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SOIL ATLAS OF ASIA



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GLOBAL SOIL PARTNERSHIP

SOIL ATLAS OF
ASIA

A collaborative initiative of the European Union and the Food and Agriculture Organization of the United Nations,
together with the Asian, Eurasian and North African and Near Eastern Soil Partnerships,
and the Asian Food and Agriculture Cooperation Initiative,
to support and encourage the sustainable use of soil resources across Asia

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The EU supports the efforts of the Secretary General of the United Nations and his Personal Envoy to find a just, lasting and mutually acceptable political solution to conflict.

Soil data

The soil maps presented in this atlas are derived from several sources (see pages 4 and 169). They include the:

- **Harmonized World Soil Database**

FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria. http://www.iiasa.ac.at/

- **Soil Geographical Database of Eurasia**

Van Liedekerke, M., Panagos, P., Daroussin, J., Jones, R., Jones, A. & Montanarella, L., 2004. The European Soil Database Version 2.0. Distributed by the European Commission's Joint Research Centre, Ispra, Italy http://esdac.jrc.ec.europa.eu/

- **Several national contributions** (see page 3)

The soil maps displayed in the atlas were elaborated by the European Commission's EU Soil Observatory, the FAO Global Soil Partnership Secretariat and Lovell Johns Ltd, UK. The final versions of the maps may differ from the source data as a result of exchanges with national experts and harmonisation exercises.

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http://www.lovelljohns.com

Front page

The striking map on the cover depicts the diversity of soil types across Asia. A broad north-south zonal pattern of soil groups can be observed, reflecting the major climatic regions.

Long and very cold winters in the north give rise to permafrost-affected Cyrosols in the arctic and tundra regions, in places extending southwards into the boreal forests. Low temperatures inhibit the decay of vegetation to form extensive Histosols together with waterlogged Gleysols, which are especially evident on the low-lying plains of Siberia.

As temperatures rise towards the south, large expanses of coniferous boreal forests are denoted by Podzols, which have developed on coarse-grained, quartz-rich deposits. Increasing clay content of soils is indicated by the presence of Albeluvisols and Luvisols.

Further south, the broad grassland belt of the steppe is denoted by Kastanozems, Chernozems and Phaeozems. These are soils with well-defined organic-rich topsoils that have developed in silty loams and reflect a decreasing southerly precipitation gradient.

Large parts of Asia, including much of the north, experience a relatively dry climate, often coupled with extremes of temperatures. The overall aridity and high temperatures of the west means that poorly developed soils, with low soil organic matter levels, low water retention capacity and elevated levels of gypsum (Gypsisols) and carbonates (Calcisols), are widespread. Desert areas with sand dunes are denoted by Arenosols which are interspersed by Regosols, and Leptosols, often denoting mountains or rocky outcrops. Cambisols, displaying only the slightest signs of soil development, are common. Saline soils (Solonetz and Solonchaks) are characteristic of depressions in arid areas and are common throughout western and central Asia.

Asia is also a mountainous continent. Containing the world's highest peaks, the various ranges of the Himalayas extend from Myanmar in the east to Afghanistan in the west. They separate the Indian subcontinent from the high Tibetan Plateau. They are a barrier to drainage and dominate the monsoonal weather patterns of southern Asia. Poorly developed and shallow, stony Regosols, Leptosols, and Cambisols denote mountainous regions, often closely reflecting the characteristics of the underlying geology. Erosion is widespread, especially on steep slopes. Higher elevations with low temperatures are denoted by Cryosols, often in conjunction with glaciers.

A hot and humid climate supports rainforests over much of south-eastern Asia. Deep chemical weathering gives rise to iron and aluminium-rich Ferralsols and Acrisols, with Lixsisols emerging in drier conditions.

Some soils are azonal, which means they can be found across Asia. In this sense, Fluvisols denote where soil development is associated with the movement of water (i.e. rivers, lakes and tides). Their occurrence on the map clearly defines the main river networks of Asia. Flow conditions determine their characteristics with medium- to fine-grained and layered soils reflecting regular flood events in broad floodplains, while coarse and unsorted soils are found in alluvial fans and dry channels that are prone to flash floods in arid regions. Several rivers form major deltas at their mouths where fine-grained, often waterlogged soils (Gleysols, Stagnosols) form alongside Fluvisols. Mangroves are a common feature of the inter-tidal zone of many southern coasts of Asia. In addition to coastal protection against storms and floods, mangrove soils store significant levels of organic carbon.

Clay-rich Vertisols that shrink and swell with changes in moisture content are also distributed across climatic zones, as they reflect the weathering of base-rich rocks (such as basalt) or the deposition in floodplains of these weathering products. There are extensive areas of such soils on the Deccan Plateau of India.

Increasing urbanisation and industrial development leads to the formation of Technosols. While important locally, these soils are not very evident at the scale of this map.

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Soil, along with water, is arguably the most precious resource on the planet. Soil provides a myriad of life-critical environmental services that are fundamental to the well-being of all creatures on the planet. This picture from West Java, Indonesia, shows terraces for rice cultivation. Paddy fields are a characteristic feature of large parts of eastern and southern Asia. Since rice has to grow in a constant depth of water, the ground must be level. This is achieved by building terraces while a complex network of channels moves the water through the landscape. To contain the water, paddy fields have an impermeable subsoil and are edged by low earth walls or bunds. While providing a staple part of the diet of many Asians, the distinctive landscape of paddy fields has high cultural significance but equally it supports biodiversity while also ensuring groundwater recharge, flood control, reduced soil erosion and risk of landslides and water purification. (DJ)



In contrast to the rather lush landscape in Java, this photograph from Yemen shows a much drier environment. It is clear that soil characteristics here will be very different to those in humid sub-tropical conditions. As typified in this scene from the Arabian Peninsula, much of western Asia is characterised by low rainfall, which means that water is scarce and a major limitation on soil-forming processes. Natural vegetation is sparse and shrubby, while agricultural areas, which are reliant on intensive irrigation practices, predominantly from underground aquifers, are in stark contrast. As in the image from Indonesia, terracing has been used traditionally to cultivate crops on steep slopes with poorly developed soils. Terraces are used to concentrate water and organic matter (predominantly manure and plant remains) to sufficient levels that agricultural crops can be grown (in this case, cereals). They also act as barriers to erosion. In such environments, rural populations depend on soil functions to provide food for their families, fodder for animals, fuel for cooking, crops for markets - activities that are fundamental to the economies of most Asian countries. However, soil erosion, increasing aridity, over-extraction of groundwater and deforestation are increasingly affecting soil fertility in many parts of this region. (BG)

Preface

The European Commission

The sustainable management of natural resources across Asia is a formidable challenge, but crucial for the survival of over 4.5 billion people in Asia and those living in other parts of the world. Asia is a major agricultural producer, with over 18 billion euro worth of agri-food imports annually to the European Union from the Association of Southeast Asian Nations (ASEAN) alone. However, despite being the cradle of agriculture, many parts of Asia are vulnerable to food insecurity. This is often a result of human-induced land degradation, driven by the desire for quick economic returns as well as the sealing of productive soils through urban expansion. Inappropriate land use tends to ignore soil's capacity to supply life-critical ecosystem services, which in turn can affect us all.

It is vital that we understand society's impact on the evolution of soils, and how their intrinsic characteristics condition their use. If we wish to assess fully the impacts of processes driving change in Asia, it is equally important to understand the consequences of climate change, population growth and the need for food security, on the diverse services provided by soils. European Union policies seek to address these key challenges through initiatives such as the European Green Deal.

The evidence for soil degradation and environmental change is as clear in Europe as it is in many parts of Asia. By building on existing cooperation with researchers from Asia, the European Union and elsewhere, the Joint Research Centre (JRC) - the European Commission's in-house science service – together with the Food and Agriculture Organization of the United Nations (FAO), have brought together people from diverse national and political backgrounds to address this relevant issue, and communicate the need to protect soils to the wider society. This is fully in line with the goals of the European Union Mission "A Soil Deal for Europe", which aims to support the transition towards healthy soils by 2030. Importantly, the Mission understands the need to recognise the potential impacts of European consumer demands beyond its borders.

In this respect, the innovative Soil Atlas of Asia, the latest in the JRC's Soil Atlas Series, aims to raise public awareness on the importance and key role of soil in Asia as a non-renewable resource that is essential to human existence. In doing so, it supports the development of protective measures to safeguard soils for current and future generations.

While it is intended primarily for the educational sectors and policymakers, the atlas aims to bridge the gap between soil science and society at large. I believe that this impressive publication will become a widely used reference and marks an important step towards a better understanding of the role of soil in the sustainable development of Asia. I am happy to see that the fruitful collaboration between the European Commission and FAO has produced such a striking publication. I encourage you to share its knowledge.



Janusz Wojciechowski
European Commissioner
for Agriculture

Food and Agriculture Organization of the United Nations (FAO)

Asia is the world's most inhabited region, and is home to almost 60% of the global population. In 2021, more than 425 million people suffered from hunger. The region's current food insecurity – aggravated by the economic fallout due to COVID-19, disruption of the international supply chain, conflicts, and increased costs of raw materials, fertilizers and energy - will be further affected by the climate crisis and the degradation of natural resources, particularly soils and water.

