



Food and Agriculture Organization  
of the United Nations

# Status of the World's Soil Resources

Main Report

Global soil  
resources

Chapter 1

Introduction

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# Global soil resources



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## 1.1 | The World Soil Charter

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“Soils are fundamental to life on earth.”

We know more about soil than ever before, yet perhaps a smaller percentage of people than at any point in human history would understand the truth of this statement. The proportion of human labour devoted to working the soil has steadily decreased through the past century, and hence the experience of direct contact with the soil has lessened in most regions. Soil is very different in this regard from food, energy, water and air, to which each of us requires constant and secure access. Yet human society as a whole depends more than ever before on products from the soil as well as on the more intangible services it provides for maintenance of the biosphere.

Our goal in this report is to make clear these essential connections between human well-being and the soil, and to provide a benchmark against which our collective progress to conserve this essential resource can be measured.

The statement that begins this section is drawn from the opening sentence of the preamble of the revised World Soil Charter (FAO, 2015):

Soils are fundamental to life on Earth but human pressures on soil resources are reaching critical limits. Careful soil management is one essential element of sustainable agriculture and also provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services and biodiversity.

The World Soil Charter presents a series of nine principles that summarize our current understanding of the soil, the multi-faceted role it plays, and the threats to its ability to continue to serve these roles. As such, the nine principles form a succinct and comprehensive introduction to this report.

Principles from the World Soil Charter:

*Principle 1:* Soils are a key enabling resource, central to the creation of a host of goods and services integral to ecosystems and human well-being. The maintenance or enhancement of global soil resources is essential if humanity's overarching need for food, water, and energy security is to be met in accordance with the sovereign rights of each state over their natural resources. In particular, the projected increases in food, fibre, and fuel production required to achieve food and energy security will place increased pressure on the soil.

*Principle 2:* Soils result from complex actions and interactions of processes in time and space and hence are themselves diverse in form and properties and the level of ecosystems services they provide. Good soil governance requires that these differing soil capabilities be understood and that land use that respects the range of capabilities be encouraged with a view to eradicating poverty and achieving food security.

*Principle 3:* Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity.

The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern.

*Principle 4:* The implementation of soil management decisions is typically made locally and occurs within widely differing socio-economic contexts. The development of specific measures appropriate for adoption by local decision-makers often requires multi-level, interdisciplinary initiatives by many stakeholders. A strong commitment to including local and indigenous knowledge is critical.

*Principle 5:* The specific functions provided by a soil are governed, in large part, by the suite of chemical, biological, and physical properties present in that soil. Knowledge of the actual state of those properties, their role in soil functions, and the effect of change – both natural and human-induced – on them is essential to achieve sustainability.

*Principle 6:* Soils are a key reservoir of global biodiversity, which ranges from micro-organisms to flora and fauna. This biodiversity has a fundamental role in supporting soil functions and therefore ecosystem goods and services associated with soils. Therefore it is necessary to maintain soil biodiversity to safeguard these functions.

*Principle 7:* All soils – whether actively managed or not – provide ecosystem services relevant to global climate regulation and multi-scale water regulation. Land use conversion can reduce these global common-good services provided by soils. The impact of local or regional land-use conversions can be reliably evaluated only in the context of global evaluations of the contribution of soils to essential ecosystem services.

*Principle 8:* Soil degradation inherently reduces or eliminates soil functions and their ability to support ecosystem services essential for human well-being. Minimizing or eliminating significant soil degradation is essential to maintain the services provided by all soils and is substantially more cost-effective than rehabilitating soils after degradation has occurred.

*Principle 9:* Soils that have experienced degradation can, in some cases, have their core functions and their contributions to ecosystem services restored through the application of appropriate rehabilitation techniques. This increases the area available for the provision of services without necessitating land use conversion.

These nine principles lead to guidelines for action by society (Box 1.1). The guidelines are introduced with a clear statement of our collective goal: *'The overarching goal for all parties is to ensure that soils are managed sustainably and that degraded soils are rehabilitated or restored.'* This opening statement is followed by a series of specific guidelines for different segments of human society. Future updates of this report will document our success in implementation of these guidelines, and in achieving the goal set by the signatories of the World Soil Charter.

## Box 1.1 | Guidelines for Action

(from the World Soil Charter)

The overarching goal for all parties is to ensure that soils are managed sustainably and that degraded soils are rehabilitated or restored. Good soil governance requires that actions at all levels – from states, and, to the extent that they are able, other public authorities, international organizations, individuals, groups, and corporations – be informed by the principles of sustainable soil management and contribute to the achievement of a land-degradation neutral world in the context of sustainable development. All actors and, specifically, each of the following stakeholder groups are encouraged to consider the following actions:

### Actions by Individuals and the Private Sector

1. All individuals using or managing soil must act as stewards of the soil to ensure that this essential natural resource is managed sustainably to safeguard it for future generations.
2. Undertake sustainable soil management in the production of goods and services.

