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NBSOIL
Nature-Based Solutions for Soil Management

Knowledge base - initial version

Deliverable 1.1

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified

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MS - Milestone

WP – Work Package

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1 Executive Summary (IUNG)

This report is first of a series of documents within task 1.1 of the NBSoil project. The task aims at gathering existing knowledge and prepare a portfolio of NBS for soil health addressing the Soil Mission objectives together with an overview article, 3 literature reviews and 3 meta analysis, which will be made available on the project's website through a series of factsheets and short cards.

This initial portfolio will be further developed with the NBS researched in depth in WP2. It will work closely with WP6 on dissemination and collaboration and with existing platforms and repositories such as Oppla, climate Adapt, WOCATand the EIP AGRI.

The first version of the knowledge base is focused upon soil related nature based solutions within the 4 main land use/land cover types:

- Agriculture
- Forestry and nature
- Urban areas
- Industrial lands

The reports summarizes a wide literature screening effort, revealing 124 papers, book chapters, reports and books addressing semantics, standards, real use cases and good practices of nature based solutions in Europe. The deliverable has the nature of a living document, as new assessments and reports are arising and partners go deeper into analyzing the listed literature.

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2 Expected impact

The deliverbale is crucial for other work packages, that focus on good practices, modelling, standards and site idetnification. It is a strarting point for further work wihtin the project.

It will provide a comprehensive knowledge base for dissemination as a basis to produce materials for advisors, providing reliable case-proven applicaitons of good practices.

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3 Introduction to Nature Based Solution in the aspect of soil health

3.1 What are Nature-based Solutions?

3.1.1 Concept & definitions

Nature Based Solutions (NbS) is an umbrella concept that covers a range of different approaches that have emerged from a variety of fields, such as ecosystem-based adaptation, green infrastructure and ecological restauration. Some of these approaches have emerged from the scientific research domain, while others from practice or policy contexts. However, they all share the objective of enhancing the beneficial features and processes of ecosystems to address societal challenges, such as food security, natural disasters, or climate change.

More broadly, the development of the NbS concept has been grounded in the recognition of the linkages and interdependencies between people and nature, as well as an increasing understanding of the complexity of social-ecological systems. NbS acknowledges that biodiversity conservation and the protection of ecosystem services are critical for several aspects of human well-being.

The term NbS has been defined and used in a number of different ways. For example, the IUCN, the European Commission and UNEA have developed their own definitions of NbS, which, while broadly similar, have a few differences.

Table 1. Definitions of nature based solutions (NBS)

NbS definitions		
Institution	Definition	Definition specificities
IUCN	Actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits (IUCN, 2020a).	IUCN's definition emphasizes the importance of a well-managed or restored ecosystem as the foundation of any NbS.
European Commission	Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions (European Commission, 2023)	The European Commission's definition is broader and places more emphasis on solutions that are not only derived from nature but are also inspired and supported by it.

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UNEA-5 resolution (United Nations Environment Assembly of the United Nations Environment Programme)	Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits (UNEA, 2022)	UNEA's definition is very similar to IUCN's definition but more specific, emphasizing that NbS could have positive impacts in several ecosystems and must address economic and environmental challenges, in addition to addressing social and environmental challenges.

Despite their differences, each of the NbS definitions have a very similar approach and common strong points. It should be highlighted that all definitions consider that for an intervention to be considered an NbS, it must provide simultaneous benefits to the environment and human well-being. In addition to the NbS definition, IUCN also proposed a set of principles to provide a clearer understanding of NbS and facilitate its operational implementation (Cohen-Shacham et al., 2019). In this regard, Nature-based Solutions:

- embrace nature conservation norms and principles;
- can be implemented alone or in an integrated manner with other solutions to societal challenges;
- are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge;
- produce societal benefits in a fair and equitable way, in a manner that promotes transparency and broad participation;
- maintain biological and cultural diversity and the ability of ecosystems to evolve over time;
- are applied at the scale at a landscape;
- recognise and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services;
- are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

3.1.2 EU research, innovation and policies

The NbS concept emerged as part of a paradigm shift that began in the 1980s, which viewed people as proactively protecting, managing, or restoring ecosystems to address major societal challenges, rather than being passive beneficiaries of nature (Cohen-Shacham et al., 2019). The term NbS first appeared in the 2000s during discussions on land-use management and planning, industrial design, and water resource management (Liu et al., 2021). In 2008, the World Bank began promoting NbS as a source of solutions to climate change challenges (World Bank, 2008). In 2009, IUCN actively promoted the NbS concept in its position paper on the United Nations Framework Convention on Climate Change (UNFCCC) COP 15. In 2012, IUCN formally adopted NbS as one of the three areas of work within its 2013-2016 Programme (Cohen-Shacham et al., 2016).

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Subsequently, the NbS concept gained significant traction and was embraced, expanded, and supported by the European Commission, and has become increasingly common in literature on approaches for enhancing resilience to the effects of climate change (Cohen-Shacham et al., 2019; IUCN, 2020a). In recent years, NbS has been integrated into policy, funding priorities, scientific literature, plans, and strategies, and has been applied and implemented by numerous institutions. The European Commission developed a Research and Innovation agenda on NbS in its Seventh Framework Program (FP7), included NbS in its Horizon 2020 Programme (Maes and Jacobs, 2015) and is addressing NbS in many of its Green Deal Calls and Horizon Europe Calls (European Commission, 2017, 2015), funding various projects to enhance the evidence base for NbS and develop multiple large-scale pilots and demonstration cases.

NbS are prominently featured in the European Green Deal and recent key European policy initiatives, such as the EU Biodiversity Strategy for 2030 (European Commission, 2020) and the new EU Strategy on Adaptation to Climate Change. NbS are also expected to play a crucial role in the implementation of the new EU Forest Strategy, as well as the upcoming EU Soil Strategy and European Zero Pollution Action Plan for air, water, and soil. Moreover, the implementation of NbS is considered a key factor for the successful deployment of other major European policies and strategies such as the Floods Directive, the Groundwater Directive, the Urban Waste-Water Treatment Directive, the Water Framework Directive, the Marine Strategy Framework Directive, and the Air Quality Directive. The NbS concept's emphasis on biodiversity makes this closely linked to the Natura2000 network, as well as the Birds and Habitats Directives (European Commission. Directorate General for Research and Innovation., 2021).

With the increasing recognition of NbS described in the previous paragraphs, came a real demand to develop and provide useful tools and guidelines, such as the IUCN NbS Standard, to clarify the NbS concept and promote its implementation (IUCN, 2020b).

3.1.3 The IUCN NbS Standard

As NbS gains traction in policy, is adopted by multiple stakeholders and is used in a wide range of initiatives, there is an increasing need for greater clarity and precision regarding what the concept entails and what is required for its successful implementation. In this context, IUCN has facilitated the co-design of an NbS standard by combining knowledge, skills, and experiences from a wide range of stakeholders (IUCN, 2020b).

The, IUCN Global Standard for Nature-based Solutions, therefore, enhance that there is a shared understanding and interpretation of the NbS concept, and facilitates the exchange of knowledge to enhance and improve applications, thereby increasing confidence in NbS among decision-makers (IUCN, 2020a). Furthermore, the IUCN Standard offers a specific and systematic framework to support the implementation of specific actions on the ground, accelerate policy development, and assess the design and execution of interventions through a process that promotes accountability (IUCN, 2020b). It also functions as a tool for developing a consistent approach to designing and validating concrete actions, avoiding a rigid framing with fixed, definitive thresholds for what NbS should achieve. The use of the IUCN Standard facilitates the identification of best practices to address environmental and social challenges, linking interventions to research narratives and relevant existing tools, approaches, and methods (IUCN, 2020a, 2020b)

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The societal challenges currently considered in the IUCN NbS Standard are (1) climate change adaptation and mitigation, (2) disaster risk reduction, (3) ecosystem degradation and biodiversity loss, (4) food security, (5) human health, (6) social and economic development, and (7) water security. As NbS continue to evolve, there may be other specific challenges addressed within this scope and the development of NbS oriented to promote soil health could help to link the IUCN Standard with soil-related actions, and potentially, identify societal challenges not yet addressed.

The IUCN Standard consists of eight criteria, each with a set of indicators, built on the NbS principles as well as feedback from a participatory process. These support users in two ways: 1) assessing the extent to which a proposed solution qualifies as an NbS, using a scale of strong, adequate, partial, or insufficient, and identifying what actions can be taken to further strengthen the intervention's robustness, and 2) facilitating the design of a solution that adheres to the criteria and indicators while building in adaptive management mechanisms to maintain the solution's impact (IUCN, 2020b).

- Criterion 1 emphasizes the importance of clearly identifying the societal challenge that the NbS will address to ensure deliberate and purposeful design aimed at meeting human well-being needs.
- Criterion 2 guides the design of an NbS by considering scale considerations. While intervention activities can be focused at the site scale, the robustness, applicability, and responsiveness of the solution should consider the interactions that occur across different social and ecological scales.
- Criteria 3, 4 and 5 outline processes that can enhance the chances of positive outcomes for biodiversity, society and the economy. However, in order to achieve these three Criteria, trade-offs need to be determined and made, which are directly addressed in Criterion 6.
- Criterion 6 addresses the practicalities of navigating and balancing the trade-offs inherent in most natural resource management decision-making processes, including balancing immediate, short-term, and long-term outcomes. It emphasizes the importance of ensuring that trade-off decisions are made with equity, full transparency, disclosure, and consensus among all stakeholders impacted by the decisions.
- Criterion 7 promotes an adaptive management approach, where learning and action complement each other to evolve and improve the NbS solution. This approach enables NbS to address uncertainties and respond to unintended, unforeseen, and undesirable consequences of the intervention.
- Criterion 8 focuses on processes for mainstreaming NbS across spatial and temporal scales, to ensure that actions and impacts are sustained beyond stand-alone projects, sharing lessons to inform other solutions, and embedding the concept and actions into policy or regulatory frameworks. This includes linking NbS to national targets or international commitments.

Each of the criteria is articulated in several indicators that may serve as a tool to enable users to evaluate the degree of alignment of their intervention with those eight Criteria and determine whether it adheres to the IUCN Standard for NbS (IUCN, 2020b).

3.2 What is soil health?

3.2.1 Concept & definitions

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Soil plays a fundamental role in terrestrial ecosystems, serving as a medium for plants and other biota, and supporting all terrestrial life by providing the necessary conditions for development. The concept of soil health recognizes that soil is a dynamic and complex system resulting from interactions between the atmosphere, biosphere, lithosphere, and hydrosphere (Lehmann et al., 2020) that delivers a wide range of vital ecosystem functions. Furthermore, soil health is a concept intimately related to soil biodiversity and it significantly contributes to incorporating the biological perspective into soil management since it is based on recognizing soil as a living resource.

In this sense**, soil health has been defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health** (Doran et al., 1996).

Soil health is a concept that has emerged from soil quality in recent decades. Those concepts have faced some criticism due to its elusive and value-laden definition and there were concerns that it was accepted prematurely before being fully formulated and tested (Aronson, 2011; Sojka and Upchurch, 1999). However, in the recent years, policymakers, scientists, and practitioners have increasingly adopted the soil health concept, in part due to its flexibility and the ability of different stakeholders to use it in their own way (Lehmann et al., 2020). The concept of soil health is linked to the emerging One Health concept, which recognizes the interdependent relationships between the health of humans, plants, animals, and the environment (Lehmann et al., 2020).

The term soil health is often understood as a complementary term to soil quality (Laishram et al., 2012). In some cases, both terms are used as synonyms (Dollinger and Jose, 2018), while others argue that there is a distinction between the two concepts (Doran et al., 1996; Pankhurst et al., 1997). Soil quality analysis and assessments have traditionally focused on specific uses and needs, such as agriculture productivity, whereas soil health also considers other attributes of the soil, mainly associated with its biota, that are implicated in processes beyond the growth of a particular crop (Pankhurst et al., 1997). Other related concepts, including soil fertility and soil security, emphasize specific aspects of the role of soil in society, ecosystems, or agriculture (Lehmann et al., 2020).

As it happened with the concept of soil quality, **there is currently no widely agreed definition for soil health**. This lack of consensus, has been further complicated since soil health includes multiple and diverse factors such as soil fertility, soil productivity, soil biodiversity and soil contamination among others (Lehmann et al., 2020). Consequently, measuring soil health and determining appropriate indicators and thresholds for different soil types, land uses, and climate contexts to support soil functions and services is challenging.

One of the significant contributions of the soil-health framework is the **incorporation of the biological perspective into soil management.** Soil functions not only depend on physical and chemical properties but also on biological properties. Soil health recognizes that soils are dynamic, living systems and soil biota and their interactions are crucial to soil functions and services (European Commission. Directorate General for Research and Innovation., 2020). Despite the recognition of soil's crucial role in water quality, climate change,

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and human health, the quantification of soil characteristics is still dominated by physical and chemical indicators, with limited functional knowledge and effective methods for assessing soil biodiversity, as biological properties are generally considered more challenging to measure, predict, or quantify (Lehmann et al., 2020). There are other soil health definitions that highlight the consideration of soil as a finite and non-renewable resource over a human time frame of decadal or generational scales (Doran et al., 1996). Nevertheless, soil health definition is evolving and it is a concept that is gaining momentum in science and policy. In the European context, the Soil Mission stands out as one of the main examples of this trend.

The **Horizon Europe Mission A Soil Deal for Europe**, is one of the current instruments of the Horizon Europe research and innovation programme. In the Mission implementation plan, soil health has been defined as the continued capacity of soils to support ecosystem services (European Commission. Directorate General for Research and Innovation., 2020). In this context, Ecosystem Services can be understood as “the contributions of ecosystems to benefits used in economic and other human activity” following the SEEA Experimental Ecosystem Accounting definition.

As a basis for reporting, the mission proposes to use a set of eight soil health indicators to assess current status of the soil health and track change as a basis to be discussed.

1. Presence of pollutants, excess nutrients and salts
2. Soil organic carbon stock
3. Soil structure including soil bulk density and absence of soil sealing and erosion
4. Soil biodiversity
5. Soil nutrients and acidity (pH)
6. Vegetation cover
7. Landscape heterogeneity
8. Forest cover

3.2.2 Soil biodiversity

Soil biodiversity has been defined as the variety of life belowground, from genes and species to the communities they form, as well as the ecological complexes to which they contribute and to which they belong, from soil micro-habitats to landscapes (FAO et al., 2020). The complex and heterogeneous physical and chemical nature of soils across multiple scales provides a wide range of habitats for a multitude of organisms (Orgiazzi et al., 2016). As a result, soil biota represents one of the largest reservoirs of biodiversity on Earth, particularly at the microbial scale (Yang et al., 2018). However, even if soil biodiversity exceeds that of other terrestrial systems by orders of magnitude it is still undervalued (FAO et al., 2020).

Soil organisms and their interactions play a crucial role in many ecological processes that support a wide range of ecosystem services essential for human well-being (FAO et al., 2020; Orgiazzi et al., 2016). For instance, processes involved in carbon and nutrient cycles, such as decomposition of organic matter and nitrogen fixation, are closely interrelated with the activities of soil biota. These processes benefit society by contributing to the delivery of 1) provisioning services such as plant production and raw material sources, and the storage

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and delivery of clean water 2) regulating services such as soil genesis, disease and pest control, climate regulation, biorremedation and detoxification of pollutants, hydrological services such water quality and flow regulation, and 3) cultural services related to landscape symbolic and spiritual value, recreation, and cultural heritage among others (FAO et al., 2020; Orgiazzi et al., 2016).