Soils is where food begins. Adopting sustainable soil management helps increase food production, enhance nutrient content of food, and adapt to and mitigate the impacts of the climate crisis. Recognizing the importance of healthy soils for food security and nutrition, and for their essential ecosystem services, we must take much-needed actions to safeguard this precious resource in Asia, and beyond, for the region and our planet.

Meeting the growing demands for safe and nutritious food calls for the urgent transformation to more efficient, more inclusive, more resilient and more sustainable agrifood systems. This transformation is at the core of the FAO Strategic Framework 2022-31, which will guide the work of the Organization over the next decade, to support Members in realizing the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). The urgently needed transformation will ensure the Four Betters: better production, better nutrition, a better environment, and a better life for all - leaving no one behind.

Innovation is fundamental to the conservation and sustainable management of soils. The *Voluntary Guidelines for Sustainable Soil Management* provide the needed guidance for countries to effectively adopt sustainable soil management. Soil information is essential for informed decision-making from the field to policy level. Accurate and timely information on soil health and nutrition is crucial to ensure the sustainable productivity of agricultural land, overcome the current fertilizer crisis, and reduce impacts caused by the overuse and misuse of fertilizers.

The Soil Atlas of Asia is an exemplary collaboration among 45 Asian countries, the Rural Development Administration of the Republic of Korea, the Joint Research Centre of the European Commission, the FAO Global Soil Partnership, and over 100 soil scientists. It presents an illustrated journey on the rich diversity of soils in the region based on state-of-the-art scientific evidence and in-depth knowledge of renowned soil experts from each country.

We need to continue working together in an efficient, effective and coherent manner to produce safe, nutritious and micronutrient-rich foods in a sustainable way that avoids soil degradation, reduces greenhouse gas emissions and decreases agrifood systems pollution.

It is my hope that this atlas will reach all populations across the region and the world, so that they can discover the richness of Asian soils and increase their understanding of the value of soils and their added benefits.



Dr QU Dongyu
Food and Agriculture Organization
of the United Nations (FAO)
Director-General

Asian Food and Agriculture Cooperation Initiative

There's a little universe in a handful of soil. Infinite lives will sprout and prosper where rock particles, water, and air are fully blended. Soil must be systematically managed to maintain the various functions and values. In other words, 'soil security' needs to be strengthened.

Rural Development Administration (RDA) has long focused on soil security. Between 1964 and 1999, the RDA conducted a detailed soil survey with the help of FAO and the UN special fund to complete a the world's first ever digital soil map at a scale of 1:5000, which underpins the Korea Soil Information System.

Based on the experience accumulated in the process, the RDA has been promoting the "Soil Atlas of Asia and national soil information system" project through the Asian Food & Agriculture Cooperation Initiative (AFACI) since 2019. Soil experts from 13 Asian countries participated to organise existing soil data for each country, investigate and analyse soil information in areas that have not yet been covered, and digitise this data and information according to international soil classification standards.

The Soil Atlas of Asia contains soil information from Asian countries, mainly AFACI member nations. During the course of completing the map, each country's soil management capabilities grew to a new level. It's a rare good example.

However, the development of tools to gain more accurate scientific soil data and information must continue so that we can analyse issues from multiple perspectives. Farmers, agricultural scientists, and policymakers should also be equipped with a system that can be easily used in various decision-making processes. RDA will contribute to Asia's soil security through active technical cooperation.

Finally, I would like to express my deep gratitude to the researchers of FAO-GSP and AFACI member countries for their hard work in completing the soil map.



Cho ChaeHo
Rural Development Administration
Administrator

Message from the Intergovernmental Technical Panel on Soils

Communities develop where natural resources are available: this is how Asia became the most populated region of the world. The Fertile Crescent is where humans started to practice agriculture about 10000 years ago. The combination of a monsoon climate and exceptionally large lowland areas allowed for Asia to become the rice basket of the world. This region hosts vast areas where soil conservation practices have been traditionally implemented for millennia. The Intergovernmental Technical Panel on Soils of the Global Soil Partnership has focused on tackling these issues over the years by providing scientific and technical advice and guidance. The Panel considers sustainable soil management key to grant self-sufficient agriculture to small-scale producers and rural communities, and to adapt to climate and global crises giving them access to sufficient and nutritious food. At the same time, sustainable soil management can become a powerful tool to mitigate climate change and generate GHG sinks.

But how to implement sustainable soil management at the field level? By knowing the status of soils, by raising awareness and by training farmers in sustainable soil management practices. In this regard, the ITPS greatly values the Soil Atlas of Asia because its preparation helped to build the capacity of local soil experts on soil assessment and digital soil mapping. The maps in the Atlas well align with the work implemented by the ITPS at the global level and contribute to the establishment or strengthening of National Soil Information Systems. The information on the status of Asian soils make the atlas an important educational tool to use in schools and universities but also by the civil society, farmers and policymakers.



Prof. Rosa Poch
Chair ITPS

Key messages

To ensure the sustainable use of soil resources, the people of Asia should strive to:

- assess the current state of soils and associated pressures across their territories;
- assess the impacts of current policies and land use practices on soil quality in areas such as agriculture, waste, urban development or mining, and to adopt preventative measures to ensure the sustainable use of soil and maintenance of soil functions and services;
- develop action programmes to deal with the main issues of local concern, including strategies for the remediation of degraded and contaminated land;
- develop systems for the collection of harmonised soil information and long-term monitoring of trends in soil functions and characteristics;
- support the networking of soil scientists and land use experts from across Asia in order to improve information exchange and develop a more comprehensive knowledge-base to underpin sustainable soil use policy development and practices;
- develop awareness raising strategies to highlight the importance of soil to everyday life and thus promote the good management of soil for future generations.



Soils underpin the classical landscapes of Asia which, in turn, reflect the principle soil-forming factors of parent material, climate, topography, vegetation (itself driven by the chemical and physical properties of the soil), time and the influence of human beings. The photograph shows a typical permanent grassland landscape from Mongolia, which is known as the steppe, and is characteristic of central Asia. The dense grass cover means that organic matter accumulation in the soil is considerable, which gives rise to dark-coloured soils. Where precipitation and evaporation are in equilibrium, leaching processes during the wet season are mitigated by the upward flow of water during dry periods, which maintains soil nutrients. In drier steppes, vegetation is sparser, the amount of organic matter is reduced and unleached mineral salt content increases. Conversely higher precipitation gives rise to greater leaching of soils with taller grasses and a savannah-like landscape of shrubs and trees. Some 'steppe' soils are among the most fertile on the planet and are intensively used for cereal cultivation, which gives rise to the term 'breadbasket soils'. (LVT)



As shown by this striking profile from Indonesia, there is a strong relationship between soils and the parent materials in which they form. Parent materials influence soil formation through their mineralogical composition, their texture, and their stratification. In this case, the parent material is ash, which has been fallen to the ground during an eruption of the volcano in the background. Volcanic soils can also develop in basaltic lava flows and cinders, which in turn give rise to soils with different characteristics. Volcanic soils are found in all climatic regions but are particularly prevalent in Asia along the western coast of the Pacific Ocean, Southeast Asia, the Deccan Plateau of India and Türkiye. (MF)

Scope of the Atlas

Soil is a naturally occurring resource made up of minerals, organic matter, air and water. It performs a number of environmental, social and economic functions that are vital to life on earth. Supplying water and nutrients to plants, soil also ensures water quality by storing, buffering and transforming pollutants. Soil is an incredible habitat that provides raw materials, preserves our history and reduces the risk of floods. Without soil, the planet as we know it would not function.

However, the importance of soil and the range of environmental services that depend on soil properties are not widely understood or appreciated by society at large. Part of the problem is that an increasingly urban society has lost contact with natural processes, many of which are invisible to our eyes. Most people expect to find food on the shelves of supermarkets and are not aware that 95% is produced in soils by farmers, thus have no appreciation of the importance of soil in its production. Concepts such as nutrient cycling and organic matter management, which are critical to soil fertility and food production, are a mystery to most. To compound matters, there has been very little dialogue between the soil science community and the general public. Most soil-related reading material is geared towards scientific journals or technical reports that are normally beyond the reach and understanding of the general public. This results in a lack of material to help interested stakeholders appreciate the value of soil or help them to preserve this precious resource.

As a consequence, soil as a topic tends not to feature prominently in the minds of the public or politicians. However, some groups are becoming increasingly aware of a greater need to inform and educate people of all ages, policymakers, land managers and other scientists of the importance and global significance of soil.

This is particularly true for the Global Soil Partnership (GSP) initiative of the Food and Agriculture Organization of the United Nations (FAO). The GSP was established in 2012 as a mechanism to improve soil governance and promote sustainable soil management at all levels.

It is in this context that the European Commission's Joint Research Centre, FAO and the Korean Rural Development Administration initiated a project to bring together experts from across Asia and other parts of the world, to produce the first ever SOIL ATLAS OF ASIA. The aim was to prepare an atlas that could portray the soils of Asia in a simple manner targeted to general public, decision-makers, politicians, teachers and even scientists in other disciplines.