### Actions by Groups and the Science Community

1. Disseminate information and knowledge on soils.
2. Emphasize the importance of sustainable soil management to avoid impairing key soil functions.

### Actions by Governments

1. Promote sustainable soil management that is relevant to the range of soils present and the needs of the country.
2. Strive to create socio-economic and institutional conditions favourable to sustainable soil management by removal of obstacles. Ways and means should be pursued to overcome obstacles to the adoption of sustainable soil management associated with land tenure, the rights of users, access to financial services and educational programmes. Reference is made to the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Forests and Fisheries in the Context of National Food

Security adopted by the Committee on World Food Security in May 2012.

3. Participate in the development of multi-level, interdisciplinary educational and capacity-building initiatives that promote the adoption of sustainable soil management by land users.
4. Support research programs that will provide sound scientific backing for development and implementation of sustainable soil management relevant to end users.
5. Incorporate the principles and practices of sustainable soil management into policy guidance and legislation at all levels of government, ideally leading to the development of a national soil policy.
6. Explicitly consider the role of soil management practices in planning for adaptation to and mitigation of climate change and maintaining biodiversity.
7. Establish and implement regulations to limit the accumulation of contaminants beyond established levels to safeguard human health and wellbeing and facilitate remediation of contaminated soils that exceed these levels where they pose a threat to humans, plants, and animals.
8. Develop and maintain a national soil information system and contribute to the development of a global soil information system.
9. Develop a national institutional framework for monitoring implementation of sustainable soil management and overall state of soil resources.

### Actions by International Organizations

10. Facilitate the compilation and dissemination of authoritative reports on the state of the global soil resources and sustainable soil management protocols.
11. Coordinate efforts to develop an accurate, high-resolution global soil information system and ensure its integration with other global earth observing systems.
12. Assist governments, on request, to establish appropriate legislation, institutions, and processes to enable them to mount, implement, and monitor appropriate sustainable soil management practices.



## 1.2 | Basic concepts

Prior to the 20<sup>th</sup> century, soil was considered almost exclusively in the context of agriculture and food production. As the global impact of humanity on natural resources has increased over the past 150 years, the connections between soil and broader environmental concerns began to be made. The recognition of these connections has accelerated through time, and new and innovative ways of relating soils to people have begun to emerge in past the two decades. The rise in complexity of soil knowledge and application was synthesized by Bockheim *et al.* (2005) (Table 1.1) in their summary of milestones in pedology; concepts introduced since 2005 have been added by the authors of this chapter. We can see that the number and breadth of concepts have been expanding rapidly over the past two decades.

**Table 1.1. | Chronology of introduction of major concepts in pedology and holistic soil management (after Bockheim *et al.*, 2005).**

Period	Pedology	Soil management
Pre 1880	Concept of soil as a medium for plant growth and as a weathered rock layer.	
1880–1900	Appearance of fundamental pedology concepts: soil as a natural body; soil horizons/profiles; soil-forming factors; early ideas of soil geography.	
1900–1940	Global acceptance of concepts of soil as a natural body and soil-forming factors; development of first regional soil classification systems; soil surveys initiated; identification of key soil-forming processes.	Soil conservation
1940–1960	Factors of soil formation and genesis of soils clarified; development of global soil taxonomic systems; intensified soil mapping.	
1960–1985	Refinement of global soil taxonomic systems; identification of pedon concept; development of early soil models and soil cover pattern concept; recognition of co-evolution of soils and landforms.	World Soil Charter (1981) Land capability/suitability assessment Assessment of human-induced degradation (GLASOD)
1985–2000	Increased understanding of soil processes; refinement of global soil models; further refinement of global soil taxonomic systems; development of statistical and computer-based soil information systems.	Sustainable soil management Soil quality Soil health
2000–2015	Earth System Science, pedosphere, digital soil mapping, pedodiversity, ethnopedology, pedometrics, proximal sensing, soil systems, hydropedology, critical zone.	Soil security Carbon sequestration

The connections between soils and societal issues – such as food security, sustainability, climate change, carbon sequestration, greenhouse gas emissions, and degradation through erosion and loss of organic matter and nutrients – are central to the recently developed concept of soil security (McBratney, Field and Koch, 2014). Soil security has been defined as the maintenance or improvement of the world's soil resources so that they can provide sufficient food, fibre, and fresh water, contribute to energy sustainability and climate stability, maintain biodiversity, and deliver overall environmental protection and ecosystem services (Bouma and McBratney, 2013).