Soil biodiversity characteristics such as microbial community abundance, diversity and activity could be considered indicators of soil health (Doran and Zeiss, 2000) considering the importance of soil biodiversity in ecosystem functioning and the delivery of several key ecosystem services, and the general consensus that a decline in biodiversity leads to a decrease in ecosystem functions and services (FAO et al., 2020). In this regard, indicators related to soil biodiversity could be explored for assessing ecosystem services, as the abundance and diversity of soil organisms often are well correlated with many beneficial soil functions and biological processes are intimately linked to the maintenance of soil properties and are potentially more sensitive to changes in the soil than indicators based on physical and chemical soil properties (Pankhurst et al., 1997).

3.3 Conclusions regarding NbS and soil health. Achievements to date and moving forward: gaps, opportunities and challenges

There are several approaches that fall under the NbS concept and contribute to improving soil health. These approaches include: 1) ecosystem restoration approaches such as ecological restoration, 2) issue-specific ecosystem-related approaches such as ecosystem-based adaptation, ecosystem-based mitigation, and ecosystem-based disaster risk reduction; 3) infrastructure-related approaches such as natural infrastructure and green infrastructure approaches, 4) ecosystem-based management approaches such as integrated coastal zone management; and 5) ecosystem protection approaches such as area-based conservation approaches.

There are specific management systems and sustainable soil management practices that have relevant impact on soil biodiversity. This includes soil and land restoration, soil erosion prevention and control, afforestation and reforestation, bioremediation, fire management, sustainable land management and conservation, soil-oriented rewilding, and several sustainable agriculture approaches such as conservation agriculture, agroforestry, organic farming, and agroecology, among others (FAO et al., 2020; Orgiazzi et al., 2016). Regenerative agriculture could be highlighted, as it is an agricultural production system specifically focused on enhancing and sustaining the health of the soil (Oberč and Arroyo Schnell, 2020). Specific management practices may include cover crops, reduced tillage, diversification of crops, soil organic amendments, mulching, and avoiding land use conversion (Doran and Zeiss, 2000; FAO et al., 2020; Orgiazzi et al., 2016).

Many of these practices and management systems are being framed under the NbS concept, although they may not strictly follow the established principles and criteria. **In this regard, there is a lack of knowledge and practical experiences that explicitly relates NbS and soil health.** However, it should also be considered that, there is a history of managing nature in ways that provide benefits for society, without using the concept NbS to describe these interventions. In this regard, it should be noted that there are many interventions that fall under the NbS umbrella that are not always explicitly considered as such on the ground.

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NbS offers a significant opportunity for innovation, providing long-term, tangible and positive impacts across society, and offering additional co-benefits in comparison with conventional or classical grey solutions (European Commission. Directorate General for Research and Innovation., 2021). However, many NbS interventions still face significant challenges in terms of up-scalling and monitoring (European Commission. Directorate General for Research and Innovation., 2021). Additionally, with multiple definitions of NbS in use, there may be confusion about the concept, potentially hindering its development and uptake. A lack of operational clarity presents a major obstacle to the credibility and applicability of new concepts (Cohen-Shacham et al., 2019). In this regard, the IUCN NbS standard provides a clear definition and a set of principles to deepen our understanding of NbS, and guide research and implementation efforts with a systematic framework that can potentially provide useful tools to guide the application of NbS towards soil health.

Even if **R+D+I activities related to soil have been underfunded** in comparison to other environmental issues, and the importance of soil and the multiplicity of ecosystem services that depend on soil properties are not well understood (Orgiazzi et al., 2016). There are significant knowledge gaps, as soil biodiversity historically did not receive as much attention and funding as biodiversity in other fields. Nevertheless, soil experts are becoming increasingly aware of the need to inform and educate the general public, policymakers, land managers, and other scientists about the importance and global significance of soil (Orgiazzi et al., 2016). Additionally, there has been widespread interest among researchers, policymakers, and stakeholders in the use of the soil-health concept (Lehmann et al., 2020). The versatility of the concept allows many stakeholders to adopt soil health and make it work for their context and build consensus across different disciplines.

To further strengthen the potential of the soil health framework, **it is crucial to deepen our understanding of the relationships between soil biota and soil functions** and to agree upon clear definitions that allow us to work together and overcome barriers related to its ambiguity. Developing an agreement on soil health indicators that can be used as quantitative tools to assess soil health is one of the major challenges. These indicators need to be robust, meaningful, and easy to measure and interpret and consider soil heterogeneity, site-specific nature of soil management, and varying ecosystem services with sometimes conflicting needs. Despite knowledge and implementation gaps, the NbS concept provides a promising approach to address soil health, considering synergies and trade-offs.

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4 Nature Based Solutions in forestry

4.1 Introduction

Forest soil has a significant impact on providing essential nutrients for vegetation growth and vitality. However, factors related to human activities such as deforestation, improper land use practices, and soil erosion have led to the deterioration of forest soil quality. Therefore, the paper was divided into 3 problematic sections: soil biodiversity, climate change and adaptation in context of forest soils and soil erosion and landslides in forests.

In some areas, this degradation has caused a decline in biodiversity as plants and animals struggle to survive in nutrient-poor soil conditions. Furthermore, soil degradation has also compromised the capacity of forests to sequester carbon, thereby exacerbating the impact of climate change. Also, human factor may have increased the vulnerability of forest soils to erosion and landslide effects.

To reverse thess troubling trend, it is essential to implement a nature-based solution for forest soil restoration, which will contribute to preserving the biodiversity that depends on it.

4.2 Soil biodiversity in forests

Biodiversity is declining at an alarming rate due to various factors, including the degradation of forest soil. Forest soil is essential for supporting diverse plant and animal species as it provides nutrients and supports the growth of vegetation. However, deforestation, improper land use practices, and soil erosion have resulted in the degradation of forest soil. This, in turn, has led to a decline in biodiversity as plants and animals struggle to survive in the nutrient-poor soil. Additionally, soil degradation has also reduced the ability of forests to store carbon, exacerbating the effects of climate change (Samec et al., 2023). To reverse this trend, it is crucial to implement sustainable land management practices that protect and restore forest soil, thus preserving the biodiversity that depends on it. The most vulnerable part of the Earth's critical zone consists of the ground (pedosphere), which includes the interfaces between the atmosphere, hydrosphere, lithosphere and biosphere. For these reasons, soil damage has long changed the nature of the entire ecosystem (Kucera et al., 2021).

Deforestation has a significant impact on biodiversity decline, and soil degradation is one of the primary mechanisms through which this occurs (Tibbett et al., 2020). Trees play a critical role in maintaining soil structure, retaining moisture, and preventing erosion. When forests are cleared, the soil is left exposed to the elements, leading to increased soil erosion and loss of nutrients. Moreover, deforestation reduces the availability of organic matter, which is essential for supporting the microbial communities that are critical for soil health. Deforestation in tropical forests has been shown to negatively impact soil microbes, mesofauna and macrofauna (Franco et al., 2019). As soil quality declines, it becomes less capable of supporting diverse plant species, leading to a decline in overall biodiversity. The loss of biodiversity can, in turn, have cascading effects on other ecosystem services, such as pollination and nutrient cycling, further exacerbating the negative impacts of deforestation. Therefore, efforts to reduce deforestation and promote reforestation are crucial for preserving biodiversity and maintaining the health of forest soil. Soil degradation caused by deforestation affects the self-organization and self-regulation of ecosystems. Disruption of soil self-organization begins with a decrease in the diversity of functional connections within microbial communities. Dysfunction of soil functional

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links consists in the loss of biodiversity and the replacement of microbial symbioses by decomposing organisms (saprophytes) that do not exchange available nutrients between organisms, but cause leakage of substances from the ecosystem. The degradation of forest soils destroys irreplaceable natural values that improve the adaptability of the cultural landscape to climate change. Disruption of soil self-organization harms both the continuity of crop production and the success of ecosystem restoration (Abbasian et al., 2016, Samec et al., 2023).

Chemical soil degradation includes acidification, salinization and poisoning. Acidification is the most extensive process of forest soil degradation leading to a decrease in habitat fertility(Samec et al., 2023). Acidification of forest soil was caused by fertilization, crop cultivation and industrial pollution. Industrially emitted CO2, SO2 and NOx create formal acids and can have a significant impact on the decline of biodiversity within a forest ecosystem. Forest soils usually have a slightly acidic pH, which supports the growth of many plant species. However, when the soil becomes too acidic due to factors such as acid rain, it can become toxic to plants and the organisms that live in the soil. The high levels of acidity can also leach essential nutrients from the soil, making it difficult for plants to grow and survive. This can lead to a decline in the diversity of plant species, which then impacts the animals that rely on these plants for food and habitat. Moreover, acidification of forest soil can alter the composition of the microbial community in the soil, disrupting the delicate balance of interactions that support the ecosystem. Therefore, acidification of forest soil can have a cascading effect on the entire ecosystem and ultimately lead to a decline in biodiversity (Spyra et al., 2017; Tibbett et al., 2020).

The salinity of forest soils is a rare phenomenon. Forest soils are saline on the surface, which is due to the high mineral content of the groundwater, the use of salt water for irrigation, or fertilization. Linear salinity occurs along road routes where chemical salting is used in winter or along river banks. The effects of salinity in forests as shown by irregularities in the uptake of water and nutrients by plants. The most important here is the disproportionate supply of sodium (sodification) which disturbs the chemical environment of the soil, thus affecting its structure and water availability for plants. The high content of sodium in plant tissues lowers the osmotic pressure, which makes the cells lose their ability to absorb other substances from the soil solution. While conifers are susceptible to soil salinity, deciduous tree species are tolerant of it. Younger plants are more susceptible than older ones. For salinity, forests are most vulnerable to floodplains due to the variability of water flow. An increase in the level of saline waters causes a decrease in the activity of soil microorganisms, a loss of oxygen in the soil environment, an increase in the concentration of Na+, Cl−, SO42− ions, including Fe and Mn compounds, and consequently a decrease in the growth of vegetation. The main threat to salinity of forests with groundwater is the inability to adapt to climate change due to the spread of micro-oxygen conditions (Samec et al. , 2023).

Soil poisoning, especially with heavy metals of industrial origin, is a dangerous phenomenon because heavy metals participate in biogeochemical cycles and accumulate in the ecosystem. Soil contamination can come from point sources such as steelworks, combined heat and power plants, or from diffuse sources such as polluted water, improper distribution of industrial or sewage sludge, or the operation of internal combustion engines. Contamination of the soil environment with heavy metals significantly reduces the concentration of microorganisms and directly harms plants. Soil contamination rate damages microbial activity much more than differences in heavy metal content at different locations. However, the decline in the number of susceptible species is being replaced by the expansion of populations of resistant species, including pests that abundantly attack damaged plants (Fiedlowa 2010, Samec et al., 2023). Accumulation of heavy metals is associated with toxic symptoms and threatens not only tree species, but also predators associated mainly with plant food: insects, earthworms, countless larvae and springtails. Accumulation of heavy metals takes place in the cells of specialized microorganisms by binding to amino acids, which changes the course of caries formation. The

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rate of biosorption on microbiologically active soil surfaces usually decreases in the order Zn > Cd > Pb > Cu > Cr (Samec et al., 2023).

Improper land use practices can have a significant impact on forest soil health and contribute to biodiversity decline. For example, in some areas, forests are cleared for industrial agriculture or livestock grazing, leading to soil compaction, erosion, and nutrient depletion. These practices often involve the use of heavy machinery, which can further damage the soil structure and lead to the loss of important soil microorganisms. Erosion of topsoil is a major threat to soil health and can lead to loss of soil fertility, decreased water-holding capacity, and a decline in the abundance of soil organisms. When soil erosion occurs, it can lead to a loss of these nutrients and destabilization of the soil, making it difficult for plants to grow and survive. This, in turn, can result in a decline in the diversity of plant species, which then impacts the animals that rely on these plants for food and habitat. Moreover, soil erosion can also lead to the loss of topsoil, which contains a high amount of organic matter and microorganisms, necessary for the proper functioning of the ecosystem. Therefore, soil erosion in forests can have a cascading effect on the entire ecosystem and ultimately lead to a decline in biodiversity (Borelli et al., 2020).

Mining is another example of improper land use practices that can have a severe impact on forest soil health. Mining operations can involve the removal of large amounts of soil, leading to soil erosion and nutrient loss. Additionally, mining can release heavy metals and other toxins into the soil, making it less hospitable to plant and animal life (Stoll et al., 2022). Finally, urbanization can also have a negative impact on forest soil health. As cities expand, forests are cleared, and the soil is often compacted due to construction and heavy foot traffic, reducing its ability to support plant life. To preserve the health of forest soil and support biodiversity, it is crucial to implement sustainable land use practices that prioritize conservation and restoration, such as reforestation, conservation agriculture, and land-use planning that balances economic development with environmental conservation (Gao et al., 2023).

Restoring the biological diversity of soil in degraded forest ecosystems is crucial for maintaining healthy ecosystems and promoting sustainable forestry practices. Soil is a complex and diverse ecosystem that supports many organisms, including bacteria, fungi, protozoa, nematodes, and earthworms. These organisms play a vital role in nutrient cycling, decomposition of organic matter, and plant growth, thereby contributing to the overall health and productivity of the forest ecosystem (Aerts and Honnay, 2011). However, disturbances such as deforestation, logging, and agricultural activities can significantly reduce the diversity and abundance of soil organisms, leading to a decline in soil fertility and ecosystem function. To restore the biological diversity of forest soil, efforts to protect and rebuild should aim to reduce soil disturbance and erosion, promote organic matter accumulation, and increase plant diversity through reforestation and agroforestry practices (Prescott et al., 2019, Khoramizadeh et al., 2021, Xu et al., 2022). Additionally, promoting natural regeneration and reducing the use of chemical fertilizers and pesticides can also contribute to the restoration of soil biological diversity in forests.

Reducing soil disturbance and erosion in forest soil is crucial for maintaining soil health and promoting biological diversity. Effective approaches to achieve this goal include implementing conservation and management practices. An important strategy for promoting the restoration of biological diversity by reducing soil disturbance and erosion is the use of sustainable forestry practices, such as selective logging and reduced impact logging (Ellis et al., 2019). These practices involve the careful and selective removal of trees while leaving the majority of the forest intact, which helps to maintain soil stability and reduce erosion. Additionally, the use of ground cover plants and mulching can help to reduce soil erosion by providing cover and preventing soil exposure to atmospheric factors. Finally, reducing the use of heavy equipment and avoiding soil

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compaction can also contribute to reducing soil disturbance and erosion in forest soils (Ellis et al., 2019, Xu et al., 2022).