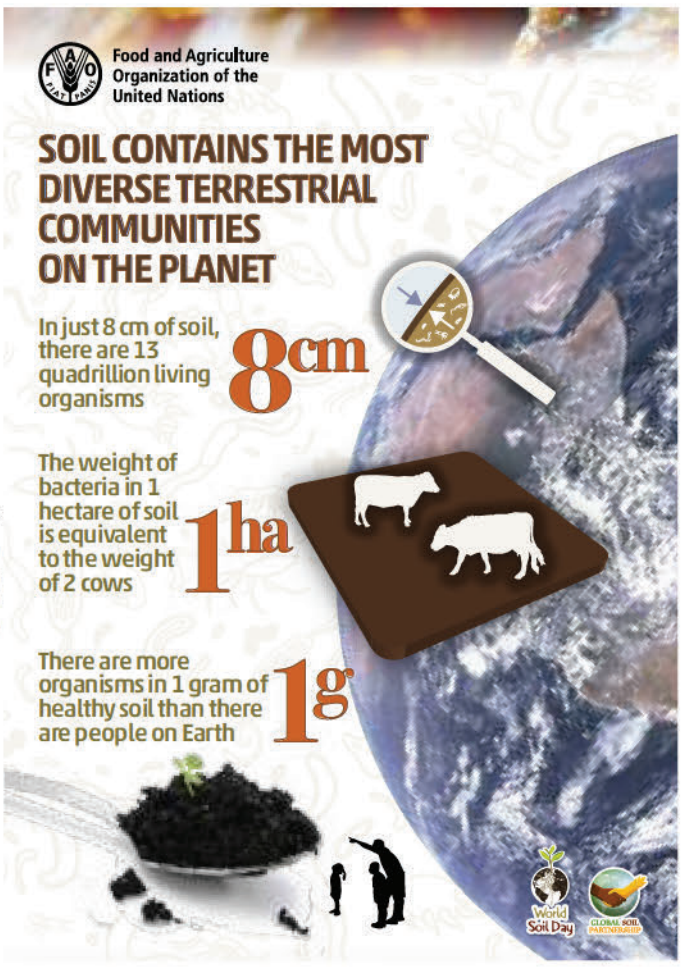
At its heart, the atlas presents a series of annotated maps that show the diversity of soil characteristics across Asia in a manner that is comprehensible to the layperson. How soils are formed, the key factors that shape soil properties and why these vary across Asia are explained in a simple and clear manner.

The atlas also describes how soils shape our daily lives, most of the time without our awareness. An important aspect of this publication is to highlight the growing pressure on soils resulting from issues such as urban expansion, inappropriate land management, pollution, increased demand for food and climate change. It is important that people understand how their actions can help protect and restore soil health while reducing degradation processes.



Over large parts of Asia, soils are developed in parent materials deposited by major river systems such as the Brahmaputra, Chao Phraya, Euphrates, Ganges, Indus, Irrawaddy, Yellow and the Yangtze. In fact the Yangtze, with a length of 6 380 km, is the longest river in Asia and the third longest in the world. Rivers are important as they transport nutrient-rich sediments that are deposited on adjacent land during floods. Despite the risk, many urban areas were historically located on floodplains due to the easy access to fresh water together with the fertility and ease of cultivation of their soils for agriculture. In fact, the floodplain of the Euphrates and Tigris Rivers is part of an area referred to as the The Fertile Crescent, which is known as the "cradle of civilisation" where, together with the Indus Valley, agriculture and early human complex social cultures flourished due to the presence of fertile soils and water for irrigation. In parallel, recent genetic studies have indicated that rice cultivation originated between 8 000 to 13 000 years ago in the Pearl River valley region in China. In these respects, Asia can truly be regarded as the birthplace of agriculture. The above photograph shows high sediment loads in the Yellow River at the Hukou Falls (China). (L)

In fact, there is an increasing realisation that in many cases, deficiency in education is a significant underlying cause of unsustainable soil management practices, of the general lack of investment (both in education and actions to protect soil) and, as importantly, of the widespread political reluctance to adopt short- and long-term actions to preserve and enhance soil conditions. After reading this atlas, we hope that the content helps you to understand better how the product of the complex interactions between climate, the landscape, the geological substrate, vegetation, living organisms, human influences and time leads to the creation of the valuable resource we call soil.



Some amazing facts that you probably never knew about soil. In addition to maintaining aboveground ecosystems, soil is an important habitat in its own right. Several tonnes of living organisms can be found in one hectare of soil, which is the equivalent of two cows – most of which still needs to be studied. (FAO)



Soil is the critical interface between the hydrosphere, atmosphere, lithosphere and organisms inhabiting it. As the regulator of biogeochemical and energy cycles, soil is extremely sensitive to the effects of climate change and to human activities. Such changes can have dramatic consequences on one of the key services provided by soil – the provision of food, fibres and fuel. These aspects are mirrored in mangrove forests, which act as the interface between the land and sea. Mangroves dominate the coastlines of subtropical southern and eastern Asia. Soils in mangrove forests reflect the interactions between abiotic (i.e. tides and landscape) and biotic (i.e the activities of plants and organisms) factors. Mangrove soils are formed in marine alluvium deposited by rivers and the sea. Topsoils can be either sandy or clayey. Below the surface, the soil is typically waterlogged, containing virtually no air, which reduces the decomposition of organic matter. Such soils are major carbon sinks. Recent findings show large differences in soil pH, salinity, bulk density, nutrient levels and organic matter content of mangrove soils that in turn influence the vegetation composition and structure of mangrove forests. Mangroves also provide coastal areas with protection from storms and erosion. However, coastal development, drainage, pollution and deforestation are resulting in a decline in mangroves. (LP)

Soils and the Sustainable Development Goals

The Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a collection of 17 global aspirations that were set by the United Nations General Assembly in 2015 for the year 2030 [1]. All countries have agreed to work towards achieving these goals. Each of the goals has a list of targets (169 in total) that are measured by a range of indicators (232 in total). Progress is assessed annually and can be inspected through portals such as the SDG Tracker (https://sdg-tracker.org/).

The Sustainable Development Goals are:

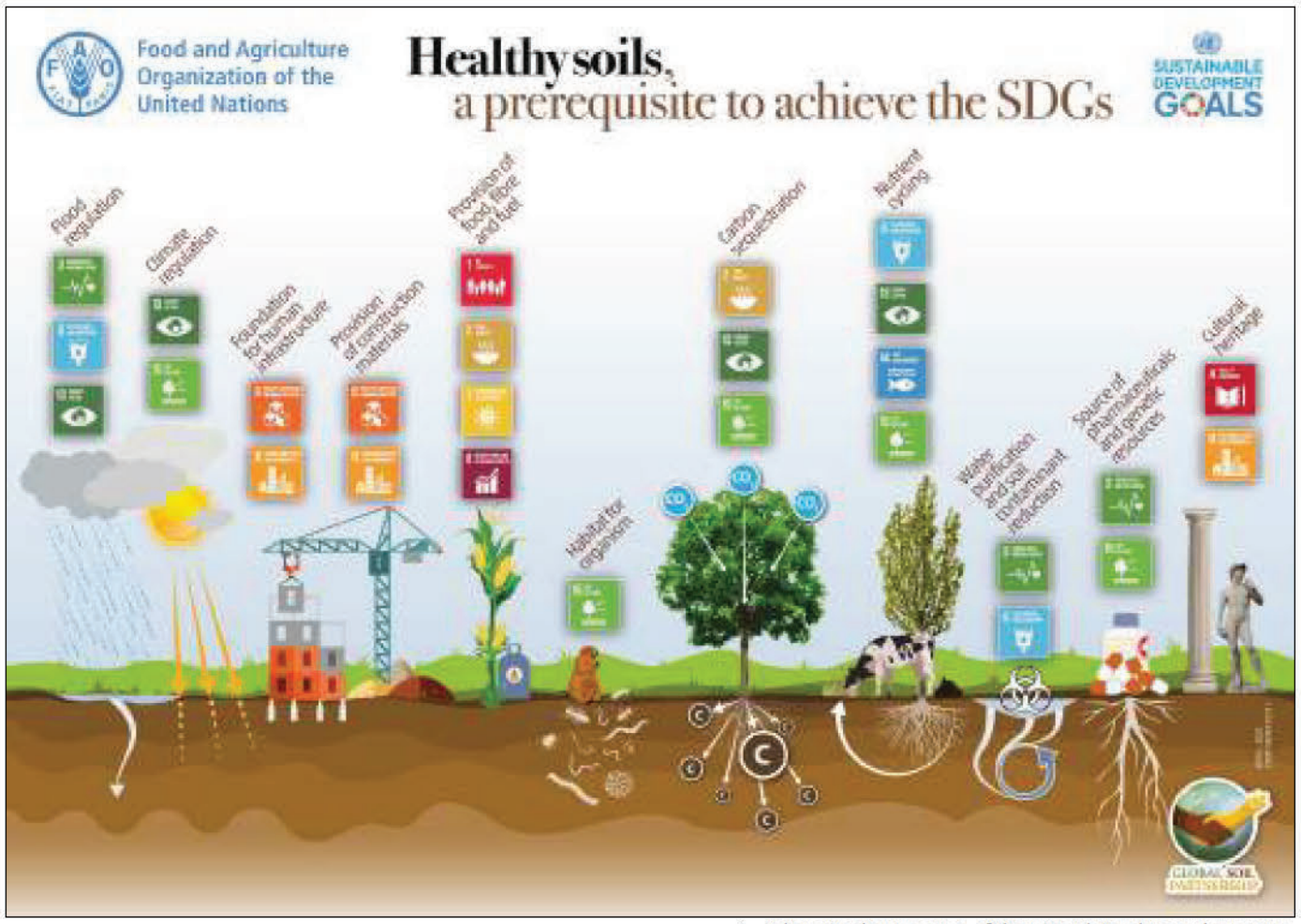
- **No Poverty**
- **Zero Hunger**
- **Good Health and Well-being**
- **Quality Education**
- **Gender Equality**
- **Clean Water and Sanitation**
- **Affordable and Clean Energy**
- **Decent Work and Economic Growth**
- **Industry, Innovation, and Infrastructure**
- **Reducing Inequality**
- **Sustainable Cities and Communities**
- **Responsible Consumption and Production**
- **Climate Action**
- **Life Below Water**
- **Life On Land**
- **Peace, Justice, and Strong Institutions**
- **Partnerships for the Goals.**

