosion. The interaction between climate change and unsustainable land use creates a self-reinforcing cycle of deterioration. Declining organic carbon stocks reduce the soil's capacity to retain water, while lower moisture levels and reduced vegetation cover increase its vulnerability to erosion.

Deforestation, the conversion of natural steppes to arable land, the destruction of shelterbelts and excessive grazing disrupt the natural mechanisms that protect soils. Vegetation slows surface runoff, reduces wind impact, promotes the accumulation of organic residues and sustains soil biological activity.

The expansion of urban areas and the construction of transport infrastructure, industrial facilities and mining operations remove land from natural or agricultural use. Covering the surface with asphalt, concrete and other impermeable materials causes soil sealing, which disrupts water infiltration, gas exchange and the functioning of soil biota. Mineral extraction involves the removal of soil cover, the

formation of open pits and spoil heaps, and changes in topography and hydrological conditions. Without appropriate reclamation, disturbed areas may remain unsuitable for economic use for extended periods.

In arid regions, irrigation is an important means of sustaining agricultural productivity; however, poorly managed irrigation can cause secondary salinisation and waterlogging. Where drainage is inadequate and evaporation is intense, dissolved salts accumulate in the upper soil horizons, creating unfavourable conditions for plant growth. Conversely, excessive drainage of peat soils and waterlogged soils accelerates organic matter decomposition, causes land subsidence and alters local hydrological conditions.

Armed conflicts create a distinct combination of factors that contribute to soil degradation. The movement of heavy military vehicles compacts the soil profile, explosions disrupt its structure, and fires destroy vegetation cover and alter the properties of the surface horizon. The destruction of industrial facilities, fuel storage facilities and other infrastructure may result in soil contamination by hazardous substances. The effects of warfare vary spatially and depend on the intensity of hostilities, soil types, geology, hydrological conditions and the composition of contaminants. Assessing affected areas therefore requires a combination of remote sensing, geographic information system (GIS) mapping, field investigations and laboratory analysis.

The most direct manifestation of degradation is a decline in the soil's capacity to supply plants with water and nutrients. The loss of the humus-rich horizon, compaction and contamination disrupt the functioning of soil organisms, reduce biodiversity and impair the recovery of plant communities.

An important environmental consequence is the disruption of the carbon balance. Soils constitute a major reservoir of organic carbon, and their degradation can deplete these stocks and increase greenhouse gas emissions. Conversely,

restoring soil structure and increasing organic matter stocks enhance ecosystem resilience to climate change.

Soil degradation reduces potential crop yields and increases expenditure on fertilisers, tillage, irrigation and land restoration. Where the soil profile has been severely damaged, restoration may require sustained funding, while individual sites may lose their economic value temporarily or for extended periods.

According to assessments presented in publications of the National Academy of Agrarian Sciences of Ukraine, degradation processes remain an important factor reducing the efficiency of agricultural land use. These publications highlight the prevalence of humus depletion, erosion, compaction and other forms of deterioration that cause economic losses and diminish soil fertility potential [1].

Declining land productivity affects rural incomes, employment and food availability. In regions where community well-being depends heavily on crop and livestock farming, prolonged land degradation can exacerbate poverty, encourage labour migration and widen regional disparities.

Soil degradation is directly linked to Goal 2, «Zero Hunger»; Goal 6, «Clean Water and Sanitation»; Goal 13, «Climate Action»; and Goal 15, «Life on Land», within the United Nations Sustainable Development Goals framework. Of particular relevance is Target 15.3, which calls for combating desertification, restoring degraded land and soil, and striving to achieve land degradation neutrality.

Ukraine has substantial soil resources, particularly owing to the widespread occurrence of chernozems, which have high natural fertility. However, intensive agricultural land use, the high proportion of land under cultivation in many regions, uneven moisture availability and insufficient adoption of soil conservation practices create conditions conducive to the spread of degradation processes.

One of the most significant problems is water erosion, which is particularly severe on sloping land in the forest-steppe and steppe zones, as well as in mountainous regions. Ploughing slopes without adequate erosion control, insufficient

shelterbelt coverage and disruption of agricultural landscape structure increase surface runoff and the loss of fertile topsoil. In mountainous areas, terrain characteristics, rainfall intensity and disturbance of vegetation cover also contribute to erosion.

In his study, M. M. Movchan examines the main approaches to addressing land degradation and desertification in Ukraine, highlighting the need to improve land-use practices, implement protective afforestation measures and restore degraded land [3].

Particular attention should be paid to soils affected by hostilities. Mechanical disturbance of the soil surface, compaction, fires, infrastructure destruction and potential contamination necessitate specialised investigations [2]. Before such land is returned to economic use, its safety, physical condition and chemical properties must be assessed. Landmine hazards must also be considered, as they impose an additional constraint on field investigations and restoration activities.

The legal framework for soil protection in Ukraine is established by the Law of Ukraine «On Land Protection», which provides for measures to ensure the rational use of land, maintain and restore soil fertility, protect soils against degradation and safeguard environmental security [4].