The accumulation of organic matter in forest soil is crucial for maintaining soil fertility and promoting biological diversity (Prescott et al., 2019). One effective way to achieve this goal is to add organic materials to the soil. This can be achieved through techniques such as composting, which involves transforming organic waste into nutrient-rich soil. Additionally, mulching with organic materials such as leaves, straw, and wood chips can also help promote the accumulation of organic matter, providing a source of organic material for soil microorganisms to break down. Promoting natural regeneration by allowing fallen leaves, branches, and other plant material to decompose on the forest floor can also contribute to the accumulation of organic matter in forest soil (Carey 2016, Khoramizadeh et al., 2021). One important approach to promoting the restoration of biological diversity in forest soil is the use of mycorrhizal fungi, which form symbiotic relationships with tree roots and play a crucial role in nutrient uptake and soil aggregation. By promoting the growth of mycorrhizal fungi in degraded forest soils, soil health can be improved and the regeneration of other soil organisms accelerated (Aerts and Honnay, 2011). Furthermore, limiting the use of chemical fertilizers and pesticides can contribute to an increase in soil microorganisms, which in turn can contribute to the accumulation of organic matter. Finally, limiting tillage and soil disturbance can also help promote the accumulation of organic matter by reducing soil erosion and promoting the growth of soil microorganisms.

Increasing plant diversity through reforestation is an important element of efforts to restore and protect forests. One effective way to achieve this goal is to plant a diverse mix of tree species in reforestation projects (Aerts and Honnay, 2011). This approach can help promote ecological resilience by increasing the number of plant species present in the ecosystem, which in turn can provide a range of ecological benefits such as improving soil health, increasing wildlife habitat, and greater carbon sequestration. In addition to tree species, enriching the understory and ground cover plant species can also contribute to increased plant diversity in forest ecosystems (Lyu et al., 2021). These plants can provide additional wildlife habitat, reduce soil erosion, and help maintain soil moisture levels (Aerts and Honnay, 2011). Overall, increasing plant diversity through reforestation is a key step in promoting the overall health and productivity of forest ecosystems.

Agroforestry is an effective way to promote the restoration of biodiversity in forest soil. Agroforestry involves the integration of tree and agriculture conservation, where the cultivation of crops and livestock is combined with the management of trees and forests. This approach can help improve soil quality, promote biodiversity, and support sustainable land use. By integrating trees into agricultural landscapes, agroforestry can provide additional benefits such as shade, windbreaks, and erosion control, which can help improve soil quality and reduce erosion. Additionally, agroforestry can provide habitats for wildlife and promote plant diversity, which can contribute to overall ecosystem health and resilience, including forest soil. Overall, agroforestry practices are an important tool for promoting the restoration of biodiversity in forest soil while also providing a range of social, economic, and environmental benefits (Sahoo et al., 2020).

Biodiversity conservation for forest soil are intricately connected to climate change mitigation and adaptation strategies. Mitigation efforts, such as reforestation and afforestation, not only sequester carbon but also promote the restoration of diverse plant species, creating habitat for a wide range of flora and fauna (Hof et al., 2017). The presence of diverse plant communities enhances soil health and fertility by fostering nutrient cycling and microbial activity (Kubiek et al., 2017). In turn, healthy forest soils support the growth and resilience of a diverse array of organisms, including microorganisms, invertebrates, and fungi, forming complex ecological networks. Preserving biodiversity in forest ecosystems is vital for their adaptation to climate change as it increases their resilience to disturbances and enables them to withstand shifting environmental conditions. Biodiversity-rich forests can better cope with extreme weather events, soil erosion, and invasive species,

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ensuring the long-term stability and functionality of forest soil ecosystems. Thus, the conservation of biodiversity and the protection of forest soil are interdependent components of effective climate change mitigation and adaptation strategies (Yang et al., 2021).

Soils play a crucial role as a global reservoir of biodiversity and are considered one of the most species-rich habitats in terrestrial ecosystems, as noted by Decaëns et al. in 2006. A decrease in soil biodiversity typically refers to a decline in the quantity and diversity of soil life forms. Such a decline can significantly impair the soil's ability to function effectively, respond to disturbances, and recover to its pre-disturbance state. Several soil threats have been identified as having a detrimental impact on soil biodiversity, including the increasingly intense climate change occurring globally, as highlighted by Tibbett et al. in 2020.

4.3 Climate change and adaptation in context of forest soils

In the context of the impact of climate change on biogeochemical processes in forest soils, it is important to consider the relationship between the three compartments of terrestrial ecosystems: the atmosphere (climate), the biosphere (vegetation) and the lithosphere (soil). Changes in any one of these compartments will impact the others (Campbell et al., 2009).

Far reaching consequences for ecosystem stability and functioning has increased drought frequency. While soil microbial communities, both fungal and bacterial, are regularly exposed to drought and wetting (DRW) cycles in most ecosystem types, increasing length of drought and frequency of DRW cycles can cause changes in microbial community composition, which finally affects biogeochemical cycling rates. Changes in the biogeochemical cycle have significant impacts on soil carbon dynamics, nutrient availability, greenhouse gas fluxes between soil and atmosphere (Gillespie et al., 2020; Jansson, et al., 2019).

Climate change can directly affect soil properties, such as water and nutrient availability, causing changes in tree growth. Soil texture is one of the characteristics of forest systems that can regulate the impact of climate change. It is a major determinant of soil water quantity and aeration, which is important for both tree growth and microbial processes (Gómez-Guerrero et al., 2018). Resulting from climate change heavy precipitation and flooding can erode forest soils and cause stored carbon to be released back into the atmosphere (Vose et al., 2018).

At the moment, action is needed in two main directions: first, action to mitigate the effects of all those adverse phenomena and processes we are already facing (passive strategy), and, second, action to better adapt forest ecosystems to future threats (active strategy). The primary driver of climate change is the over-abundance of carbon dioxide in the atmosphere. Forests have an important role to play in the fight against climate change because they help to slow the rate of climate change by removing carbon dioxide from the atmosphere and storing it (Verkerk et al., 2022).

Contrary to common perceptions that living plant biomass is mainly responsible for carbon accumulation, a greater part of the carbon stored in the forest ecosystem is found in the soil (Birdsey, 1992). The amount of carbon in the soil depends on the amount of organic matter supplied to the soil and the conditions for the transformation of this matter, influencing the intensity of mineralisation and humification processes. The aforementioned are determined by the conditions of the environment (type of bedrock, terrain and associated air-water relations) and climate (mainly temperature and amount of precipitation). Soils play a key role in the global carbon cycle. A global carbon stored in soils (excluding permafrost) is more than three times higher than carbon stocks in vegetation (Verkerk et al., 2022).

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One of the ecosystems with the highest carbon content and with most of the carbon stored in the soil in the world are the Mangrove forests. In Sanderman et al. (2018) there was developed a machine-learning model of the distribution of carbon density in these forests. The model was able to capture 63% of the variability in soil organic carbon density. There is a relationship between environmental features (ex. terrain topography) and SOC stocks. Zeraatpisheh et al. (2013) evaluated how the spatial resolution of environmental variables changed their ability to predict soil organic carbon (SOC) stocks in Vermont, U.S.

Adequate soil moisture and pH are very important. A healthy soil with an optimum acidity index can store water and thus all the organisms living in it have conditions for growth, thus absorbing and building carbon into their structures. Ensuring optimum moisture content and proper plant cultivation contributes to the absorption of carbon dioxide from the atmosphere. According to the FAO (Food and Agriculture Organisation of the United Nations), restoring currently degraded soils could remove as much as 63 million tonnes of carbon, offsetting a small but significant percentage of global greenhouse gas emissions. Healthy soils retain carbon underground. It should also be emphasised that natural and semi-natural areas are a powerful protective base against the effects of climate change (FAO, 2015).

The new approaches of forest management are needed to enable greater carbon sequestration by forest ecosystems. One of these is a concept of back-converting managed forests to untouched old-growth forests for the sake of climate change mitigation (Jandl, 2019). Old growth forests have traditionally been considered insignificant as carbon sinks, as carbon uptake was thought to be balanced by respiration. In Zhou et al. (2006) it was shown that soils in the upper 20-cm soil layer of extant old-growth forests in southern China accumulated atmospheric carbon at an unexpectedly high rate from 1979 to 2003. This phenomenon points to the need for future research into the complex responses and adaptation of underground processes to global environmental change.

4.4 Soil erosion and landslides in forests

Floods and landslides in a changing climate pose significant threats to forest soil due to various soil-related factors. Inadequate soil management practices, such as deforestation, improper land use planning, and unsustainable agriculture, can weaken the integrity of forest soils, making them more susceptible to erosion during heavy rainfall events. The loss of tree cover reduces the ability of forest soils to absorb and retain water, leading to increased surface runoff and the potential for flooding. Additionally, the removal of vegetation destabilizes slopes, increasing the risk of landslides, especially in hilly or mountainous regions. Soil compaction resulting from human activities further exacerbates these risks by reducing soil permeability and increasing surface runoff (Danáčová et al., 2020).

According to the European Environment Agency (EEA), water erosion affects approximately 105 million hectares, or 16 % of Europe’s total land area (excluding Russia) were estimated to be affected by water erosion in the 1990s.

During the period from 2000 to 2002, the Organization for Economic Cooperation and Development (OECD) estimated that more than 20% of agricultural land in Italy was categorized within the moderate to severe risk classes for soil water erosion, with erosion rates equal to or exceeding 11 tons per hectare per year. In a separate study, the Institute for Environmental Protection and Research conducted a comprehensive mapping effort in Italy, identifying approximately 485,000 landslides. These landslides encompass an area of 2,070,000 hectares, accounting for 6.9% of the country's total land area. Additionally, the institute also mapped the areas of row crops and woodland, assessing their degrees of criticality at different levels (Constantini et al., 2013).

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It is important to emphasize that the majority of shallow landslides primarily affect the soil layer rather than the underlying substratum. These landslides occur due to a multifaceted interplay among various factors, including climate conditions, landscape morphology, soil properties, land use practices in forested areas, and the way they are managed. Hence, by considering the soil characteristics alone, it becomes feasible to comprehend the underlying causes of these mass movements and determine appropriate technical measures for their prevention. For instance, it has been well documented that the improper management of woodland on Andosols placed on fragile morphologies can dramatically increase the risk of landslides. Shallow landslides in woodlands often concern the soil cover and are triggered by an improper land management (Constantini et al., 2013). In Taiwan, floods primarily occur as a result of intense rainstorms that surpass the threshold of 250 mm. These floods are not noticeably influenced by the current low rate of annual forest removal. However, the rapid urbanization of certain forested watersheds can lead to heightened peak flows and diminished low flows, primarily due to the substantial reduction in soil infiltration capacities. (Cheng, 2002).

Depending on the level of degradation of agricultural land, well designed, located and managed forestry can reduce the volume of sediment, nutrients and salt volumes transported into river systems, although not necessarily their concentrations (van Dijk AIJM, 2007). Afforestation is not likely to reduce major large-scale flooding or deep-seated landslides, but may reduce shallow landslides and local 'flash' floods. The influence of afforestation on global precipitation patterns is complex and land use change would need to occur on a large scale to have a discernible influence.

Based on our summary, we propose that the most important factors determining the impact of afforestation on water resources can be classified as relating to (i) forest hydrology and related soil properties, (ii) benchmark landscape condition and (iii) water resources system configuration.

Radial gradients of sap flow in the sapwood can result in errors (Clearwater et al., 1999), and stand level estimates require scaling procedures to extrapolate up from individual trees. Scaling can be particularly difficult in forests with age and species diversity. This technique only measures one component of evapotranspiration (transpiration), a further limitation when the overall water budget is required. Forest cutting and road development can increase the delivery of water to soil and streams, increasing streamflows, the initiation of debris slides and debris flows, and the availability of sediment and coarse, woody debris in streams (Swanson et al., 1998).

The current method of mapping landslide susceptibility has been subject to criticism in recent studies. The critique centers around the use of similar geo-environmental factors across different regions and time periods. These studies argue that the approach relies on fixed variables such as distance to roads and land-use/land-cover, without accounting for dynamic changes in these factors. The current land-cover, as represented in available images, may not accurately reflect the actual conditions of an area during a landslide event. In this research, an examination was conducted to assess how well a geographic object-based random forest method can model the vulnerability of both protected and non-protected forests to landslides. The study utilized a database comprising various object features associated with conditioning factors like topography, hydrology, geology, soil, and vegetation, as well as triggering factors including rainfall, floods, earthquakes, deforestation, forest fragmentation, logging, and mining. The random forest algorithm was employed to map the susceptibility of landslides in the two forest areas, incorporating these factors into the analysis (Shirvani, 2020).

Around 88% of the vulnerability of protected forests was accounted for by the conditioning factors, with a significant emphasis on topographic characteristics contributing to 60% and hydrologic features contributing to 18%. In addition, triggering factors recorded 22% of importance, focusing on natural triggering factors (16%).

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The mapping of landslide susceptibility in the protected forest relied on the top five variables, namely TRI, slope, earthquake, elevation, and TCI. These variables played a crucial role in assessing the likelihood of landslides in the area. In contrast, the importance values were distributed among the object features of both the conditioning and triggering factors in the non-protected forests. This study indicates that different forest areas can be affected by different conditioning and triggering factors that control their susceptibility to landslides. Consequently, there are no uniformly predefined influential variables for mapping landslide susceptibility in forest areas (Shirvani, 2020).

When it comes to the type of land which is the most vulnerable to landslides, barren land, such as riverbeds, floodplains, denudational hills, sites of debris flow, gullies, and landslide-prone areas, experience the highest level of geo-environmental stress. On the other hand, dense forest areas, specifically oak, pine, and mixed forests, experience the least amount of geo-environmental stress and consequently display low vulnerability to floods. These forested areas exhibit lower rates of stream runoff, sediment load delivery and denudation (Rawat et al., 2012). It indicates that forest are very effective against soil erosion in areas mentioned above.

To mitigate the impacts of floods and landslides on forest soil, implementing measures such as reforestation, terracing, and contour plowing can help restore soil structure, improve water infiltration, and enhance slope stability. By adopting sustainable land management practices, protecting forest ecosystems, and promoting soil conservation, the vulnerability of forest soils to floods and landslides can be reduced, ensuring their long-term stability and resilience (Rogger et al., 2017).

4.5 Summary

To sum up, main problems of forest soils area: biodiversity decline, chemical soil degradation, climate change, erosion and landslides. Forest soil degradation disrupts the delicate balance of nutrients and organisms necessary for supporting diverse plant species, ultimately leading to a decline in overall biodiversity. The decline in biodiversity is intricately linked to the degradation of forest soil caused by deforestation, improper land use practices, and soil erosion. Additionally, chemical soil degradation, such as acidification, salinization, and soil poisoning, further contributes to the loss of biodiversity within forest ecosystems.

To restore and protect forest soil, various actions can be taken, including nature-based solutions, including agroforestry, increasing plant diversity, landslide prevention, proper plant cultivation and water management. Such actions are important for maintaining healthy soil ecosystems, promoting sustainable forestry, and mitigating the impacts of climate change.

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4.6 Literature

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5 Nature Based Solutions in urban environment

5.1 Urban soil contamination and exposure pathways

Heavy metal pollution in urban soils is difficult to control because of its wide sources, many forms, and complex migration. The three wastes, traffic exhaust, sewage irrigation, improper fertilizer, and pesticide application have become the main sources of heavy metals in urban soils.

Heavy metals such as lead (Pb), zinc (Zn), chromium (Cr), nickel (Ni), arsenic(As), mercury (Hg) or cadmium (Cd) are the most frequently studied inorganic contaminants in urban soils and can be linked to adverse health hazard effects since they cannot be decomposed by micro-organisms having long-term toxicity for plants, animals and humans.