The SDGs build on a series of global commitments by the United Nations (UN) that started in June 1992 at the Earth Summit in Rio de Janeiro, Brazil, where more than 178 countries adopted the concept of Agenda 21. This was a comprehensive plan of action to build a global partnership for sustainable development to improve the lives of people and protect the environment. The Rio Summit was instrumental in the launching of three highly important policy drivers. These were:

a. a recommendation to establish the United Nations Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (generally referred to as the UNCCD)
b. to open the Convention on Biological Diversity (CBD)
c. to sign the United Nations Framework Convention on Climate Change (UNFCCC).

In September 2000, UN Member States unanimously adopted the Millennium Declaration at the Millennium Summit, which led to the elaboration of eight Millennium Development Goals (MDGs) to reduce extreme poverty by 2015. These aimed to:

- eradicate extreme poverty and hunger
- achieve universal primary education
- promote gender equality and empower women
- reduce child mortality
- improve maternal health
- combat HIV/AIDS, malaria, and other diseases
- ensure environmental sustainability
- develop a global partnership for development.



Schematic showing some of the inter-relationships and synergies between soil functions or ecosystem services and selected Sustainable Development Goals. (FAO)

At the UN Conference on Sustainable Development in Rio de Janeiro, Brazil, in June 2012 (also known as the Rio+20 Conference), countries adopted the document "The Future We Want" where it was decided to establish the UN High-level Political Forum on Sustainable Development that would lead a process to develop a set of 'sustainable development goals' that built upon the MDGs.

Soils and the SDGs

The unique and cross-cutting role of soils in relation to agriculture, the water cycle, and how we use land to reduce rural poverty, or in mitigating the effects of climate change and underpinning biodiversity, means that soils are at the heart of the SDGs. This means that how we deal with soil health will indirectly determine whether the SDGs will be achieved by 2030.

Poverty, food insecurity and malnutrition, environmental pollution, climate change, natural resources degradation, loss of biodiversity, population growth, are some of the global societal challenges at the heart of the SDGs. Soil is implicitly mentioned in the following SDGs:

Goal 2: ending hunger

This goal looks to end hunger and improve nutrition by promoting sustainable agriculture. As the basis for more than 95% of global food production, sustainable soil use is crucial.

Goal 3: good health and well-being

This goal looks to improve people's health. In addition to concerns about the overexploitation of soils and loss of essential minerals, this goal contains a specific target to reduce deaths and illnesses resulting from soil pollution.

Goal 15: Life on land

Efforts to reduce land degradation are the scope of SDG 15, especially target 15.3, which aims to combat desertification, restore degraded land and soil (including land affected by desertification, drought and floods), and strive to achieve a land-degradation-neutral world. We cannot afford to lose more fertile land if we want to have enough food for the world's growing population.

In addition, it is clear that the provision of ecosystem services, where soil properties and functions play a key role, are very important to:

Goal 1: no poverty - healthy fertile soils underpin agriculture and support rural economies.

Goal 6: clean water - filtering and buffering capacities of soil protect water supplies from pollution.

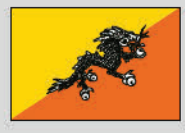
Goal 11: sustainable cities - soil is at the heart of green infrastructures that support sustainable urban development through natural cooling, stormwater management, more biodiversity, better air quality and higher mental well-being.

Goal 13: climate action - soil is the world's largest carbon sink and can help mitigate the effects of climate change by storing carbon in the soil and reducing greenhouse gas emissions (see pages 24-25).

Goal 14: life below water - the reduction in nutrient pollution of the seas depends on a better understanding of the soil fertilisers and organic wastes that are applied to land.

Furthermore, **SDGs 7 (Affordable and Clean Energy)** and **12 (Responsible Consumption and Production)** will require the availability of healthy soil resources.

Sustainable development in Bhutan



The concept of sustainable development in Bhutan extends beyond economic growth alone as the nation has defined the pursuit of collective happiness as the principal guiding philosophy for the long-term well-being of the country. The Gross National Happiness (or GNH) is expressed through four pillars (sustainable and equitable socio-economic development; environmental conservation; preservation and promotion of culture; and good governance) and nine domains of happiness (psychological well-being, health, use of time, education, cultural diversity and resilience, good governance, community vitality, ecological diversity and resilience, and living standards). As with the SDGs, each domain is measured through a series of indicators.

The United Nations Convention to Combat Desertification

The United Nations Convention to Combat Desertification (UNCCD) is the only global legally binding framework to address arid, semi-arid and dry sub-humid areas, known as drylands, where some of the most vulnerable ecosystems and peoples can be found. The term 'arid' is used to describe regions that are characterised by having little or no precipitation (generally 0 to 800 mm per year, occurring infrequently and irregularly). An important concept to emerge from the UNCCD is that of Land Degradation Neutrality (LDN).

The UNCCD, ratified by 196 countries and the European Union, promotes long-term strategies for national action programmes that are supported by international cooperation and partnership arrangements. The Convention defines land as "the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system".

In this context, desertification is seen as an extreme case of land degradation, which is expressed by a persistent reduction or loss of biological and economic productivity of lands that are used by people whose livelihoods depend on this productivity. However, the loss of this productivity is partly driven by that use through soil erosion, a deterioration of the physical, chemical and biological or economic properties of soil, and the long-term loss of natural vegetation.

To combat desertification, the UNCCD has adopted a target of Land Degradation Neutrality, which is defined as a "state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD, 2015).

While LDN implicitly recognises that eradicating land degradation is unattainable in the foreseeable future, it also stresses that land productivity and provision of ecosystem services on degraded land can be recovered or restored.

Further details can be found at [2].

Soil and the United Nations Convention on Biological Diversity (CBD)

The CBD, which came into force in 1993, looks to ensure the conservation of biological diversity (or biodiversity), coupled with the sustainable use of its components and an equitable sharing of benefits arising from genetic resources. It is a key driver of the concept of sustainable development.

Initially, no attention was given by the Convention to the large biodiversity pool stored belowground. In 2002, the COP in Nairobi decided to establish an international initiative for the conservation and sustainable use of soil biodiversity as a cross- cutting initiative within the programme of work on agricultural biodiversity. FAO in the framework of the Global Soil Partnership and, in consultation with other organisations, was invited to facilitate and coordinate this initiative. The recent COP15 adopted a new action plan that was intended to promote the mainstreaming of soil biodiversity conservation into all sectors. Soil biodiversity is becoming more relevant and the new action plan is aimed to contribute to the just adopted biodiversity framework.

One of the ongoing challenges is to promote awareness so that societies' better understand of the role of soil biodiversity in agricultural production, land management practices and ecosystem and environmental health. A good example is the Global Atlas of Soil Biodiversity (see pages 28-29).

Further details can be found at [3].

Soil and the United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC aims to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In 2015, the parties agreed that future global warming should be limited to 1.5 °C relative to the pre-industrial level.

While the Convention initially set non-binding limits on greenhouse gas emissions for individual countries, in 1997, the Kyoto Protocol established legal obligations for developed countries to reduce their greenhouse gas emissions.

While soils received comparatively little attention in the early days of the Convention, the Paris Agreement of 2015 mandated countries to adopt policies and measures that reduce greenhouse gas emissions and increase the resilience of ecosystems. Implicit in this statement is the continued and increased sequestration of carbon by soils (see pages 24-25), the restoration and protection of soils to ensure the continuous delivery of ecosystem functions in a changing climate, and the reduction of the use of land that results in high levels of emissions, particularly methane and nitrous oxide.

Further details can be found at [4].