There have been major developments over the past three decades in our broader understanding of human impact on the earth and of frameworks to assess this impact. The structure and content of this report comprise a synthesis of themes and concepts from many major initiatives in environmental science and pedology. The most important of these themes and concepts are discussed in the following paragraphs.

## Sustainable soil management

The concept of sustainable development is most closely associated with the 1987 report of the United Nations World Commission on Environment and Development, better known as the Brundtland Commission after its chairperson, Gro Harlem Brundtland of Norway (World Commission on Environment and Development, 1987). The report popularized a compelling definition of sustainability: development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainability has since been widely applied to many aspects of human society, including wide application in soil science and land management generally. As defined in the World Soil Charter, sustainable soil management comprises activities that maintain or enhance the supporting, provisioning, regulating and cultural services provided by soils without significantly impairing either the soil functions that enable those services or biodiversity. The concept of sustainable soil management is central to pillar one of the Global Soil Partnership<sup>1</sup>: "Promote sustainable management of soil resources for soil protection, conservation, and sustainable production".

## Soil degradation and threats to soil functions

The concept of soil degradation and its assessment have been developed as part of more holistic assessments of human-induced degradation carried out by FAO, UNEP and other UN agencies.

An early initiative was the Global Assessment of Soil Degradation (GLASOD) project undertaken in the late 1980s to inventory soil degradation. GLASOD evaluated 13 types of soil degradation: water erosion (topsoil loss and mass movement, including rill and gully formation), wind erosion (topsoil loss, terrain deformation – primarily dune activity), and overblowing (surface burial from aeolian deposition), loss of nutrients and/or organic matter, salinization, acidification, pollution, compaction and physical degradation, waterlogging, and subsidence of organic soils. GLASOD has not been updated (see Chapter 3 for more details).

The Soil Thematic Strategy of the European Union (CEC, 2006) formalized the concept of threats to soil and its many functions. Five specific threats are identified under Article 6 of the draft Soil Framework Directive proposed in the Strategy: (1) erosion by wind and water; (2) organic matter decline; (3) compaction; (4) salinization; and (5) landslides of soil and rock material. Elsewhere in the proposed Directive, soil sealing ('the permanent covering of the soil with an impermeable surface' p.15) and soil contamination ('the intentional or unintentional introduction of dangerous substances on or in the soil' p. 18) are also identified as threats.

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<sup>1</sup> The Global Soil Partnership was initiated by FAO and the EU in 2011. For a description of the five pillars, see Table 8.1 in Chapter 8. For a full description of the Partnership, see [www.fao.org/globalsoilpartnership](http://www.fao.org/globalsoilpartnership).



## Soil functions and ecosystem services

The assessments of threats to soil functions leads to a need to formally identify the functions that the soil performs. The proposed Soil Framework Directive (CEC, 2006) of the European Union recognizes seven soil functions that are vulnerable to soil threats:

1. biomass production, including agriculture and forestry
2. storing, filtering and transforming nutrients, substances and water
3. biodiversity pool, such as habitats, species and genes
4. physical and cultural environment for humans and human activities
5. source of raw materials
6. acting as a carbon pool
7. archive of geological and archaeological heritage.

The EU Soil Thematic Strategy was developed at the same time as the Millennium Ecosystem Assessment (MA, 2005) initiated by the United Nations in 2000. The goal of the MA was to assess the consequences of ecosystem change for human well-being and to lay the scientific basis for actions that would promote conservation and sustainable use of ecosystems. The MA was built on the framework for ecosystem services developed by Daily, Matson and Vitousek (1997) and Costanza *et al.* (1997).

The categories of ecosystem services were formalized by the Millennium Ecosystem Assessment into four broad classes: provisioning, regulating, supporting, and cultural services. The range of major ecosystem services provided by soil, and the specific soil functions that enable those services, are summarized in Table 1.2.

## Soils and natural capital

The services provided by soils are primarily determined by the three core soil properties (texture, mineralogy, and organic matter), which together form the natural capital of soils (Palm *et al.* 2007). Soil texture and mineralogy are inherent properties of soil that are initially inherited from the parent materials and which change only very slowly over time. In a natural state, soil organic matter (SOM) reaches equilibrium with the environment in which the soil forms, but SOM responds quickly to human-induced changes. Management of SOM is central to sustainable soil management because of its rapid response to change and our ability to manipulate it.