According to the European Environment Agency (EEA), there are as many as **2.5 million potentially contaminated sites** across Europe that need to be investigated. Of these, approximately **14% (340 000 sites)** are expected to be contaminated and likely to require remediation. Soil pollution affects soil fertility; this jeopardizes food security, which is essential for human survival. It also poses risks to human health — both indirectly through the consumption of contaminated food and drinking water and directly through exposure to contaminated soil. Soils in urban areas, such as parks and home gardens, are a repository for contaminants. The degree of exposure is likely to depend on weather and soil conditions, as well as on the distance to sources of pollution. As green areas provide a potential exposure pathway for organisms and humans, soil pollution there requires particular attention.

A meta-analysis conducted to evaluate the level of China's heavy metal pollution in soils found that the average concentrations of Cd, Pb, Zn, Cu, Hg, Cr, Ni, and As in China were 0.19, 30.74, 85.86, 25.81, 0.074, 67.37, 27.77 and 8.89 mg/kg respectively. The average pollution level of heavy metals in urban soils was higher than in agricultural.

A recent article shows that urban greenspaces and adjacent natural areas (i.e., natural/semi-natural ecosystems) shared similar levels of multiple soil contaminants (metal (loid)s, pesticides, microplastics, and antibiotic resistance genes) across the globe. The article also reveals that human influence explained many forms of soil contamination worldwide. Socioeconomic factors were integral to explaining the occurrence of soil contaminants worldwide. The article further shows that increased levels of multiple soil contaminants were linked with changes in microbial traits including genes associated with environmental stress resistance, nutrient cycling, and pathogenesis.

There are several ways to prevent soil contamination. Some of them include:

- The use of bio-fertilizers and manures can help to reduce the use of chemical fertilizers and pesticides. Biological pest management approaches can help reduce the use of pesticides, reducing soil contamination.
- Material recovery and recycling.
- Daily environment supervision should be enhanced by making a layout plan that should include close supervision of the soil environment including regular information updates.
- Using more environmentally friendly gardening products and fewer pesticides in your yard helps prevent soil pollution. Together with eating less meat, growing your own food and purchasing local and organic fruits and vegetables.

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Urban soil contamination is a serious issue that can have negative impacts on human health and the environment. There are several methods to clean up urban soil contamination, including physical, chemical, and biological methods. The choice of method depends on the type and extent of contamination.

Common contaminants in urban soils include pesticides, petroleum products, radon, asbestos, lead, chromate copper arsenate and creosote. In urban areas, soil contamination is largely caused by human activities. Some examples are manufacturing, industrial dumping, land development, local waste disposal, and excessive pesticide or fertilizer use.

A recent review article published in Geoderma discusses the ecosystem services of urban soils and how they can be maintained. The authors highlight the importance of soil in providing numerous vital ecosystem services (ESs) such as flood mitigation, buffering the urban heat island effect, capturing air pollution, physical support for infrastructure, urban food growing and access to green space for mental and physical health; whilst at local and global scales, they contribute to nutrient cycling and carbon storage.
Another study investigated potential soil contamination inside and outside formal sector recycling plants in seven countries. They collected 118 soil samples at 15 recycling plants and one battery manufacturing site and analyzed them for total lead. Lead levels in soils ranged from < 40–140,000 mg/kg.

5.2 Phyto- and bio-remediation methods for soil cleanup

Bioremediation is a biological method that uses living microorganisms such as bacteria and fungi to break down organic pollutants in the soil. In-situ techniques use specific bacteria to break down the contamination or plants that can accumulate the contaminants. Ex-situ techniques use slurries or solids to treat contaminated soil. Bioremediation is a biological approach that uses microorganisms to degrade or transform hazardous organic and inorganic pollutants into less toxic or nontoxic substances. Bioremediation has been used to remediate contaminated soils in various settings including urban areas.
A recent study discusses how bioremediation is a green approach for restoration of polluted soil and water by transformation of toxic pollutants into less hazardous or completely non-hazardous forms. The bioremediation technology includes extensive use of microorganisms or their enzymatic machineries, phytoremediation (plants) and more.

A review article published in the International Journal of Environmental Research and Public Health describes the application of bioremediation in urban soil contamination. The article highlights the importance of bioremediation in the remediation of contaminated urban soils and its potential to reduce the risk of exposure to hazardous substances.
Bioremediation has several advantages over other methods of soil remediation. It is a natural process that does not require the use of chemicals or heavy equipment. It is also less expensive than other methods and can be used in situ, which means that it can be applied directly to the contaminated soil.
Phytoremediation is an eco-friendly approach that uses plants to remove or degrade hazardous substances from the environment. Plants can absorb and accumulate heavy metals and organic pollutants from the soil through their roots and translocate them to the aboveground parts of the plant where they can be harvested and disposed of.

Phytoremediation could be a successful cleanup measure to revegetate heavy metal-polluted soil in a cost-effective way. To improve the efficiency of phytoremediation, a better understanding of the mechanisms underlying heavy metal accumulation and tolerance in plant is indispensable

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A recent review article describes the mechanisms of how heavy metals are taken up, translocated, and detoxified in plants. The article also focuses on the strategies applied to improve the efficiency of phytostabilization and phytoextraction, including the application of genetic engineering, microbe-assisted and chelate-assisted approaches. Some of these applications are described in detail in the section below.
Biological methods for urban soil cleanup have some disadvantages. One of the main disadvantages is that they are often slow and require a lot of time to be effective. Another disadvantage is that they can be expensive and require a lot of resources to implement. Additionally, biological methods may not be effective in all situations and may not be able to remove all contaminants from the soil[1].

Both phytoremediation and bioremediation are eco-friendly approaches that can be used to remediate contaminated soils. However, phytoremediation is limited to the removal of contaminants that can be taken up by plants, while bioremediation can be used to remediate a wider range of contaminants.

Phytomanagement is a phytotechnology that focuses on the use of plants and associated microorganisms, together with ad hoc site management practices, for an economically viable and ecologically sustainable recovery of contaminated sites. It promotes the recovery of soil ecological functions and decreases pollutant linkages while providing economic revenues by producing non-food crops for biomass-processing technologies. Potential environmental benefits also include the provision of valuable ecosystem services such as water drainage management, soil erosion deterrence, carbon sequestration, regulation of nutrient cycles, xenobiotic biodegradation, and metal (loid) stabilization.

5.2.1 Tools for application of phytoremediation

Phytoremediation of soil contaminated with heavy metals involves various steps and processes, which include heavy-metal uptake (phytoextraction), accumulation and translocation of heavy metals (phytoaccumulation), emission to atmosphere (phytovolatilization) and their stabilization in the root zone (phytostabilization).

Strategies applied to improve the efficiency of phytostabilization and phytoextraction, including the application of genetic engineering, microbe-assisted and chelate-assisted approaches have been described by many authors.

Microbe-assisted phytoremediation is a bioremediation technique that is considered as a promising technology to reduce or mitigate contaminants from the environment. Studies have reported that microbes, including bacteria and fungi, exhibit beneficial roles in growth promotion, stress alleviation, and degradation.
Some examples of microbes used in phytoremediation include bacteria such as Pseudomonas putida, Rhizobium leguminosarum, and Bacillus subtilis, and fungi such as Trichoderma harzianum and Aspergillus niger. These microbes can help to degrade pollutants in the soil and make them less harmful. They can also help to promote plant growth and reduce stress.
Microbe-assisted phytoremediation is considered a potential approach for the treatment of mixed pollutants. Studies have reported that microbes, including bacteria and fungi, exhibit beneficial roles in growth promotion, stress alleviation, and degradation. The advantages of using microbe-assisted phytoremediation include its cost-effectiveness and environmental safety. The disadvantages of using microbe-assisted phytoremediation include the need for specific environmental conditions to work effectively and may not be effective for all types of contaminants.

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Multiple biotechnological tools, including genetic alteration of plants, can be employed to strengthen the phytoremediation capacity. Plant genetic engineering for phytoremediation can be an effective approach to exploit potential genes involved in metal uptake, translocation, reduction, complexation, vacuolar sequestration, and volatilization.

A recent article discusses various genetic engineering approaches for intensifying the phytoremediation capacity of plants for heavy metal and metalloids (Cd, Pb, Cr, As, Se and Hg), highlighting the recent advances and their limitations. It also evaluates various limitations and challenges of the genetic engineering approaches. The review discusses the molecular understanding of various regulatory and signaling molecules and their utilization in improving the phytoremediation potential of plants.

Genetic engineering can be used to enhance the phytoremediation capacity of plants by exploiting potential genes involved in metal uptake, translocation, reduction, complexation, vacuolar sequestration, and volatilization. However, one needs to understand the mechanism of the increased accumulation of heavy metals in hyperaccumulators and translate the findings into high biomass crop plants for sustainable cleansing of the environment.

Chelate-assisted phytoremediation is a technique that uses chelating agents to mobilize metals into the soil solution and bioavailable forms, where they can be taken up by selected plant species. Various types of chelates, both synthetic and natural, can be used in this process. This technique includes interactions between soil, targeted element(s), chelate and plant in complex processes of solution and transport of elements from soil and their uptake and translocation in plants.

Chelate-assisted phytoremediation can boost the metals removal efficiency, high phytotoxicity tolerance and increase translocation and accumulation of metals in the aboveground parts of the plants. The advantages of using chelate-assisted phytoremediation include its low cost and shorter time-span needed for remediation compared to traditional phytoremediation process. However, it is still prone to several limitations and drawbacks. Leaching of mobilized metals from chelate-treated soils is often reported, sometimes also accompanied by leaching of soil macronutrients. Moreover, low biodegradability of applied chelates can cause additional toxicity and leaching to the soil and waters. Application of biodegradable chelating agents with short degradation periods instead of synthetic and low-degradable chelates has been viewed as an alternative for reducing the environmental risks connected with the use of chelates.

Improvements in phytoremediation can be achieved through the utilization of organic amendments such as agro- and industrial wastes (e.g., sugar beet residue and composted sewage sludge), biochar, humic substances, plant extracts and exudates. These natural materials can influence soil structure and characteristics, plant growth and bioavailability of pollutants.

Organic amendments can be used for urban soil cleanup and phytoremediation. They can improve phytoremediation by reducing the concentration of pollutants or rendering them harmless. Organic amendments can be used to improve soil quality and reduce the bioavailability of contaminants. They can also enhance the growth of plants and microorganisms that are involved in the degradation of contaminants. Organic amendments include agro- and industrial wastes such as sugar beet residue, composted sewage sludge or molasses, biochar, humic substances, plant extracts and exudates.

5.3 Policies in support of pollution reduction in urban soils

The EU soil strategy for 2030 sets out a framework and concrete measures to protect and restore soils and ensure that they are used sustainably. It sets a vision and objectives to achieve healthy soils by 2050, with

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concrete actions by 2030. The strategy contains several key actions such as tabling a dedicated legislative proposal on soil health by 2023 to enable the objectives of the EU soil strategy and achieve good soil health by 2050.

A recent article talks about the importance of urban soil remediation in the EU soil strategy for 2030. The article states that urban soil remediation is important because it can help reduce the risk of exposure to contaminants in urban areas. It also talks about the zero-pollution target that, by 2050, soil pollution should be so low that it no longer harms human health.

The zero-pollution vision for 2050 is for air, water, and soil pollution to be reduced to levels no longer considered harmful to health and natural ecosystems, that respect the boundaries with which our planet can cope, thereby creating a toxic-free environment. This is translated into key 2030 targets to speed up reducing pollution at source. These targets include: improving air quality to reduce the number of premature deaths caused by air pollution by 55%; improving water quality by reducing waste, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%); improving soil quality by reducing nutrient losses and chemical pesticides' use by 50%; reducing by 25% the EU ecosystems where air pollution threatens biodiversity; reducing the share of people chronically disturbed by transport noise by 30%, and significantly reducing waste generation and by 50% residual municipal waste.

The European Environment Agency (EEA) has published a report on soil pollution and health. The report presents available knowledge and trends on soil pollution and associated impacts on health and assesses progress towards achieving relevant zero pollution targets and policy objectives. The report states that hotspots for human exposure to soil pollution are contaminated sites, certain agricultural and urban soils, and land that has previously been flooded. Many contaminated sites in Europe still have not been registered, characterised, monitored or remediated, thus posing significant risks to human health. There is evidence that pollutants are accumulating in soil above critical thresholds set to protect soil health.
The EU Soil Strategy for 2030 sets the vision to have all soils in healthy condition by 2050 and to make protecting, restoring and sustainably using soils the norm. It also announces that the Commission will table a new Soil Health Law, providing a comprehensive legal framework for soil protection.

The European Commission has announced that it will propose a Soil Health Law in 2023 to significantly improve the state of soils by 2050 and to protect soils on the same legal basis as air and water. The Soil Health Law proposal will provide definitions for healthy soils and establish monitoring requirements at the EU level and for Members States.

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6 Nature based solutions in industrial environment

Nature-based solutions (NBS) are actions and initiatives inspired and supported by nature. Such actions involve the protection, restoration and sustainable management of natural and semi-natural ecosystems, the sustainable management of aquatic and terrestrial ecosystems and the creation of new ecosystems. NBS are already widely discussed and applied to increase the sustainability of resources and energy use, maintain and protect ecosystem values, provide ecosystem services, increase the resilience of territories, promote social cohesion, support climate change mitigation and adaptation, and increase carbon sequestration.

Industrial waste contains various amounts of harmful substances and hazardous compounds. Their content in the soil changes the strength of the top layer, reducing the fertility and biological activity of the soil. Industrial areas typically have higher levels of trace elements and organic pollutants. Disposal and treatment of municipal and industrial waste accounts for around one-third of Europe's soil pollution problem. Industrial brownfields can release pollutants, intentionally or unintentionally, directly into the environment. The main contaminants associated with this activity are mineral oils, trace elements (such as arsenic, cadmium, lead, nickel or zinc) and organic pollutants such as halogenated and non-halogenated solvents, PCBs and PAHs. Industrial accidents or problems related to abandoned industrial sites, which have a long-term impact on the environment, are also important sources of industrial pollution releases, e.g. through landfills located there, which are not managed in an environmentally friendly manner (FAO and UNEP. 2021).

Best practice concepts for available extraction, production, recycling and disposal techniques are included in many national legal standards. Most countries have adopted legislation on industrial waste, but the degree of stringency and compliance varies. A common source of soil contamination is the uncontrolled disposal of industrial waste, which transfers a range of pollutants to the soil. Uncontrolled release of industrial waste into the environment without treatment can cause serious environmental problems. This can reduce the productivity of soils and thus negatively affect agricultural production in the vicinity of industrial areas. Like pollutants, they affect the chemical and biological properties of soils. Hazardous chemicals from industrial plants can also leach into groundwater. The presence of pollutants in the soil or groundwater may cause them to enter the food chain of humans or other living organisms, causing serious consequences for their life functions (FAO and UNEP. 2021).

In the industrial sector, NBS can bring benefits such as producing non-food crops for biomass-processing technologies (biofuel and bioenergy sector, eco materials, bio sourced-chemistry, etc.), thus contributing to the international demand for sustainable and renewable sources of energy and raw materials for the bioeconomy.
There are several methods for cleaning up industrial-contaminated soils. Some of these methods include biological treatment/bioremediation, chemical oxidation, soil stabilization, and physical methods like soil washing.