Land degradation and restoration

Land degradation, in its many forms, occurs in all parts of the world and negatively affects 3.2 billion people. It represents an economic loss in the order of 10% of annual global gross product. In this context, combating land degradation and restoring degraded land is an urgent priority in efforts to protect the biodiversity and ecosystem services that are vital to all life on Earth and to ensure human well-being. A ground-breaking report by IPBES concluded that avoiding land degradation and restoring degraded lands made sound economic sense that resulted in increased food and water security, increased employment, improved gender equality, and help avoid conflict and migration. Avoiding land degradation and restoring degraded lands are also essential for meeting the Sustainable Development Goals (see adjacent page).

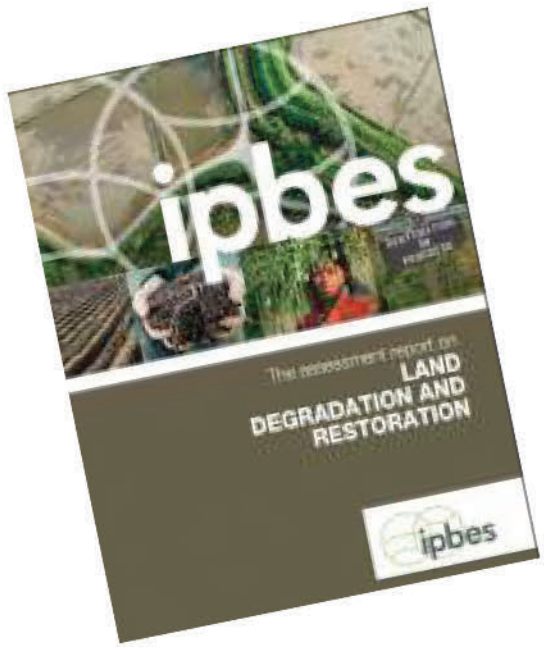
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is the science panel supporting the UNCBD (see adjacent column). In 2018, they produced an Assessment of Land Degradation and Restoration that provided a critical assessment of the issues facing decision-makers.

A key message of the report is the need for the protection and sustainable management of soil, supplemented by an increased drive towards restoration of degraded land. Studies from Asia indicated that the cost of inaction in the face of land degradation is at least three times higher than the cost of action. In comparison, the benefits of restoration are, on average, 10 times higher than costs.

Pages 174-185 of the atlas describes the main degradation processes affecting Asia. These include the loss of soil at a faster rate than it is formed through erosion (by wind, water and harvesting of root crops), nutrient removal, depletion of soil organic matter, surface sealing by urban development, pollution, compaction by heavy machinery, increasing salinity and acidity. These are predominantly driven by excessive and increasing consumer demands on land resources, coupled with population growth, competing needs on soil-based ecosystem services and a lack of planning and policies that recognise the value of soil. All result in the application of inappropriate land management practices, the negative outcomes of which are magnified by climate change. Potential solutions, interventions and responses are also presented and discussed (see concluding remarks).

The IPBES Assessment of Land Degradation and Restoration can be found at:

https://www.ipbes.net/assessment-reports/ldr



The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) groundbreaking report in 2018 was the first comprehensive evidence-based assessment of land degradation. The report was prepared by over 100 international experts from 45 countries and draws on more than 3 000 scientific papers and reports, as well as indigenous and local knowledge. The report highlights the implications of land degradation in achieving the Sustainable Development Goals, Aichi Targets and meeting the ambitions of the Paris climate agreement. (IPBES)

What is aridity?

Scientifically, land is arid when the aridity index (AI), the amount of precipitation received divided by the amount of water lost through evapotranspiration, is less than 0.5.

Dry environments are referred to as:

- hyper-arid (AI < 0.03): generally without vegetation as annual rainfall rarely exceeds 100 mm. Precipitation events are infrequent and irregular, with dry periods often lasting several years.
- arid (AI 0.03-0.20): highly variable annual precipitation of between 100-300 mm giving rise to sparse native vegetation (generally grasses, herbaceous shrubs and small trees).
- semi-arid zone (AI 0.20-0.50): annual precipitation varies from 300-800 mm occurring either in summer or winter. Climate can support rain-fed agriculture and livestock production.

It is worth noting that aridity is not necessarily linked to high temperatures. The cold Polar regions are characterised by annual precipitation of 50-250 mm, falling as rain in the summer and snow in the winter. However, low evaporation levels support tundra vegetation.

For more on soils in dry conditions, see pages 50-51.

What is a COP - the language of treaties?

Many international environmental treaties establish a body to monitor the agreement on which they are founded. Usually, that body is composed of countries or states that are, in legal terms, party to the agreement - they have signed, ratified or agreed to support the agreement.

For the three agreements described on this page, these bodies are known as the Conference of the Parties, which is abbreviated to COP. In practical terms, the COP is a large meeting that reports the progress of the Convention in meeting its objectives. In addition to plenary sessions where all members can formally discuss issues, the COPs contain hundreds of smaller meetings that focus on very specific issues or lobby for changes or new developments. COPs tend to occur every 1-3 years (e.g. UNFCCC annually, UNCCD biannually).

COPs are supported by a permanent Secretariat that makes arrangements for meetings, compiles and transmits reports, and supports any subsidiary bodies established under the Convention (e.g. the Committee for Science and Technology under the CCD).

While they appear similar, Intergovernmental Panels established by the UN on climate change (IPCC) and biodiversity protection (IPBES) are not formally part of these treaties but support the respective conventions.

FAO and the EC

FAO and soil

Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization (FAO) is a specialised agency of the United Nations established in 1945. It leads international efforts to defeat hunger and achieve food security for all and make sure that people have regular access to enough high-quality food to lead active, healthy lives.

FAO Strategic Framework 2022-2031 seeks to support the 2030 Agenda through the transformation to MORE efficient, inclusive, resilient and sustainable agri-food systems for better production, better nutrition, a better environment, and a better life, leaving no one behind (four betters). The four betters reflect the interconnected economic, social and environmental dimensions of agri-food systems. They also encourage a strategic and systems-oriented approach within all FAO's interventions through four accelerators: (i) technology, (ii) innovation, (iii) data, and (iv) complements (governance, human capital, and institutions).

Its Latin motto, fiat panis, translates into English as "let there be bread". The headquarters of FAO are located in Rome, Italy. The current Director-General is Dr Qu Dongyu (see the preface to the atlas), who was appointed to the position in August 2019. FAO has 194 Member Nations, one Member Organization (the European Union), and two Associate Members .

Given FAO's mandate on food security and nutrition, soils play a key role as approximately 95% of food is produced there by farmers.

As the main UN specialised agency dealing with food and agriculture, FAO is mandated to address key policy and programme guidance in many fields related to agriculture, agri-food systems and nutrition, thereby building on research findings and lessons learnt from the experience of its members, development partners and its portfolio of projects. The resulting policy and technical documents are the achievement of a multi-stakeholder dialogue, made possible by FAO's role as convener and facilitator of such consultations enabling an active interface between research, field practice and policy.

In the area of soils, FAO has a long-standing history that started with the production of the first ever World Soil Map and has been producing a very rich list of soil publications covering all the soil spectrum. FAO has also implemented a vast amount of technical projects around the world supporting its members in the sustainable use of soils. Since its establishment, FAO through its Land and Water Division has produced flagship technical tools and publications that had been adopted by its members. They include the FAO Soil Bulletins, the framework for Land Evaluation, Land Use Planning, the Agro-ecological zoning, the Harmonized World Soil Database among others.

For further information, please see [5].

FAO in Asia

FAO has 48 national offices throughout Asia. Reflecting the scale of the continent, FAO has a Regional Office for Asia and the Pacific, which is located in Bangkok, a Regional Office for Europe and Central Asia, which is located in Budapest, and a Regional Office for the Near East and North Africa, which is located in Cairo.

Countries have indicated the most crucial areas of potential FAO assistance by setting clear priorities and areas of cooperation. The Country Programme Framework sets the national priorities related to food security and nutrition, agricultural productivity and sustainable natural resources management, resilience of livelihoods to threats and crises, and governance.

For further information, please visit [6].

What is the Global Soil Partnership?