## Planetary boundaries and safe operating space for humanity

Specific soil processes are central to Earth-system processes that provide the safe operating space for humanity – the concept of ‘planetary boundaries’ that cannot be exceeded without causing potentially disastrous consequences for humanity (Röckstrom *et al.* 2009; Steffen *et al.*, 2015). Currently stresses in the nitrogen cycle, climate change, and biodiversity loss are suggested to be beyond safe operating boundaries. Human impact on the natural reservoir of soil biodiversity and on the rate of N and C cycling in soils is a significant aspect of this stress. Whereas GLASOD had highlighted *nutrient depletion* through crop production without the application of sufficient manure and fertilizer to replenish nutrient loss, the concept of planetary boundaries also focuses our attention on *over-application of nutrients* in some regions and its consequences for atmospheric and hydrological systems. Addressing the nutrient deficit in regions such as Sub-Saharan Africa while remaining within the safe operating space for humanity requires a significant reduction of nutrient additions in area of excess inputs (Steffen *et al.*, 2015).



## Biodiversity

Biodiversity cuts across most of the concepts presented above, and loss of biodiversity is identified by Röckstrom *et al.* (2009) as one of three components currently operating beyond safe planetary boundaries. Biodiversity is more than simply an ecosystem service, even though specific benefits can be identified from the biodiversity pool. This cross-cutting importance of biodiversity was formalized in the Convention on Biological Diversity signed in 1992 at the United Nations Conference on Environment and Development in Brazil. Soils are widely recognized as a major reservoir of global biodiversity, and preservation of this (largely unknown) pool of biodiversity is essential.

**Table 1.2 | Ecosystem services provided by the soil and the soil functions that support these services.**

Ecosystem service	Soil functions
Supporting services: Services that are necessary for the production of all other ecosystem services; their impacts on people are often indirect or occur over a very long time	
Soil formation	<ul style="list-style-type: none"> <li>∑ Weathering of primary minerals and release of nutrients</li> <li>∑ Transformation and accumulation of organic matter</li> <li>∑ Creation of structures (aggregates, horizons) for gas and water flow and root growth</li> <li>∑ Creation of charged surfaces for ion retention and exchange</li> </ul>
Primary production	<ul style="list-style-type: none"> <li>∑ Medium for seed germination and root growth</li> <li>∑ Supply of nutrients and water for plants</li> </ul>
Nutrient cycling	<ul style="list-style-type: none"> <li>∑ Transformation of organic materials by soil organisms</li> <li>∑ Retention and release of nutrients on charged surfaces</li> </ul>
Regulating services: benefits obtained from the regulation of ecosystem processes	
Water quality regulation	<ul style="list-style-type: none"> <li>∑ Filtering and buffering of substances in soil water</li> <li>∑ Transformation of contaminants</li> </ul>
Water supply regulation	<ul style="list-style-type: none"> <li>∑ Regulation of water infiltration into soil and water flow within the soil</li> <li>∑ Drainage of excess water out of soil and into groundwater and surface water</li> </ul>

Climate regulation	∑ Regulation of CO <sub>2</sub> , N <sub>2</sub> O, and CH <sub>4</sub> emissions
Erosion regulation	∑ Retention of soil on the land surface
Provisioning Services: products ('goods') obtained from ecosystems of direct benefit to people	
Food supply	∑ Providing water, nutrients, and physical support for growth of plants for human and animal consumption
Water supply	∑ Retention and purification of water
Fibre and fuel supply	∑ Providing water, nutrients, and physical support for growth of plant growth for bioenergy and fibre
Raw earth material supply	∑ Provision of topsoil, aggregates, peat etc.
Surface stability	∑ Supporting human habitations and related infrastructure
Refugia	∑ Providing habitat for soil animals, birds etc.
Genetic resources	∑ Source of unique biological materials
Cultural services: nonmaterial benefits which people obtain from ecosystems through spiritual enrichment, aesthetic experiences, heritage preservation and recreation	
Aesthetic and spiritual	∑ Preservation of natural and cultural landscape diversity ∑ Source of pigments and dyes
Heritage	∑ Preservation of archaeological records

The contribution of many of the concepts outlined above is apparent throughout the World Soil Charter. This synthesis of concepts is perhaps most evident in the definition of sustainable soil management used in the World Soil Charter:

Soil management is sustainable if the supporting, provisioning, regulating and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity.

The concepts of soil functions, the threats to functions, and the ecosystem services provided by soils are central both to the structure of this book and to the content of each chapter.

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