Each method has its own advantages and disadvantages, and the most appropriate method will depend on the specific site conditions and the type of contamination present.
A recent paper discusses the need for sustainable remediation strategies for the clean-up of contaminated soil and groundwater at brownfield sites. Widespread pollution from industrial activities has driven land degradation with detrimental human health effects, especially in urban areas. Remediation and redevelopment of the

estimated 5 million brownfield sites globally is needed to support the sustainable transition and increase urban ecosystem services, but many traditional strategies are often environmentally harmful.
Conventional remediation strategies, such as dig and haul, or pump and treat, ignore secondary environmental burdens and socioeconomic impacts; over their life cycle, some strategies are more detrimental than taking no action. Chemical oxidation converts contaminated soils into non-hazardous soils. Soil stabilization involves the addition of immobilizing agents to reduce a contaminants' leachability. Soil washing uses water to separate or remove contaminants.
Sustainable remediation technologies, such as sustainable immobilization, low-impact bioremediation, new forms of in-situ chemical treatment and innovative passive barriers, can substantially reduce the environmental footprint of remediation and maximize overall net benefits. Compared with traditional methods, they can typically reduce the life-cycle greenhouse gas emissions by ~50–80%.
Integrating remediation with redevelopment through nature-based solutions and sustainable energy systems could further increase the socioeconomic benefit while providing carbon sequestration or green energy. The long-term resilience of these systems still needs to be understood, and ethics and equality must be quantified to ensure that these systems are robust and just.
Some examples of sustainable remediation technologies include sustainable immobilization, low-impact bioremediation, new forms of in-situ chemical treatment and innovative passive barriers.
Sustainable remediation brings a new approach within contaminated sites management, compared to that of traditionally considered. In general, sustainable remediation reflects the perception that remediation activities can bring about environmental, social, and economic impacts, both positive and negative, and that considering these aspects in isolation is no longer enough. A balance needs to be struck among the benefits.

The traditional approach to managing contaminated sites is based almost exclusively on the risk, time, and cost and efficiency of decontamination, often provoking exhaustive remediation. This approach has been replaced by sustainable management concepts through dissemination and incorporation of the term "sustainable remediation" (SR). SR has evolved since the establishment of the first Sustainable Remediation Forum (SURF) until recent publication of the American Society for Testing and Materials (ASTM) and International Organization for Standardization (ISO) standards.
Sustainable Remediation can include biological methods such as bioremediation. There are several biological methods for the remediation of industrial sites. Biological remediation or biodegradation constitutes many types of methods involved in the removal or degradation of heavy metals through biological activity. These include bioremediation systems that rely on microbial metabolism for site clean-up and phytoremediation, which utilizes natural processes harboured in (or stimulated by) plants.
These biological treatments may either include aerobic (presence of oxygen) or anaerobic (absence of oxygen) processes and can be used for heavy metal removal.

Low-impact bioremediation is a sustainable remediation technology that can substantially reduce the environmental footprint of remediation and maximize overall net benefits. Bioremediation is a green remediation approach that relies upon the ability of certain living organisms, including species of plants, bacteria, fungi or soil animals, to degrade or detoxify contaminants in their tissues.
Bioremediation uses microorganisms (which may be indigenous or isolated from any other site), naturally occurring bacteria, fungi and plants to degrade or detoxify the contaminants (hazardous to human health and environment) into less toxic forms. The bioaugmentation process is used when microorganisms are imported to a contaminated site to enhance detoxification.

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The public considers it more efficient than other technologies because bioremediation is based on natural attenuation (NA). Bioremediation has certain limits such as high aromatic hydrocarbons are resistant to microbial attack. Bioremediation system mostly runs under aerobic conditions. Important factors include availability of contaminants to the microbial population and the environmental factors (pH, temperature, soil type, nutrients and presence of oxygen).
NA is an in-situ treatment that reduces contamination in soil and groundwater using naturally occurring processes in soil. This treatment acts without human intervention and the activity focuses on the verification and monitoring of processes to assure their sustainability over time and their effectiveness.

Natural attenuation encompasses processes that lead to a reduction of the mass, toxicity, mobility, or volume of contaminants without human intervention. The US EPA has recently published guidelines for the use of Monitored Natural Attenuation (MNA) for a variety of contaminated sites.
Low-impact bioremediation and phytoremediation are sustainable remediation technologies that can be used to restore contaminated industrial sites. Biological remediation including bioremediation and phytoremediation employs microorganisms and/or plants to remove, degrade and/or immobilize contaminants in the environment. With its advantages being low-cost, simple operation, and eco-friendly, biological remediation has wide application in restoring contaminated sites.
Sustainable immobilization, low-impact bioremediation, new in-situ chemical treatment and innovative passive barriers are promising remediation strategies that have proven successful in real-world applications.
Passive barriers are a sustainable remediation technology that can be used to restore contaminated industrial sites. They are a cost-effective method for in-situ remediation of contaminated groundwater and are designed to intercept and treat contaminated groundwater as it flows through the barrier. The barrier contains reactive materials that remove or degrade contaminants as the groundwater passes through.
Innovative passive barriers are one of the sustainable remediation technologies that can substantially reduce the environmental footprint of remediation and maximize overall net benefits.
One advantage of low-cost bioremediation is that it is an appropriate method to decontaminate soil and water naturally, with the help of the biological processes of ecosystems and solar energy, without the need to add chemical substances that can become more dangerous than the same pollutants. However, there are also some challenges associated with low-cost bioremediation. For example, it may not be effective for all types of contaminants or in all environmental conditions. Additionally, it may take longer to achieve remediation compared to other methods.

Phytoremediation is an environmentally friendly technique, the system of which is based on the ability of plants to absorb heavy metal ions from the environment and their accumulation in various parts of the plant (root, stem, leaves, flowers, fruits). This process has no adverse effect on soil structure, fertility or microbial activity. An important factor when introducing this method to a given area is the selection of appropriate plant species. Plants used during the phytoremediation treatment must be tolerant to high concentrations of metals in soils, have a fast growth rate, and have the highest biomass increase possible. For this purpose, plant species that naturally occur in an industrially degraded area are used, as well as other species that will be able to survive in a given area. Plants that can bioaccumulate high concentrations of a given metal are called hyperaccumulators. They may accumulate more than 100 mg/kg^{-1} dry biomass for Cd or more than 1000 mg/kg^{-1} dry biomass for Ni, Cu or Pb or more than 10 000 mg/kg^{-1} Zn or Mn in their shoots.
The advantage of using phytoremediation techniques is the possibility of using them over large areas, and the metals accumulated in plant biomass can be recovered through physico-chemical, thermal or biological processes. In addition, the properties of soils improve, the microflora from the rhizosphere is restored and the transfer of nutrients is intensified (Nejad et al. 2017, Gavrilescu 2022).

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Quite often, the use of one technique may not be effective enough to clean a contaminated area. Therefore, a possible solution is to use two techniques simultaneously. For example, one of the nature-based solutions recommended by the European Commission that contribute to reducing the level of toxic compounds in the soil is plant-assisted bioremediation (PABR). PABR is a technique in which plants are used to stimulate the reduction of the content of persistent organic pollutants in the soil with the help of microorganisms and the phytostabilization of inorganic pollutants. Such a synergistic interaction between the rhizosphere of the plant root system and the natural soil microflora enables the removal, transformation or retention of toxic substances in the substrate (Nejad et al. 2017; Ashraf et al. 2019; Gavrilescu 2022).

Over the past few decades, many techniques have been developed for the remediation of environments polluted by heavy metals. Basically, there are two main strategies to improve soil quality: removing heavy metals and immobilizing them irreversibly. A common source of soil contamination is the uncontrolled disposal of industrial waste, which transfers a range of pollutants to the soil. Uncontrolled industrial waste, if released into the environment without treatment, can cause serious environmental problems. This can reduce the productivity of soils and thus negatively affect agricultural production in the vicinity of industrial areas. Like pollutants, they affect the chemical and biological properties of soils. Hazardous chemicals from industrial plants can also leach into groundwater. The presence of pollutants in the soil or groundwater may cause them to enter the food chain of humans or other living organisms, causing serious consequences for their vital functions. This is why it is so important to restore soils to their natural state in and around industrial areas (Nejad et al. 2017; FAO and UNEP. 2021).

Nature-based solutions, such as bioremediation or phytoremediation techniques, may be effective for this purpose. These methods have a number of advantages, including being environmentally friendly. However, there is still a need for a lot of research devoted to the improvement of solutions supporting the remediation of industrially polluted environments (Nejad et al. 2017; FAO and UNEP. 2021).

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7 Summary and conclusions

61% of soils in the EU are considered unhealthy (EEA, 2022), which presents an obvious risk to both food safety as well as food quality and customer health. Soils play a fundamental role in terrestrial ecosystems, serving as a medium for plants and other biota, and supporting all terrestrial life by providing the necessary conditions for development. The concept of soil health recognizes that soil is a dynamic and complex system resulting from interactions between the atmosphere, biosphere, lithosphere, and hydrosphere (Lehmann et al., 2020) that delivers a wide range of vital ecosystem functions. Furthermore, soil health is a concept intimately related to soil biodiversity and it significantly contributes to incorporating the biological perspective into soil management since it is based on recognizing soil as a living resource.

One of the significant contributions of the soil-health is the **incorporation of the biological perspective into soil management.** Soil functions not only depend on physical and chemical properties but also on biological properties. Soil health recognizes that soils are dynamic, living systems and soil biota and their interactions are crucial to soil functions and services (European Commission. Directorate General for Research and Innovation., 2020).

There are several approaches that fall under the NbS concept and contribute to improving soil health. These approaches include: 1) ecosystem restoration approaches such as ecological restoration, 2) issue-specific ecosystem-related approaches such as ecosystem-based adaptation, ecosystem-based mitigation, and ecosystem-based disaster risk reduction; 3) infrastructure-related approaches such as natural infrastructure and green infrastructure approaches, 4) ecosystem-based management approaches such as integrated coastal zone management; and 5) ecosystem protection approaches such as area-based conservation approaches.

NbS offers a significant opportunity for innovation, providing long-term, tangible and positive impacts across society, and offering additional co-benefits in comparison with conventional or classical grey solutions (European Commission. Directorate General for Research and Innovation., 2021).

NBSoil project investigated several real-life cases of NbS utilized in agricultural, forestry, urban and industrial lands. Within the urban areas we've listed three documented cases of communal urban gardening. Within industrial lands 3 cases of afforestation of urban brownfields, phytoremediation and bioremediation. Further cases are being analyzed and will be added to the deliverable consequently in upcoming month.

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Nature-Based Solutions for Soil Management

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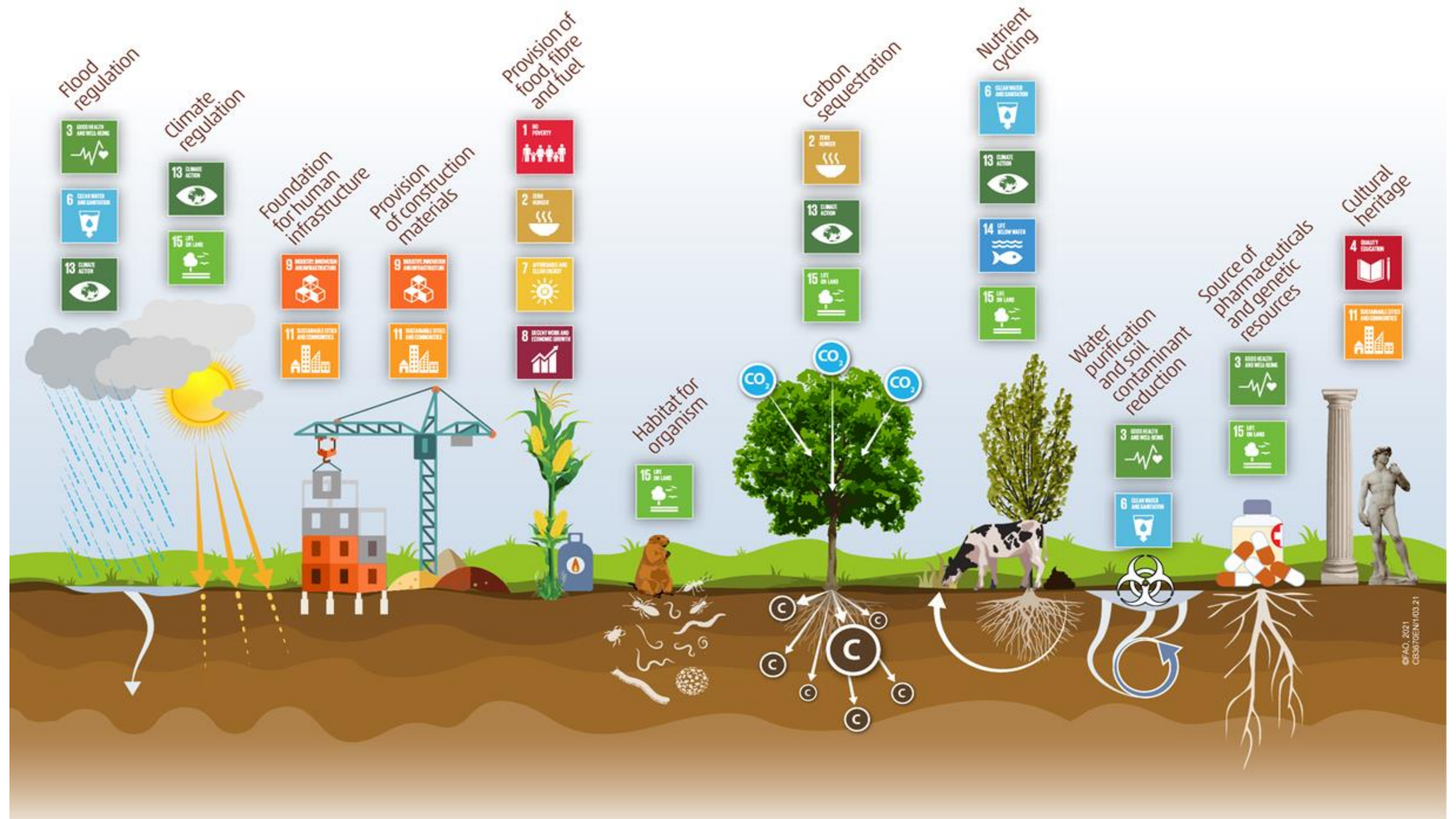
In 2015, all United Nations member states adopted the 2030 Agenda for Sustainable Development, a shared plan for peace and prosperity for people and the planet, now and in the future. At its heart are 17 Sustainable Development Goals (SDGs), which represent an urgent call to action by all countries - developed and developing - in a global partnership.

Representatives from countries around the world have pledged, among other things, to protect the planet, combat climate change and its effects, and protect terrestrial ecosystems through sustainable forest management, combat desertification, halt and reverse land degradation, and halt biodiversity loss. Many of these goals cannot be achieved without healthy soils and sustainable land use.

Healthy soils

- are essential for all life-sustaining processes on Earth
- have the continued capacity to support ecosystem services



Healthy soils, a prerequisite to achieve the SDGs. Source: fao.org

The following is an overview of the Sustainable Development Goals inextricably linked to soils.