GLOBAL SOIL PARTNERSHIP

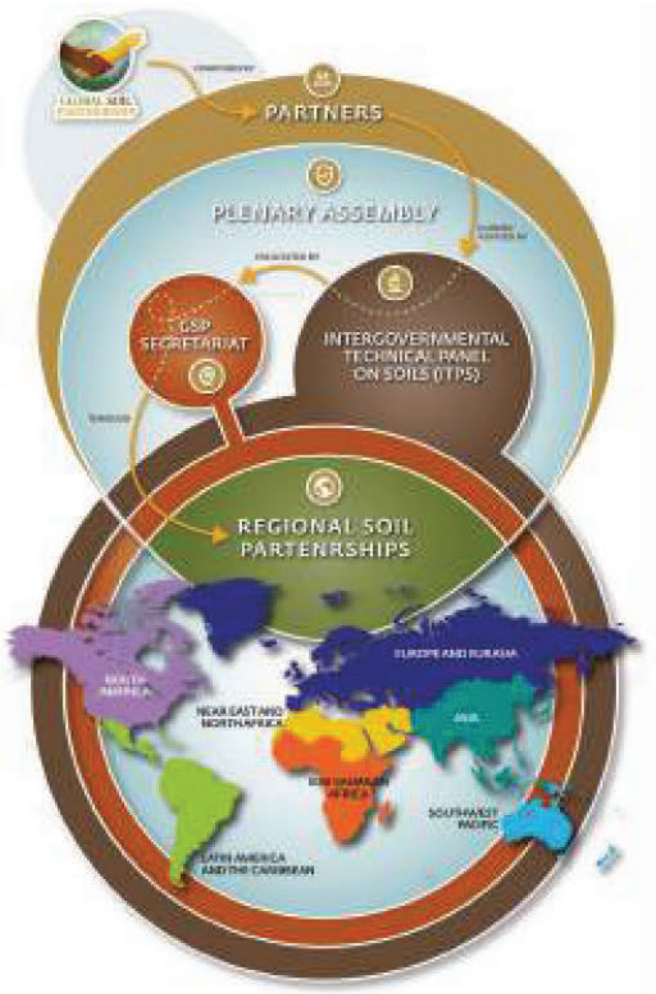
Acknowledging that 95% of food comes from soil and that soil health is critical to the provision of key ecosystem services to enable life on earth, FAO members established the Global Soil Partnership (GSP) in 2012 to position sustainable soil management on the international agenda and enhance soil governance.

Since its inception, the GSP has proven to be an effective mechanism for raising awareness on the importance of soils on food security and nutrition, human and environmental health and climate action. It has built strong ties with the three Rio Conventions to recognise the role of soils in combating climate change, preventing land degradation and preserving global biodiversity. Billions of citizens have learnt about soils through the celebration of the International Year of Soils in 2015 and the annual celebration of World Soil Day. Governments are now taking concrete actions to promote sustainable soil management and protect and restore their limited soil resources.

The GSP has played – and is currently playing - a leading role in helping FAO members to mainstream soil health and sustainable soil management in national legislation, strategies, and actions on the ground through tools like SoilLEX, the Global Soil Doctors Programme, and the RECSOIL initiative. The work of technical networks like the Global Soil Laboratory Network (GLOSOLAN) and the International Network on Soil Information Institutions (INSII) is further helping to bridge the gap between science and policy. The country-driven approach for generating global soil property maps and national soil information systems demonstrated to be innovative and inclusive, and is significantly marking a new era on soil data/information availability.

The Soil Atlas of Asia is a further step towards improving knowledge about the state of soil in the region, and has served as a key tool for improving national capacities in soil data and information availability. It is the objective of the GSP to promote this document and associated national soil information systems as a basis for informed decision-making that leads to sustainable soil management in Asia. For further information, please visit:

For further information, please see [7].



The main structures of the Global Soil Partnership. Building on five regional partnerships, the GSP works to position soils in the Global Agenda and to promote sustainable soil management. The partners meet at an annual global and regional plenary assembly to report on and share experiences relating to its Action Areas 2022-2030. (FAO)

Regional Soil Partnerships



The Global Soil Partnership leverages a strong regional and national component that allows for the downscaling the implementation of sustainable soil management and response to specific regional and national priorities. Regional Soil Partnerships (RSPs) covering all regions of the world are particularly important to enhance collaboration among all relevant stakeholders and governments in the same region, thereby guiding the GSP towards the identification of regional goals and priorities and their required implementation mechanisms. The Soil Atlas of Asia has been prepared with the support of the following Regional Soil Partnerships:

The **Asian Soil Partnership** consists of Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, the Democratic People's Republic of Korea, India, Indonesia, Japan, the Lao People's Democratic Republic, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, the Philippines, the Republic of Korea, Singapore, Sri Lanka, Thailand, Timor-Leste and Viet Nam.

The **Near East and North African (NENA)** Soil Partnership consists of the following countries, of which the ones in bold are addressed in this atlas: Algeria, **Bahrain**, Egypt **(Sinai)**, **the Islamic Republic of Iran**, **Iraq**, **Jordan**, **Kuwait**, **Lebanon**, Libya, Morocco, **Oman**, **Qatar**, **Saudi Arabia**, **the Sudan**, **the Syrian Arab Republic**, Tunisia, **the United Arab Emirates**, **Yemen** and the **Occupied Palestinian Territory**.

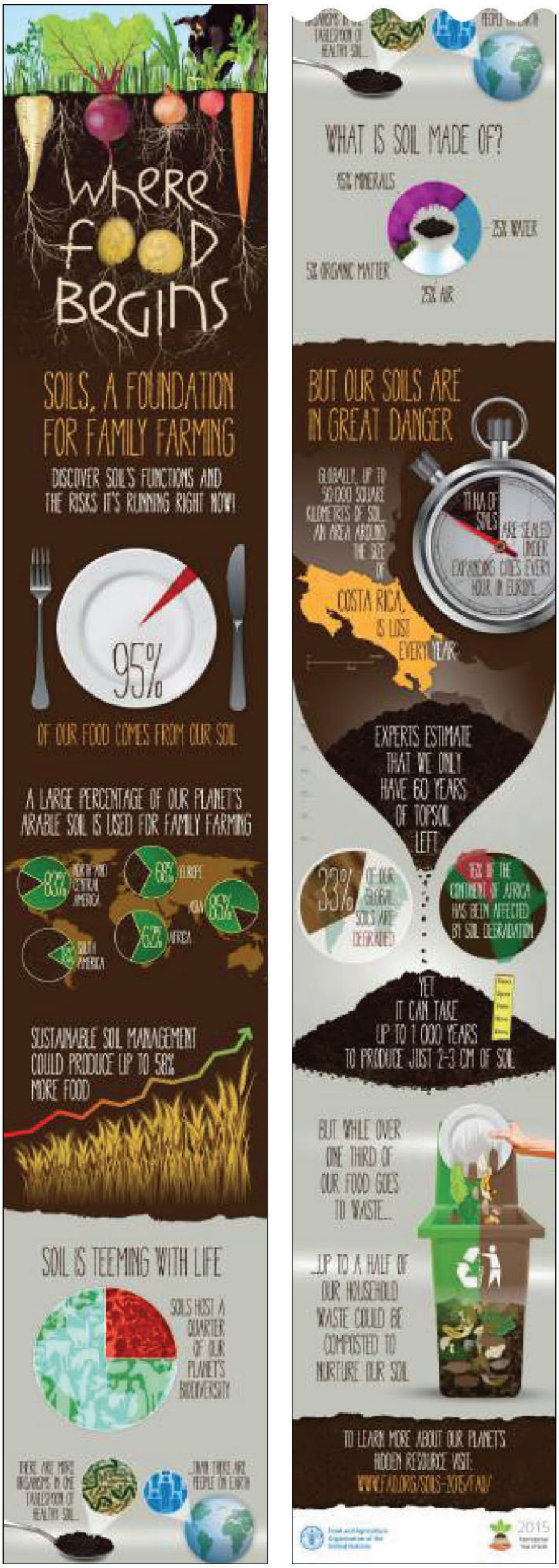
The **Eurasian Soil Partnership (EASP)** is a sub-regional soil partnership within the European Soil Partnership, that addresses the specificities of the eastern European and Eurasian GSP members. It consists of the following countries, of which the ones in bold are addressed in this atlas: **Armenia**, **Azerbaijan**, Belarus, Georgia, **Kazakhstan**, **Kyrgyzstan**, the Republic of Moldova, the Russian Federation **(Asian part)**, **Tajikistan**, **Türkiye**, **Turkmenistan**, and **Uzbekistan**.



Third Asian Soil Laboratory network (SEALNET) meeting in Manila, Philippines. (FAO)



The Intergovernmental Technical Panel on Soils (ITPS) is composed of 27 leading soil experts representing all the regions of the world. (FAO)



A striking example of citizen engagement and awareness raising material produced by FAO's Global Soil Partnership for the International Year of Soil. (FAO)

Soil in the European Union

Within the European Union, soils are currently in the limelight. The current political, economic and climate crises have prompted an unprecedented awareness about their importance for food security, climate and the environment across policy, science, business the media and society.