Addressing soil degradation requires a shift from predominantly reactive measures aimed at mitigating its consequences towards preventive land resource management. This approach should be based on assessing local environmental conditions, identifying risks, adopting sustainable land-use practices and regularly monitoring changes in soil condition.

A priority is the adoption of soil conservation farming systems. These include scientifically informed crop rotations, cover cropping, the use of green manure crops, the return of crop residues to the soil, optimisation of tillage practices and reduced mechanical soil disturbance.

Under suitable soil and climatic conditions, minimum tillage or no-till systems can help reduce erosion, conserve moisture and increase organic matter stocks in the

upper soil horizon. However, these practices are not universally applicable: their effectiveness depends on soil type, climate, weed management, crop rotation design and farm management.

Measures to reduce water erosion include contour tillage, slope terracing where appropriate, the establishment of grass cover on erosion-prone sites, the creation of buffer strips along watercourses and the restoration of shelterbelts. Controlling wind erosion requires maintaining vegetation cover, retaining stubble and other crop residues, establishing windbreaks and managing grazing sustainably.

Increasing soil organic matter content is an important component of restoring degraded soils. This can be achieved through the application of organic fertilisers and compost, the cultivation of green manure crops and perennial grasses, and farming systems that maintain inputs of crop residues. Conserving soil biota requires curbing excessive agrochemical use, limiting compaction, maintaining plant cover diversity and preserving natural habitats.

Preventing salinisation and waterlogging requires improvements to irrigation and drainage systems, monitoring of irrigation water quality, maintenance of an appropriate soil water and salt balance, and consideration of natural drainage conditions. Water-saving technologies can reduce pressure on water resources, but their use should be accompanied by soil monitoring and an assessment of long-term effects.

Land reclamation is necessary in areas disturbed by mining, industrial construction, erosion and other forms of technological disturbance. It involves restoring landforms, establishing a suitable substrate, reapplying previously stored fertile topsoil where conditions permit, restoring vegetation cover and subsequently monitoring ecosystem stability.

On contaminated land, the first priority is to determine the composition, concentration and spatial distribution of contaminants. Depending on the assessment

findings, remediation may involve removing or containing contaminated material, biological treatment, phytoremediation and other techniques.

In areas affected by hostilities, restoration should proceed in stages: surveying the site and ensuring safety, assessing soil physical and chemical properties, establishing remediation priorities, restoring soil cover and monitoring outcomes. Land should be returned to agricultural use only after its safety has been established.

Effective management of degradation processes requires reliable information on their spatial distribution and changes over time. Modern soil monitoring combines field surveys, laboratory analyses, cartographic materials, statistical data and remote sensing.

Geographic information systems enable the integration of data on topography, soils, climate, land use and vegetation cover. Digital elevation models can be used to identify slopes at high risk of erosion, while satellite imagery enables the monitoring of vegetation changes, exposed soil surfaces, fire impacts and other indicators of degradation. However, remote sensing cannot replace field investigations and laboratory analyses, particularly when determining humus content, salinity, or concentrations of heavy metals and other contaminants.

Addressing soil degradation requires effective legislation, economic incentives and coordination among public authorities, research institutions, land users and local communities. Priorities include ensuring compliance with land protection requirements, encouraging the adoption of soil conservation practices and improving monitoring systems.

A notable example is Directive (EU) 2025/2360 on soil monitoring and resilience, which entered into force on 16 December 2025. It establishes a common framework for monitoring soil condition, enhancing soil resilience and managing contaminated sites, with the aim of achieving healthy soils by 2050 [9].

At the international level, FAO recommendations on sustainable soil management and the approaches promoted by the United Nations Convention to

Combat Desertification to achieve land degradation neutrality are also important [10,11]. Their practical implementation involves halting further soil deterioration, restoring degraded areas and maintaining land productivity over the long term.

Further development of soil protection systems also requires scientific support for reclamation, economic incentives for sustainable land use and stronger environmental education. Harmonised indicators of soil condition should ensure the comparability of monitoring results and the timely detection of adverse changes.

Particular attention should be paid to integrating data across different scales, from local soil surveys to international land degradation assessment systems. This will enable national findings to be compared with international indicators, help establish funding priorities and support the assessment of progress towards the Sustainable Development Goals.

Soil restoration should also be understood as a long-term process whose effectiveness is determined by actual improvements in soil properties as well as the area treated. Indicators of success may include reduced soil losses through erosion, stabilisation or increases in organic carbon stocks, restoration of soil structure, improved soil water conditions, reduced contamination and the recovery of ecological functions.

Soil conservation and restoration should be regarded as a strategic prerequisite for sustainable human development [8]. The effectiveness of efforts to combat degradation will depend on society’s ability to reconcile economic needs with environmental limits, ensure responsible land use and shift from natural resource depletion towards long-term conservation and regeneration.

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