Zero hunger - extreme hunger and malnutrition remains a barrier to sustainable development and creates a trap from which people cannot easily escape. 2 billion people in the world do not have regular access to safe, nutritious and sufficient food. In 2019, 144 million children under the age of 5 were stunted, and 47 million were affected by wasting. Today, soil, drinking water, oceans, forests and biodiversity are being rapidly degraded. Starting in the 1900s, wehave lost 75% of the world's diversity in agricultural crops. To eradicate world hunger, to ensure that all people have access to safe, nutritious and sufficient food all year round, it is necessary to improve soil quality, ensure sustainable food production systems and implement appropriate agricultural practices that will increase productivity and production and help sustain ecosystems.

Good health and well-being are linked to the soil, because healthy soils produce healthy crops, which in turn nourish people and animals, keeping them healthy and productive. There is evidence that healthy soils are the basis for nutritious and healthy food. Soils contribute to global health by storing and supplying nutrients, which in turn supports food and fiber production. However, global agricultural intensification has led to negative impacts on regulatory ecosystems services for soil, air.

Soils play an important role in the movement, storage and transformation of water and affect the quality and availability of water supply. Countries are currently facing increasing challenges related to water scarcity and pollution. Accordingly, advances in soil science affect the prospects for achieving Sustainable Development Goal 6 - **clean water and sanitation**. Every person in the world should have access to clean water. Water scarcity, poor water quality and inadequate sanitation have negative impacts on food security, poverty reduction, ecosystems and also education and human rights.

Cities face a challenge related to their governance. The question arises - how to strive for the successful development of cities and the creation of jobs without overexploitation of land. SDG 11 - **sustainable cities and communities** is about making cities and neighborhoods safe, resilient and sustainable and addresses in particular soil issues such as waste management and ensuring universal access to safe, inclusive and accessible green and public spaces. The objective is also directly related to soil issues as it deals with climate change mitigation and adaptation, and soils will play an important role in this respect as they provide numerous ecosystem services.

Sustainable soil management is also key to achieving Sustainable Development Goal No. 12. It is important to ensure consumption patterns that ensure that chemicals do not enter the soil, which could have a negative impact on our health and environment. Sustainable soil management that maintains or increases soil organic matter (SOM) can mitigate climate change, improve soil quality and food security. Particularly beneficial for SOM is tillage, the introduction of crop residues, organic matter, including organic waste, and crop rotation with wide soil cover.

Goal 13 - **climate action** is about taking urgent action to combat climate change and its effects. The increase in carbon dioxide concentrations has increased the average temperature by 1 °C. Climate change has a major impact on soil and vice versa, so without healthier soils and sustainable land and soil management, we will not be able to face the climate crisis and produce enough food while adapting to the changing climate.

The main objective of this goal is to address threats to biodiversity, ensure the protection, restoration and sustainable use of terrestrial and inland freshwater ecosystems, including forests, wetlands, mountains and drylands, promote the implementation of sustainable management of all types of forests, stop deforestation, combat desertification and restoration of degraded land and soils.

The NBSOIL project will help achieve Sustainable Development Goals by promoting existing knowledge of nature-based solutions (NBS) for soils and how they can benefit society, and by promoting activities to protect, sustainably manage and restore natural or modified ecosystems that respond effectively and adaptively to societal challenges while ensuring human well-being and biodiversity benefits. To meet these objectives, the project's goals focus on six multifunctional practices, namely: organic fertilizers, cover crops, paludiculture, forest diversification, bioremediation, green and blue infrastructure. The knowledge base will present the NBS portfolio for soil health, addressing the objectives of the EU Soil Mission.

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THE MISSION ‘A SOIL DEAL FOR EUROPE’ EXPLAINED

The Mission ‘A Soil Deal for Europe’: 100 living labs and lighthouses to lead the transition towards healthy soils

Soil is the basis for 95% of our food, so life on Earth depends on healthy soils. In addition, soil provides clean water and habitat for biodiversity and contributes to resilience to climate change, and supports our cultural heritage and landscapes, and is the foundation of our economy and prosperity.

Soil is a fragile resource that needs to be carefully managed and safeguarded for future generations. One centimetre of soil can take hundreds of years to form, but can be lost in just a single rainstorm or industrial incident.

Soil health is threatened globally because of a range of human activities, such as competition for land, intensive land use, production, consumption patterns, urbanisation, and anthropogenic climate change. The process of soil degradation can lead to a collapse of landscapes and ecosystems, making societies more vulnerable to extreme weather events, food insecurity and contamination, and political instability. It is estimated that between 60 and 70% of EU soils are unhealthy, and the costs of soil degradation in the EU exceed 50 billion € per year.

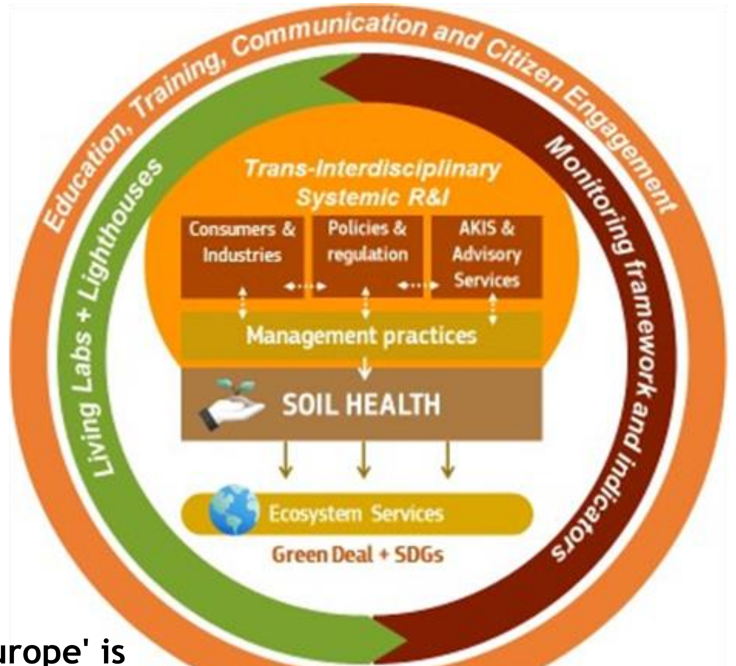
In recognition of the importance of soils, and the pressure soil functions are under, the EU made soils one out of her 5 Missions.

WHAT THIS EU MISSION DEALS WITH?

The Soil Mission ‘A Soil Deal for Europe’ is at the heart of the EU Green Deal, which is a package of policy initiatives to overcome the threats of climate change and environmental degradation.

The Mission leads the transition towards healthy soils by:

- funding an ambitious research and innovation programme with a strong social science component
- putting in place an effective network of 100 living labs and lighthouses to co-create knowledge, test solutions and demonstrate their value in real-life conditions
- developing a harmonised framework for soil monitoring in Europe
- raising people’s awareness on the vital importance of soils



The main goal of the Mission 'A Soil Deal for Europe' is to establish 100 Living Labs and Lighthouses to lead the transition towards healthy soils by 2030

WHAT ARE LIVING LABS AND LIGHTHOUSES?

Livings labs and lighthouses are key to accelerating the adoption of sustainable practices by users and to developing solutions adapted to local conditions.

Living labs are places where to experiment on the ground. Soil health living labs will be partnerships between multiple partners and different actors, like researchers, farmers, foresters, spatial planners, land managers, and citizens who come together to co-create innovations for a jointly agreed objective. Living Labs will be established at territorial, landscape or regional scale, with several experimental sites covered underneath. This is an innovative way to do research and innovation: in a Living Lab, experimentations happen in real-life conditions, operating with end-users i.e. commercial farms or forest exploitations, real urban green parks or industrial sites, and other actors such as NGOs or local authorities. This is key to make sure that research and innovation find solutions to societal challenges and challenges that land managers face on the ground.

Lighthouses are single sites, like a farm or a park, where to showcase good practices. These are places for demonstration and peer-to-peer learning. Here good practices are tested or in place and can be showed to inspire other practitioners to move towards sustainable land management. In addition, in lighthouse sites, researchers work together with land managers to ensure that research responds to concrete needs encountered in the field.

Living labs are collaborative initiatives to co-create knowledge and innovations while lighthouses are places for demonstration of solutions and of exemplary achievements

Living labs and Lighthouses are specifically intended to contribute to soil health by meeting specific soil health mission objectives

THE 8 MISSION OBJECTIVES

1. Reduce desertification
2. Conserve soil organic carbon stocks
3. Stop soil sealing and increase re-use of urban soils
4. Reduce soil pollution and enhance restoration
5. Prevent erosion
6. Improve soil structure to enhance soil biodiversity
7. Reduce the EU global footprint on soils
8. Improve soil literacy in society

Source:
1) https://europa.eu/!xY9wVF
2) https://matical.com/the-5-eu-missions-implementation-plans-have-been-published/
3) The Farm to Fork strategy, the EU Biodiversity Strategy, the Climate Adaptation Strategy, the Zero Pollution Action Plan for air, water and soil, the new EU Forest Strategy, the Long-term Vision for Rural Areas, the Organic Action Plan, the Commission’s recommendations for CAP strategic plans, the Circular Economy Action Plan, the EU Nature Restoration targets.
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URBAN SOIL


Author: L.Poreba

Urbanisation

Europe's landscape is changing. Cities are expanding turning productive agricultural land into urban areas. Today 70% of Europeans live in urban areas, which account for 5% of the EU's land area. Urbanisation is a major threat to the environment and the soil. The effect of urbanisation is soil sealing, which is the most noticeable form of human transformation of soils.

Urban soils

Urban soils are the soils of urban, industrial, communication, mining and military areas. This type of soils can be found in parks, along roads, sports fields, urban rivers, in suburban areas, near landfills and mining areas, and near industrial buildings and plants and transport facilities.

They are soils that have been heavily modified by human activities through mixing, importing and exporting materials. They are often characterised by contamination, compaction and sealing, and deposition, removal or mixing of natural substrates. Often they are characterised by artefacts, deep mixing of material and artificially formed organic or mineral layers that are often impermeable to water and roots (5).

Importance of urban soils

Urban soils are an important component of the urban ecosystem, so it is very important to manage them properly, i.e. to ensure soil quality adequate to maintain plant and animal productivity, maintain or improve water and air quality, and support human health and housing. Urban soils provide a range of ecosystem services relevant to cities. The most important for the urban environment are regulating and cultural services. Regulating services mitigate flooding, buffer the urban heat island effect, capture pollutants and are responsible for nutrient cycling. Urban soils also have the potential to store significant amounts of carbon, especially in arid climates. Unsealed urban soils support a wide range of soil organisms. From a cultural point of view, it is mainly the physical support of infrastructure and access to green spaces that affects both the physical and mental health of residents (1, 5).

Effects of soil sealing

Reduction of soil retention function
- Acceleration of surface runoff (risk of flooding and intensification of erosion)
- Reduction of infiltration and lowering the level of groundwater (lack of drinking water and increased drought)
- Reduction of the ability to filter, retain and neutralize organic and inorganic pollutants (municipal and industrial wastewater and dust)

Disturbance of habitat and ecological functions
- Decrease in the amount of soil organisms, plant and animals
- Local extinction of species
- Replacing native species with foreign ones
- Interruption of ecological corridors (which hinders the migration of animals and plants)

Local climate change
- Urban heat island
- Intensification of the drought
- Temperature extremes
- Disturbances in air circulation

Impediment of the circulation of elements and chemical compounds (loss of soil organic cover)

Groundwater contamination on the edges of urbanized areas

Nature-Based Solutions in urban areas

Nature-Based Solutions in cities are often overlooked, but they play a significant role in mitigating climate change and maintaining biodiversity. They are critical in maintaining human health and well-being.
One example of NBS is ***urban farming*** i.e. the practice of cultivating, processing, and distributing food in or around urban areas. It is the growing of fresh produce within the city for individual, communal, or commercial purposes. Many European cities have communal urban gardens available to the public providing space for citizens to cultivate plants for food, recreation and education. Urban farming has many environmental and social advantages. First, it contributes to increased local and healthy food production and increased biodiversity. FAO studies show that a microgarden of one square meter can produce any one of the following: 30 kg tomatoes a year, 36 heads of lettuce every 60 days, 10 cabbages every 90 days, 100 onions every 120 days. It also has an impact on mitigating the urban heat island effect and reduces the risk of flooding. Second, it strengthens social ties through recreation and connection to nature (2, 4).

Green roofs are specific type of urban farming. They can transform the impermeable areas of building roofs into multifunctional spaces which can help mitigate climate change and increase food production. Green roofs reduce the urban heat island effect by increasing evapotranspiration. In winter they can reduce heat loss and energy consumption. The plants on green roofs can capture air pollutants and dust and thus contribute to smog reduction. Green roofs can also reduce the amount of stormwater runoff resulting in decreased stress on sewer systems.


Author: L.Poreba

In summer they can retain 70-90% of the precipitation. Besides green roofs have excellent noise reduction and they increase biodiversity and provide habitat for various bird species. Green roofs improve health and well-being of citizens and beautify buildings and their surroundings (3).

Another example of NBS in urban areas are ***green and blue spaces***. They can be made by afforestation or creation of parks on abandoned sites. Green and blue infrastructure has many benefits especially cultural ones. It creates space for relaxation, recreations and having sport. It also increase biodiversity in cities and help mitigate urban heat island effect.


Author: L.Poreba

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NBS FOR FOREST SOILS IN EUROPE

- From an environmental perspective, forests play various roles in the ecosystem, including contributing to soil protection from erosion caused by wind and water.
- Erosion by either wind or water reduces the soil depth.
- Soils are not only an exhaustible, but also an easily degradable and difficult to restore natural resource.

Forest soil is a multifunctional element of the environment. Among its most important functions are:

- ensuring the proper circulation of components and energy flow within forest ecosystems, and indirectly in the entire biosphere by participating in the production of biomass (including wood) and creating the physical, chemical and biological conditions for the efficient mineralisation of organic residues,
- retention of water, minerals, energy carriers, etc., necessary to ensure the continuity of the processes mentioned in the previous point,
- ability to carry out self-regulating processes,
- ability to neutralise or buffer negative external influences.

- Forest soil degradation has a destructive effect on the forest biocenosis - damage within the living matter of the forest must adversely affect the properties and functions of the forest soil.
- Forest soils in Europe play a crucial role in nutrient cycle. The litterfall from trees provides a continuous supply of organic matter to the forest floor, which decomposes and releases nutrients back into the soil. This nutrient cycling process supports the growth and sustainability of forest ecosystems.

- European forest soils have a symbiotic relationship between trees and mycorrhizal fungi. These fungi form a mutually beneficial association with tree roots, aiding in nutrient absorption, particularly phosphorus, and enhancing the tree's ability to withstand stress and disease.
- Europe is home to a wide range of forest types, including deciduous forests, coniferous forests, mixed forests, and Mediterranean forests. Each forest type has its own unique soil characteristics.
- Climate change affects forest soils in Europe. Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events can impact soil moisture, nutrient availability, and soil carbon storage. These changes can have consequences for forest ecosystem dynamics, including shifts in species composition, changes in the timing of seasonal events, and altered nutrient cycling processes.