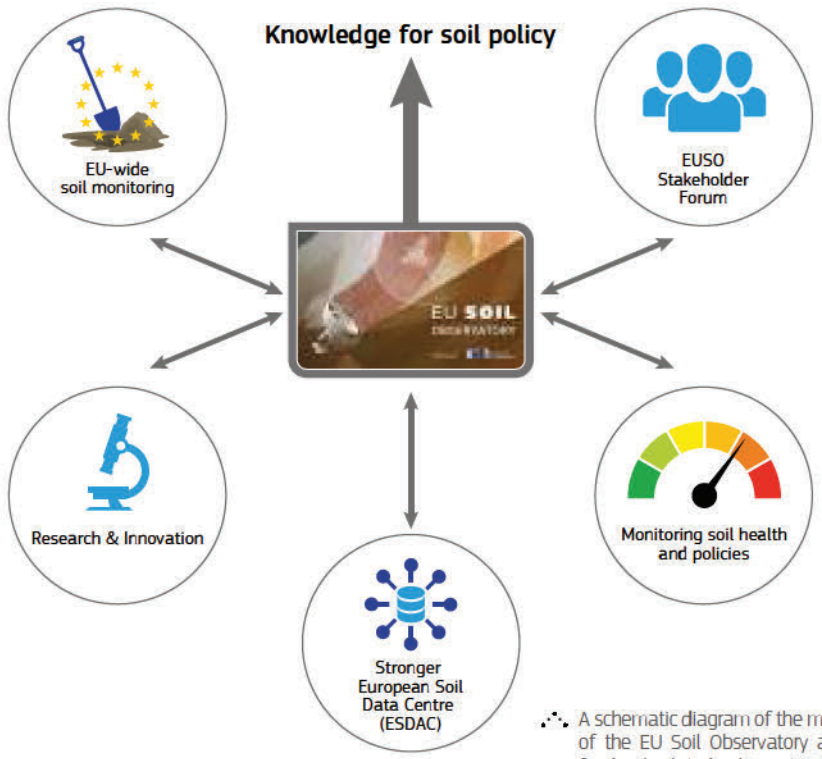
There is widespread agreement that the continued unsustainable use of soils is compromising a key part of the European Union's natural capital. There is also increasing awareness that European consumer demands may be driving pressures on soil in other parts of the world. The European Green Deal, published in 2020 [8], fully reflects the recognition of healthy soils and their role in turning climate and environmental challenges into opportunities across all policy areas. The Green Deal aims to boost the efficient use of resources by moving to a clean, circular economy that stops climate change, reverts biodiversity loss and cuts pollution.

A clear commitment was manifested by the adoption in 2021 of the EU Soil Strategy for 2030, which sets out a framework to protect and restore soils, while ensuring their sustainable use [9]. It sets a vision and objectives to achieve healthy soils by 2050. The Strategy contains a proposal for a Soil Health Law that should afford soils the same protection as that offered to water and air. At the time of writing, the European Commission is expected to adopt the proposal for the Law in mid-2023.

The Strategy is supported by a dedicated Mission in the European Union's Horizon Europe Research and Innovation Programme. Entitled "A Soil Deal for Europe", it aims to create 100 living labs and lighthouses to lead the transition towards healthy soils by 2030 while also addressing key knowledge gaps through research [10].

In parallel, the European Commission's Joint Research Centre established the EU Soil Observatory (EUSO) to provide Commission services, as well as the broader soil user community (e.g. researchers, policymakers, farmers, land managers & owners, NGOs, education, industry, interested public), with the knowledge and data flows needed to prepare and support the policies that safeguard soils [11].

In addition to supporting policy development, the EUSO assesses the impact of policies by monitoring and modelling changes in soil health. An important element in ensuring healthy soils is to raise public awareness of the importance of soils. Over the past 20 years, the JRC has developed a series of novel atlases highlighting the diversity of soils around the world. This atlas is the latest addition.



A schematic diagram of the main objectives of the EU Soil Observatory and how they feed soil-related policies. (JRC)

The Joint Research Centre (JRC)

As the European Commission's in-house science service, the Joint Research Centre (JRC) provides independent, evidence-based science and knowledge, supporting EU policies to positively impact society.

The JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the EU Member States, the scientific community and international partners.

For more information, please visit [12].

The European Commission

The European Commission – the executive body of the European Union – is responsible for proposing legislation, implementing decisions, upholding European Union treaties and managing the day-to-day business of the European Union. The President of the Commission, proposed by the European Council and elected by the European Parliament, chairs a cabinet of 27 other Commissioners who lead policy portfolios. The Commissioners are supported by a civil service, made up of staff from across the European Union, that is divided into Directorates-General (or DGs). Each DG covers a specific policy area, such as agriculture, environment or trade.

For more information about the workings of the European Commission, please visit [13].

Raising awareness about soil

Raising awareness about healthy soils

Raising awareness is critical to the protection and sustainable management of soil resources. Many people still associate soil with dirt. But dirt is dead, while soil is teeming with life. Our very existence depends on soil and the numerous functions it performs. 95% of the food we eat comes from soil. Soil filters contaminants and protects water reservoirs from pollution. It stores water and reduces the risk of flooding during heavy rains. Soils also play a key role in carbon sequestration, helping to fight climate change. Nevertheless, 33% of global soils are degraded.

Soil degradation is a silent process that goes undetected until it is too late to act.

Human activities related to inappropriate land use and soil management practices exacerbate soil degradation. Still, the lack of societal consciousness of the importance and fragility of soil resources has resulted in a lack of political action for their preservation. In this regard, education and awareness-raising activities play a key role in bringing soils closer to all, from policymakers to farmers and citizens. The scope of this atlas is therefore to engage with as many stakeholders as possible to showcase the beauty, diversity and value of soil.



What does soil awareness mean?

Soil awareness means developing responsible behaviours towards soils and soil management, based on knowledge and attitudes. The more we know about the role that soil plays in sustaining the environment, the more we understand how important it is and, hopefully, the more likely we will look after it. However, even though many nations are now strengthening normative and regulatory frameworks, soil management and protection is still not considered a priority for many.



FAO's Global Soil Partnership has proven its ability to raise awareness about the critical role of soils, as evidenced by its successful campaigns for the International Year of Soils 2015 and World Soil Day. From informative videos to engaging infographics, the Partnership has left an indelible mark in promoting soil health globally. (FAO/GSP)

Who needs to be informed about soils and why it is important to teach the importance of soil to society?

From young children, school teachers, farmers, gardeners and the general public to land planners and politicians, everyone needs to understand the key role that soils play in our daily lives.

Children

Children, of all ages, love playing with soil and have the capacity to learn with simple "hands-on" activities. Children's views and drawings usually depict their perception of soil in simple language and shapes. However, while they certainly find it fun to play in it, the role of teachers and educators is also important to ensure that they understand why soil is the basis of life, not only for food production, but also for the multitude of ecosystem functions and services it provides.



Children's hands-on workshop in December 2017 organised by the Indonesian Center for Agricultural Land Resources Research and Development. (ICALRD)

University students

The knowledge of soil in general, and soil biology and ecology in particular, is often neglected, even in degrees that have a direct connection with the study of terrestrial ecosystems. It is clear that the study of soil biodiversity and the current soil education and awareness programmes on soils should be reviewed and improved at university level, not only in subjects such as agricultural sciences, forestry and environmental sciences, but also in engineering, architecture, land use planning and social and political sciences, because they also deal with and impact the management of our planet, including soil resources.

Policymakers

The decisions made by policymakers affect our everyday lives. Since the temporal horizon in politics is very limited and more related to political elections than to real-world processes, soils are often overlooked in politics. Increasing awareness about the importance and value of soil in decision-making processes could help overcome short-term interests.

Private sector and agribusiness

Concrete actions are needed to involve the private sector in soil conservation, restoration and protection, similar to what has been done for air and water in recent decades. Governments, scientists, farmer organisations and citizens have a role to play in demanding a greater commitment from the private sector to valuing and protecting soils against any degradation process. As the private sector becomes increasingly engaged in sustainability strategies, the circular economy and climate change actions, it is fundamental that it also understands and appreciates the potential of soil to solve many of the problems the planet is facing, including its vital role in carbon sequestration. Indeed, improving soil health and quality is a smart and cost-effective investment.

Smallholder farmers and farmer organisations

Farmers generally have a good knowledge about soil because it is core to their livelihoods. However, they might not fully understand the complexity of the soil system, with the result that they accidentally mismanage it. The practice of unsustainable soil management can also be related to the fact that farmers are increasingly asked to react to short-term market-driven pressures that push them towards mono-cropping and intensive farming systems.

Citizens

Ultimately, the most important goal must be to raise soil awareness among the public. This is the only way to have a bottom-up change in lifestyle, aimed towards a more sustainable use of our planet's resources.



Indigenous community worshipping the mother soil and seeds as well as pledging to its protection. Vaagdhara, NGO working with local communities in Rajasthan, Gujarat and Madhya Pradesh States, India. (SS)

Where can you learn about soil?

Often the best place to make people aware of the importance, complexity and beauty of soils is out on a farm, or in a woodland or a garden. In these environments, people can discover soil characteristics for themselves and the role soil plays in keeping our environment alive. The use of magnifying lenses or microscopes to show the variety of soil organisms found in a few grams of soil is such a simple lesson and is guaranteed to leave a long-lasting impression. In addition, an enormous amount of educational material is available for students, teachers and the public. This includes computer programmes, lesson plans, supporting materials and activities for both the classroom and outdoors. In recent years, FAO's Global Soil Partnership has produced a broad array of scientific and normative publications and reports as well as a lot of communication material, videos, animations, infographics and social media cards, including experiments for children that are freely available on the following website:

https://www.fao.org/global-soil-partnership/resources/publications/en/

The Global Soil Doctors Programme: Supporting action at the farm level

The Global Soil Doctors Programme is a farmer-to-farmer training initiative led by FAO's Global Soil Partnership. The programme helps farmers implement sustainable soil management principles, by providing them with targeted training on how to preserve and restore good soil condition and functions, and helps raise awareness on soils globally. Inspired by a pioneering activity in Thailand, the programme is now under active development in Latin America and the Caribbean, Africa and Asia with projects successfully running in Mexico, Bolivia, Bangladesh, Kazakhstan and Burkina Faso. Governmental entities together with academia, the private sector, extension services and farmer communities are all playing an active role in the programme's implementation.