NBS practices

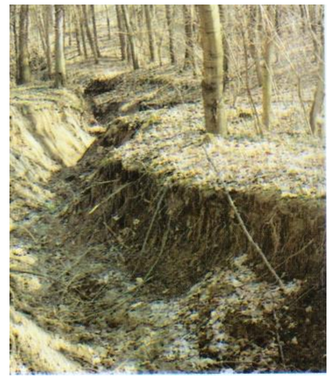
Reducing soil disturbance and erosion in forest soil is crucial for maintaining soil health and promoting biological diversity. Effective approaches to achieve this goal include implementing conservation and management practices. An important strategy for promoting the restoration of biological diversity by reducing soil disturbance and erosion is the use of sustainable forestry practices, such **as selective logging** and **reduced impact logging**. These practices involve the careful and selective removal of trees while leaving the majority of the forest intact, which helps to maintain soil stability and reduce erosion. Additionally, the use of ground cover plants and mulching can help to reduce soil erosion by providing cover and preventing soil exposure to atmospheric factors. Finally, reducing the use of heavy equipment and avoiding soil compaction can also contribute to reducing soil disturbance and erosion in forest soils.

The accumulation of organic matter in forest soil is crucial for maintaining soil fertility and promoting biological diversity. One effective way to achieve this goal is **to add organic materials to the soil**. This can be achieved through techniques such as **composting**, which involves transforming organic waste into nutrient-rich soil. Additionally, **mulching** with organic materials such as leaves, straw, and wood chips can also help promote the accumulation of organic matter, providing a source of organic material for soil microorganisms to break down. Promoting natural regeneration by allowing fallen leaves, branches, and other plant material to decompose on the forest floor can also contribute to the accumulation of organic matter in forest soil.

One important approach to promoting the restoration of biological diversity in forest soil is **the use of mycorrhizal fungi**, which form symbiotic relationships with tree roots and play a crucial role in nutrient uptake and soil aggregation. By promoting the growth of mycorrhizal fungi in degraded forest soils, soil health can be improved and the regeneration of other soil organisms accelerated. Furthermore, limiting the use of chemical fertilizers and pesticides can contribute to an increase in soil microorganisms, which in turn can contribute to the accumulation of organic matter. Finally, limiting tillage and soil disturbance can also help promote the accumulation of organic matter by reducing soil erosion and promoting the growth of soil microorganisms.

Increasing plant diversity through reforestation is an important element of efforts to restore and protect forests. One effective way to achieve this goal is to plant a diverse mix of tree species in reforestation projects. This approach can help promote ecological resilience by increasing the number of plant species present in the ecosystem, which in turn can provide a range of ecological benefits such as improving soil health, increasing wildlife habitat, and greater carbon sequestration. In addition to tree species, enriching the understory and ground cover plant species can also contribute to increased plant diversity in forest ecosystems (Lyu et al., 2021). These plants can provide additional wildlife habitat, reduce soil erosion, and help maintain soil moisture levels). Overall, increasing plant diversity through reforestation is a key step in promoting the overall health and productivity of forest ecosystems.

Agroforestry is an effective way to promote the restoration of biodiversity in forest soil. Agroforestry involves the integration of tree and agriculture conservation, where the cultivation of crops and livestock is combined with the management of trees and forests. This approach can help improve soil quality, promote biodiversity, and support sustainable land use. By integrating trees into agricultural landscapes, agroforestry can provide additional benefits such as shade, windbreaks, and erosion control, which can help improve soil quality and reduce erosion. Additionally, agroforestry can provide habitats for wildlife and promote plant diversity, which can contribute to overall ecosystem health and resilience, including forest soil. Overall, agroforestry practices are an important tool for promoting the restoration of biodiversity in forest soil while also providing a range of social, economic, and environmental benefits.



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INDUSTRIAL SOILS

Industrial waste contains various amounts of harmful substances and dangerous compounds. Their content in the soil changes the strength of the top layer, reducing the fertility and biological activity of the soil. **Disposal and treatment of municipal and industrial waste is responsible for around one-third of the soil pollution problem in Europe.** They contribute to the release of pollutants, intentionally or unintentionally, directly into the environment. Industrial areas tend to have higher levels of trace elements and organic pollutants. The main pollutants associated with this industrial activity are mineral oils, trace elements (such as arsenic, cadmium, lead, nickel or zinc) and organic pollutants such as halogenated and non-halogenated solvents, PCBs and PAHs. [1 2 3]

Best practice concepts for available extraction, production, recycling and disposal techniques are included in many national legal standards. Most countries have adopted legislation on industrial waste, but the degree of stringency and compliance varies. Another main source of environmental pollution are industrial failures or problems related to abandoned industrial sites, which have a long-term impact on the environment, e.g. through landfills located there that are not managed in an environmentally friendly way. [1 2 3]

Photo. 1. An area near a copper ore mine in the Silesian Province (Poland) (D. Gmur)

Types of industrial waste

Industrial waste is divided into two types:

Biodegradable, i.e. those that can be converted into non-toxic substances as a result of the action of certain microorganisms. Examples of this type of waste are: paper, leather, wool, animal bones, wheat and others.

Non-biodegradable, these are industrial wastes that are unable to break down into non-toxic chemicals. Examples of non-biodegradable waste are plastics, fly ash, synthetic fibres, gypsum, glass items, radioactive waste and other materials. **Non-biodegradable and hazardous waste constitutes 10 to 15% of all industrial waste, and the growth rate of this category of waste increases year by year.**[2]

Impact of industrial waste on soil

A common source of soil contamination is the uncontrolled disposal of industrial waste, which carries a range of pollutants into the soil. Uncontrolled industrial waste, when released into the environment without treatment, can result in serious environmental problems. This may reduce the productivity of the soil and thus have a negative impact on agricultural production in the vicinity of industrial sites. As well as pollutants affect the chemical and biological properties of soils. Hazardous chemicals from industrial plants can also leach into groundwater. The presence of pollutants in soil or groundwater may result in their entry into the food chain of humans or other living organisms, causing serious consequences for their life functions.[2]

Nature-based solution for industrial soils

Nature-based soil remediation technologies use soil-dwelling organisms to biodegrade, stabilize or separate contaminants. These methods are often based on the use of microorganisms (bacteria, fungi and archaea) and plants. Nature-based technologies are successfully used to clean soils contaminated with petroleum hydrocarbons, chlorinated solvents, polycyclic aromatic hydrocarbons, pesticides and trace elements. The time taken to achieve the remediation goal can vary greatly depending on the technique, concentration and type of contamination.

One nature-based solution to remediating polluted areas is phytoremediation. There is *in situ* technology that use plants for treating polluted soils. Phytoremediation is widely used to remediate soils that have been contaminated with trace elements, but can also be effective in facilitating the removal and biodegradation of organic pollutants.

This process is effective thanks to the use of processes:

- stabilization of pollutants, as a result of which pollutants are less mobile in the soil,
- removal of contaminants by facilitating their degradation or transfer to other media.

Depending on the mechanism of plants in the remediation process and the type of pollutants, phytoremediation can be divided into several techniques:

- phytostabilization,
- phytoextraction,
- phytodegradation,
- rhizodegradation,
- phytovolatization.

Photo 2. Area subjected to phytoremediation of a brownfield site located near a copper ore mining area (Poland) (D. Gmur).

The main objective of **phytostabilization** is to reduce the availability and mobility of pollutants in the soil. The immobilization of trace elements in the soil depends on the plant species and habitat conditions. The technique uses pollution-tolerant plants to consolidate and immobilize contaminated soils to prevent the spread of pollution by wind and water erosion.

The task of **phytoextraction**, on the other hand, is to remove both inorganic and organic pollutants from the soil by direct uptake by plants. The rate and proportion of contaminants that are transferred from the roots to the shoot system depends on the contaminant and the plant species. It is also important that the above-ground parts accumulate trace elements and other contaminants, as a result of which their toxicity may increase. Therefore, it is important to select species that are unlikely to enter the food chain. There are many options for managing crops after harvest, including energy generation, biofuel production, gasification, composting and phytomining.

Rhizodegradation is based on the decomposition of organic pollutants in the soil by the activity of fungi and microorganisms associated with the rhizosphere. This technique uses plants whose root secretions affect the activity of microorganisms and biodiversity, and can support the biotransformation of organic pollutants through cometabolism.

Phytovolatization is a technique that involves specialized plant enzymes. The task of enzymes is to transform and volatilize inorganic and organic pollutants in the plant - microorganism - soil system. Basically, the pollution is transferred from the soil to the plant, where it is transformed and released into the atmosphere.

The effectiveness of phytoremediation techniques is greatly influenced by the properties of the pollutants and soil, as well as the plant species used in the process. In this case, native plant communities that tolerate the specific environmental conditions of the site, such as the level and type of pollution and climatic conditions, will be more effective in this case. However, germination and development of vegetation directly on contaminated soils, even using tolerant plant species, can be difficult due to the other extreme characteristics of contaminated soils. The effectiveness of the process can be increased by adding additives to the soil, for example: chelating agents to increase the mobility of trace elements or amendments to regulate soil pH.

The positive aspect of phytoremediation is the desire to reduce soil contamination, reduce soil erosion and improve landscape and soil functions. [4]

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SOIL DEGRADATION IN EUROPE

61% of soils in the EU are not healthy

Soil is one of the essential components of land, playing a crucial role in nature's cycles, particularly water and nutrient cycles. Soil is the source of 90% of all food, feed, fibre and fuel production in the EU — and it also provides valuable raw material for the horticulture and construction sectors.

Even a small patch of soil can teem with life, ranging from tiny organisms to fungi and earthworms, all playing a vital role in the functioning of the soil ecosystem. In this space, nutrients are also turned into forms that plants can take up, allowing biomass to form and store carbon. It is here that drinking water starts its natural purification process.

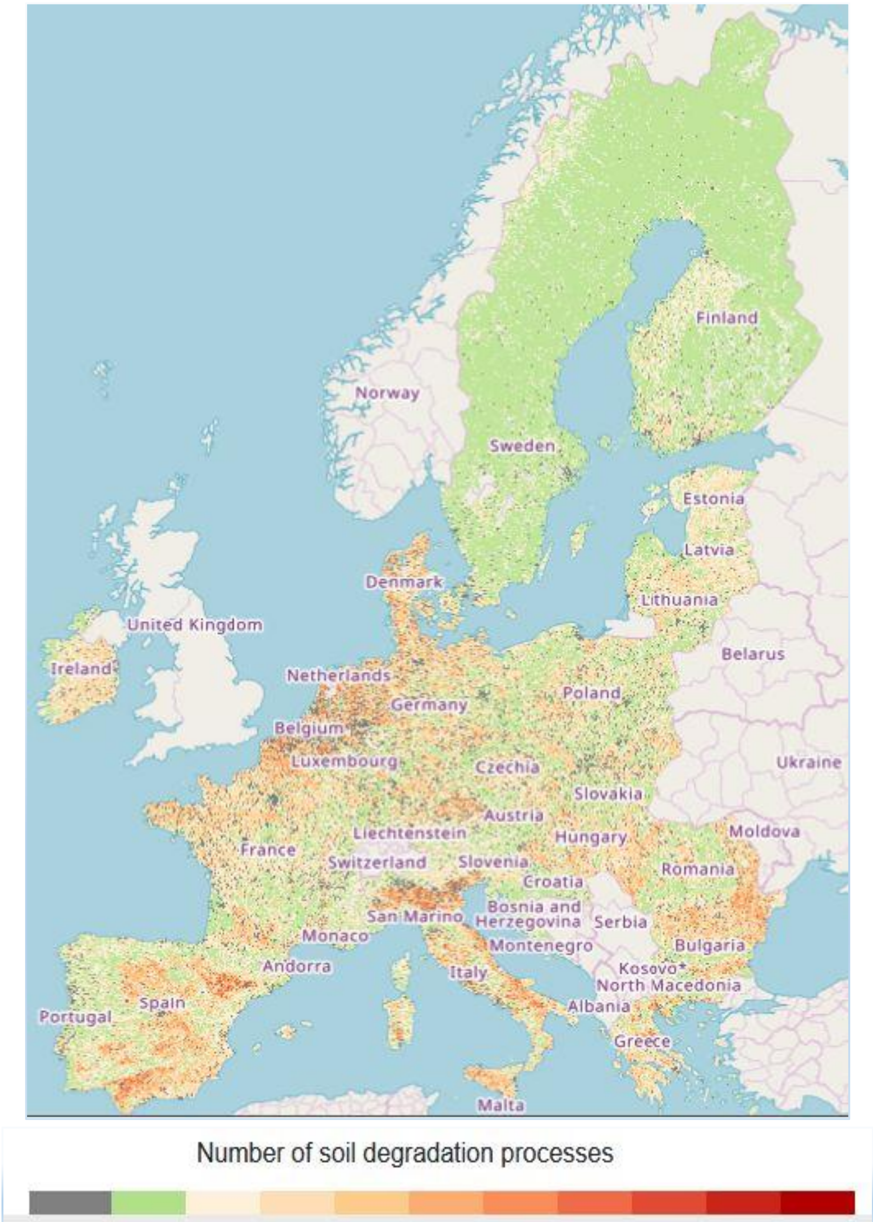
These natural processes are under threat from pollutants released by industry, transport and other economic activities. Unsustainable farming practices, fertilizers and pesticides also contaminate the soil. Eventually, this pollution affects plants, animals and human health. Soil degradation in the EU also comes with an economic cost of more than EUR 50 billion per year.

EEA assessments highlights that:

- Around 2.8 million contaminated sites are found in Europe. Industrial activities and waste disposal are primary sources of contamination.
- 60-75% of EU agricultural soils have excessive nutrient inputs.
- 80,000 sites have been cleaned up in countries where data is available.
- Heavy metals and mineral oil are the most frequent contaminants at European investigated sites.
- Over 80% of soils tested in one study contained pesticide residues, with 58% containing two or more types of residues.
- Soil degradation in the EU costs more than EUR 50 billion per year.
- In 2019, EU Member States reported net greenhouse gas emissions of 64 $MtCO_2e$ from soils to the atmosphere, which is equivalent to just under 2% of the total net emissions reported in that year.

European Union Soil Observatory soil health dasboard

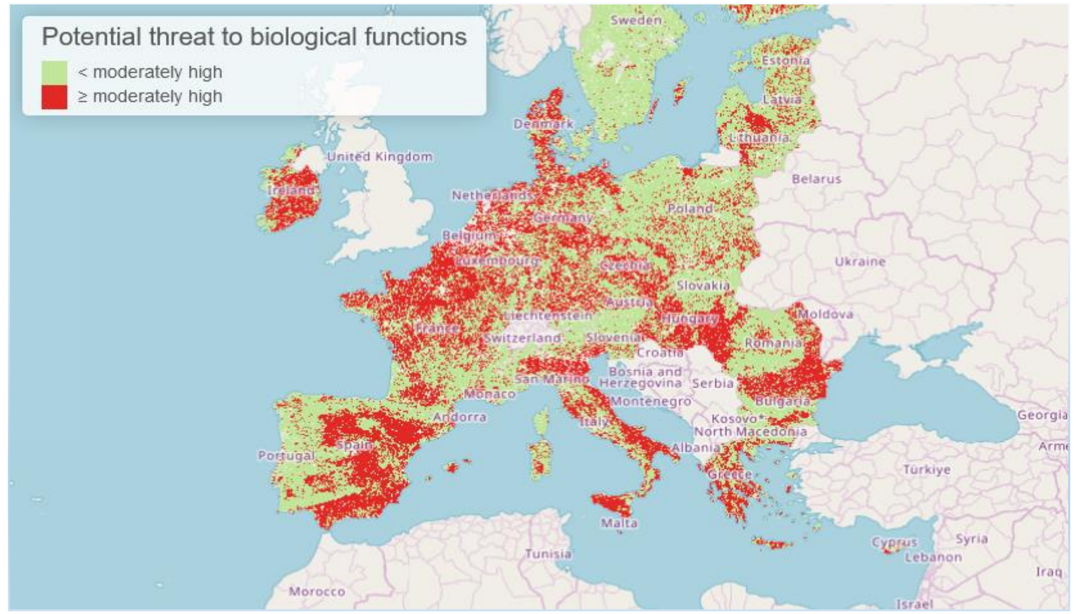
Three out of most prominent degradation indicators out of 15:

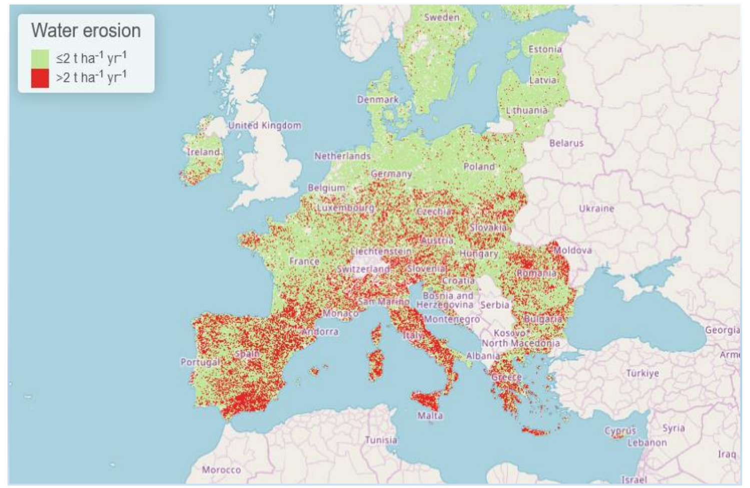


Threat to soil biological functions

Organisms living in soils - from worms to fungi and bacteria - are driving soil functions, and as such, the provision of essential soil ecosystem services. However, many factors can negatively affect soil conditions and threaten soil biodiversity. This layer combines a set of 13 factors, such as habitat fragmentation land use change, soil pollution or soil sealing, known to be potential threats preventing soil biodiversity from performing its biological functions. Soils are considered unhealthy where the risk is estimated to be moderately high or high (out of five, these are the two highest classes in terms of risk potential). Despite the intrinsic limits of this knowledge-based assessment, a remarkable potential risk to soil biodiversity is observed

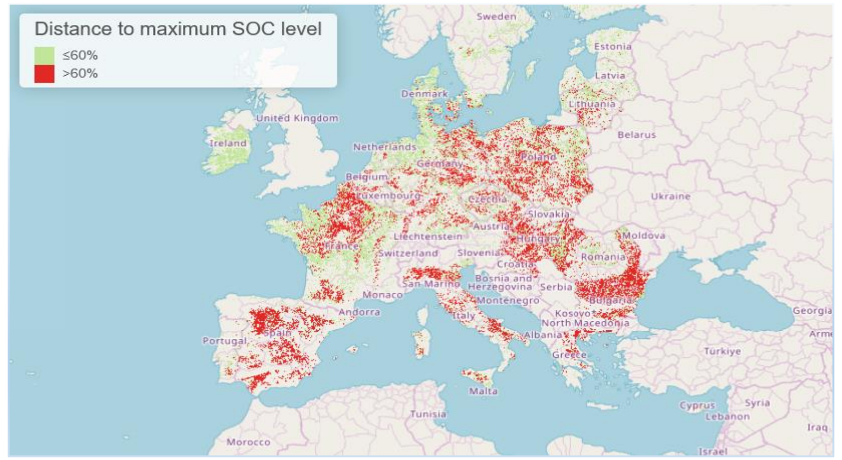
https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/





Soil erosion due to water is a major degradation process. The extent to which soil erodes depends on the rainfall (intensity, frequency, duration and amount), the soil erodibility (i.e. its resistance against rainfall drops), topography (slopes), the soil coverage by vegetation and the soil management. The layer displayed here is the result of a model combining these factors to estimate the long-term average annual rate of soil erosion on all erodible lands in the EU. The layer covers all erodible types of land (agricultural, forests, grasslands, sparse vegetation areas). Soils which were estimated to have an erosion rate higher than 2 tonnes ha^{-1} yr^{-1} are considered unhealthy, because this is significantly higher than the average rate of soil formation in Europe estimated **to be 1.4 tonnes ha^{-1} yr^{-1}**

Soil organic carbon (SOC) is critical for soils to achieve many ecosystem services. However, SOC levels vary greatly based on a range of factors, notably soil type and climate. Finding a SOC metric that works for all soils and climate is therefore a challenge. The layer presented here shows the distance between the current level of SOC and a 'maximum' level of soil organic carbon content achievable in the medium-long term. The layer covers cropland and grassland in the EU. For each pixel, the maximum SOC level is calculated as the increase in SOC content that would be achievable if the land was kept under continuous grassland for 40 years (without ploughing). In this layer, soils are considered unhealthy if the distance that separates them from the maximum is more than 60% of current levels. Conversely, soils are healthy if current levels of SOC are close to the maximum (distance less than 60%). The 60% threshold has been chosen as providing a reasonable and pragmatic distance gap from the maximum SOC level achievable.



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SOIL EROSION - the main threat to soil longevity

The term **soil erosion** is considered to have been coined by **Hough Hammond Bennett**, who began systematic research on soil degradation by water and wind in 1903. The summary of this research was the report "Soil erosion a national measure", submitted in 1928 to the United States Department of Agriculture.

Soil is a finite resource, as it forms very slowly, down to 1 inch per 1000 years. Soil erosion, meant as mechanical removal of material from upper soil horizon, occures in nature at a paste in balance with soil creation. Human activities accelerate however its intensity up to thousand times, leading to swift degradation of soils worldwide.[1]

Soil erosion is one of the ten major soil threats identified in the 2015 Status of the World's Soil Resources report and subsequently addressed in the FAO's Voluntary Guidelines for Sustainable Soil Management (VGSSM).
Soil erosion is defined as the net long-term balance of all processes that detach soil and move it from its original location through three major pathways: water, wind and tillage. Erosion hampers the provision of many vital ecosystem services normally provided by healthy soils.
Soil erosion negatively impacts agricultural food production, water quality, and the environment in general. On farmlands, soil erosion reduces soil water infiltration capacity, moisture availability, drainage capacity, plant rooting depth, and loss of soil nutrients. The displaced soil particles from eroded sites cause sedimentation and pollution of Surface water storage, blockage of waterways, and destruction of infrastructures. Therefore, our ability to feed and live in an ecologically stable environment now and in the future will depend on our ability to reduce and further reverse the rates at which our soils are currently eroding. [2]

FAO Global Symposium on Soil Erosion 2019 key highlights:

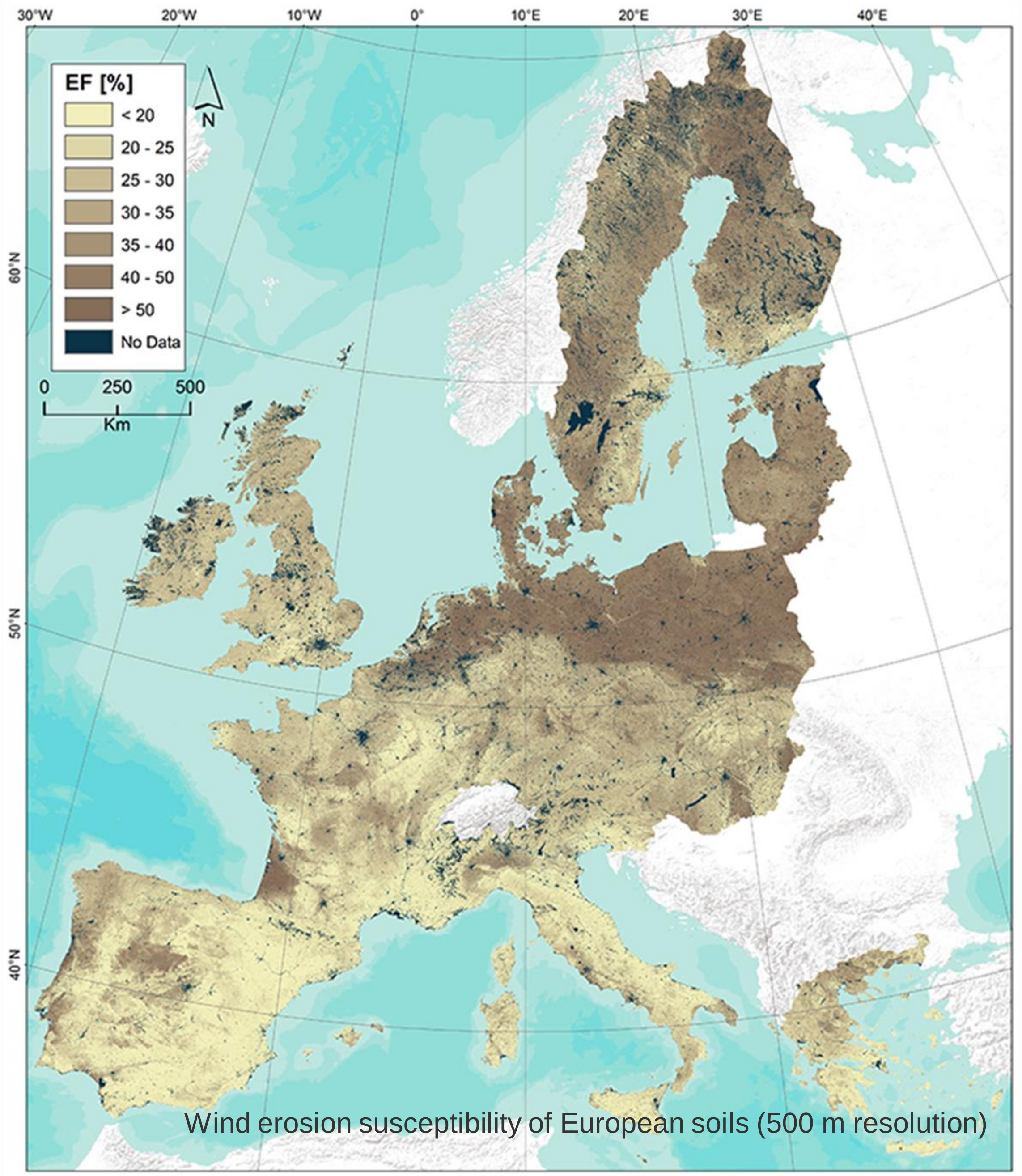
- 33% of the Earth's soils are already degraded and over 90% could become degraded by 2050 .
- The equivalent of one soccer pitch of soil is eroded every five seconds.
- Estimated rates of accelerated soil erosion on arable or intensively grazed lands are 100-1 000 times higher than natural erosion rates.
- Soil erosion can lead up to 50% loss in crop yields.
- The economic cost of soil degradation for the European Union is estimated to be in the order of tens of billions of euros annually.[2]

Soil erosion by wind

Wind erosion is a widespread phenomenon causing serious soil degradation. It is estimated that about 28% of the global land area experiencing land degradation suffers from this wind-driven soil erosion process. In agricultural lands, soil erosion by wind mainly results from the removal of the finest and most biological active part of the soil richest in organic matter and nutrients. Repeated exposure to wind erosion can have permanent effects on agricultural soil degradation, making it difficult to maintain favorable soil conditions in the long run.

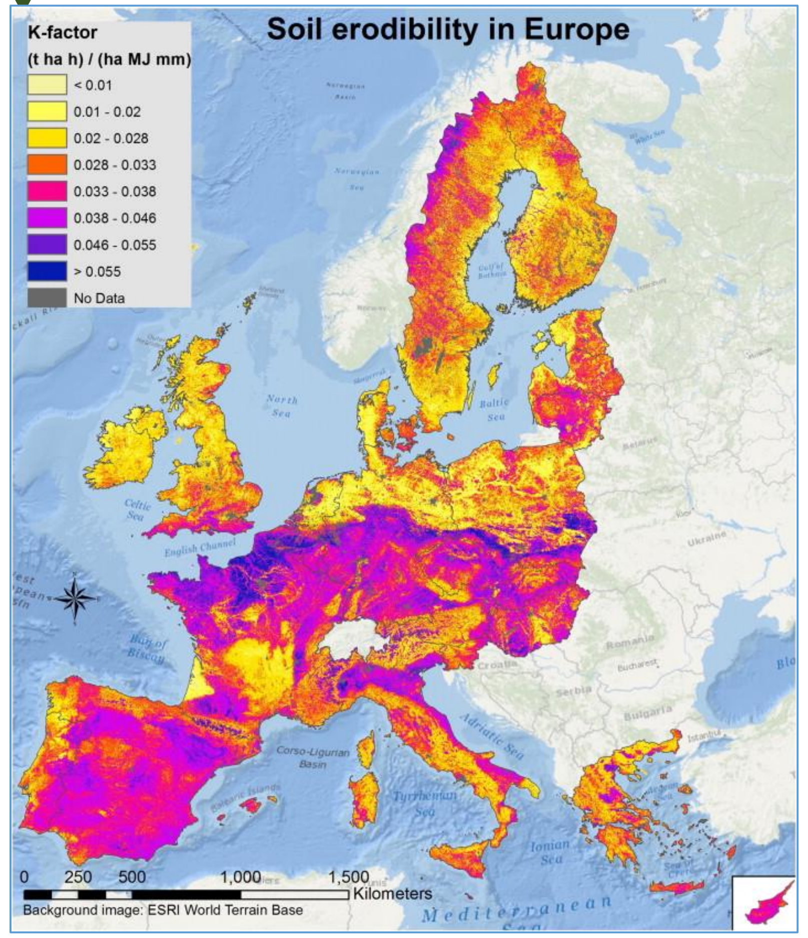
According to the European Environment Agency, about 42 million ha of European agricultural land may be affected by wind erosion. However, little is known about the extent and magnitude of wind erosion throughout Europe. It is a slow yet persistent soil degradation factor.[3]

According to various research results most favourable condiitons for the occurence of soil erosion are strong winds occuring along drought on sandy soils. It remains a silent yet progressing soil threat ,much less spectaclar than its „sister" proces of erosion by water. The most spectacular records of its occurence remain the dust storms bound to catastophic droughts with most well known phenomena of Dust Bawl that occured on Great Planes in 1931 returning up till the extreme Black Sunday April 15th 1935 with wond over 100km/h. In consequence the Congress issued law aimed at soil protecton.



Wind erosion susceptibility of European soils (500 m resolution)

Soil erosion by water



Soil erosion due to water is the most prominent soil degradation proces in terms of the area affected and volume of soil lost annualy. It may reach extreme intensity producing gullies in single rainfall event eg. On badly designed road drainage driving contentrated water flow on bare soil.


R. Wawer

The best conditions for the soil erosion by water to occur in its highest intensity are intensive rainfalls falling on water-saturated soils with high silt content. Loess soils are most susceptible to that conditions and host the mostdense and deep gully network on the globe, including Naleczow Plateau n Poland, where gully density reaches 13km/km2.

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