Training session in the framework of the Global Soil Doctors Programme in Bangladesh in October 2021. (PB)



The Global Soil Doctors Programme has developed a wide range of educational resources on soil properties and threats. The toolkit offers posters and field exercises in multiple languages, including local dialects. (FAO/GSP)

How to go beyond soil scientists and engage citizens?

Soil scientists are now aware that they can no longer work in silos disconnected from the general public. The soil science community is currently taking up the challenge of providing reliable, simple and readily accessible information to all possible stakeholders. Raising the awareness among non-soil experts about soil facts and issues requires the use of communication experts and designers who disseminate on global platforms with good outreach. While almost everyone knows that soil is where food begins, very few are aware that soil is the very backbone of the essential services and functions that enable life on Earth. In essence, that is the message that the European Commission and FAO's Global Soil Partnership have strived to communicate over the past decade.

How to get the message across?

Raising soil awareness can take many forms, ranging from social media posts and websites to outdoor lessons and learning through playing. For webinars, global events, symposia and official international days and events of the European Union and United Nations, simple and easy-to-understand messages are developed and disseminated to inform people without compromising the scientific accuracy of the message. Communication actions have proven to have a strong impact among the soil science community and beyond, and motivate and engage a wide range of stakeholders.

Activities, contests, and live performances are perfect tools to increase people's understanding of how soils are connected to their daily lives. Via a combination of social media posts, contests engaging all citizens, and media coverage, advocacy campaigns of the Global Soil Partnership have garnered the support of thousands of followers. Over the past ten years, hundreds of fact sheets, infographics, posters, videos, press releases, etc. have been prepared in over 30 languages and shared with various target groups through centralised websites.



Soil Awareness Workshop for students in Sathupally, Telangana state, India. (FAO)

Shaping soil health together, topic by topic

Every year since 2017, global science-policy symposia have been organised by the Global Soil Partnership to debate the primary threats to soils. In 2017, soil organic carbon loss was put forward, 2018 was dedicated to soil pollution and 2019 to soil erosion. In 2021, soil biodiversity loss and salt-affected soils were tackled, while soils for nutrition were discussed in 2022. Designed around the topic of each symposia, outreach activities take place throughout the year, culminating in the second half of the year with the World Soil Day (5 December).



Annually, global science-policy symposia convene to tackle diverse challenges facing soils by gathering academics, research institutions, decision-makers, and pertinent organisations to develop implementation plans and actions. (FAO/GSP)

Social media and written press

Social media has completely transformed the way people share and absorb information. It has become the fastest and easiest way to access news and stories around the world. This makes the media, including television, film, radio, the internet and, the traditional press, perfect for reaching a mass audience. The identification of different target audiences is key to tailoring the message through digital and outreach channels and encouraging people to take action. Social media kits are prepared by the European Union and FAO's Global Soil Partnership and shared though Twitter, Facebook, LinkedIn, YouTube, Flickr, TikTok, WeChat, Weidbo, Instagram and more - and posts are sent out to major corporate accounts and key stakeholders. Web stories and press releases are disseminated through the internet, news agencies and other official channels. These are widely taken up by major media wires and top-tier newspapers, magazines and specialised journals, thereby reaching all possible stakeholders.

Speaking up for soils through key awareness-raising platforms: International Year of Soils 2015 (IYS) and World Soil Day (WSD)

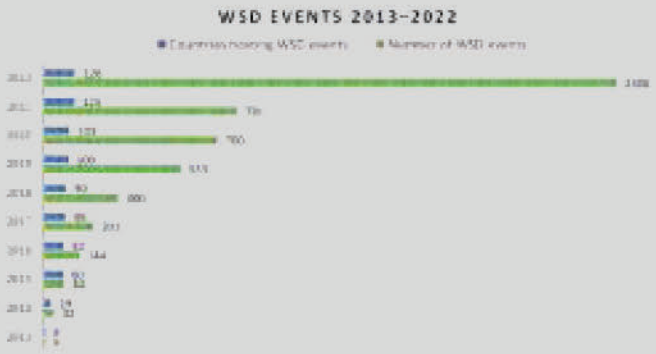
FAO's Global Soil Partnership (GSP) has contributed to the adoption of two awareness-raising platforms at the UN level: an International Year of Soils and turning the International Union of Soil Sciences' World Soil Day into an international day observed by the UN. Recognising that soils constitute the foundation for agricultural development, essential ecosystem services and food security and nutrition, after nearly three years of intensive consultations, the 68th UN General Assembly declared 2015 the International Year of Soils and designated the 5th of December as World Soil Day.

Through WSD campaigns, the GSP has sought to highlight the main pressures on our soils, create networks, and build stewardship for soil health. The development of WSD follows the evolution of the GSP's growth and increased capacity to foster action. Used both to increase awareness-raising momentum and as part of the organisation's strategy to upscale soil governance, WSD has become the key advocacy tool and the focus of strategic communication since 2015.

WSD has adopted a different theme each year to highlight areas needed for action – threats to soil resources – and provide a common focus to the communication campaign. Themes covered to date include 'Healthy soils for a healthy life' (2015), 'Soil and pulses, symbiosis for life' (2016), 'Caring for the soils starts from the ground' (2017), 'Be the solution to soil pollution' (2018), 'Stop soil erosion, Save our future' (2019), 'Keep soil alive, Protect soil biodiversity' (2020), 'Halt salt-affected soils, Boost soil productivity' (2021) and 'Soils, Where food begins' (2022).

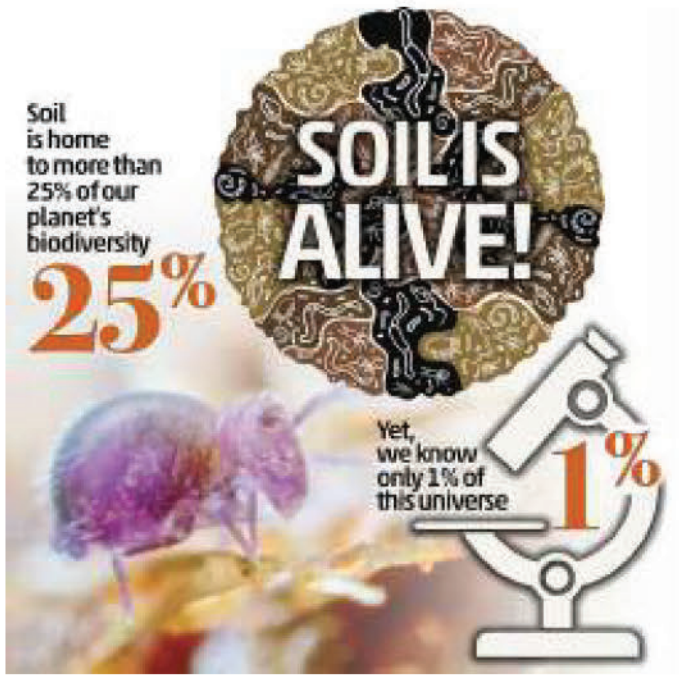
Since 2015, World Soil Day acts as a global celebration consisting of activities such as photography exhibitions, film festivals, lectures, panel discussions, puppet shows, food bazaars, tree planting, fashion shows, concerts, sports competitions, quizzes, drawing contests, seminars, workshops, speeches, public awareness campaigns and poetry recitals. These events involve not only FAO offices and GSP partners, but also international and national NGOs, politicians, international celebrities and influencers,

WSD engagement in a nutshell



- 7000 events (seven celebrations of World Soil Day and the 2015 International Year of Soils)
- 2.5 Billion Social Media outreach posts
- 15 Billion Media outreach campaigns

Advocacy activities organised in the last decade have been successful in placing soils at the centre of the policy debate. Supporting and promoting sustainable soil management is the only alternative to guarantee healthy soils for food security and the provision of ecosystem services.





The late King Bhumibol Adulyadej of Thailand kick-started the celebrations for the International Year of Soil and World Soil Day in 2015. World Soil Day, which is celebrated annually on December 5th, coincides with His Majesty's birthday and recognises his tremendous contributions to food security and sustainable development. (LDDT)

and local dignitaries, as well as farmers and soil practitioners. Yet, WSD is not just a day but an ongoing strategy. WSD campaigns constitute a yearly call to act, trigger international attention and build new working relationships with strategic partners and donors.

Recognising soil champions

At every World Soil Day since 2016, the **Glinka World Soil Prize** is awarded to those who are committed to solving acute national, regional or local problems of soil degradation. Glinka winners receive a cash prize of $15 000 and worldwide recognition.





Delivery of the Glinka World Soil Prize 2022 by QU Dongyu, FAO's Director-General to Ashok Kumar Patra, Indian Institute of Soil Science. (FAO/AB)

Since 2018, the **King Bhumibol World Soil Day Award** aims to encourage WSD promoters and organisers to facilitate challenging and outstanding celebrations across the globe. The award is given to mark exceptional efforts in organising high-impact celebrations. Winners receive a prize of $15000 and are designated as the top worldwide WSD organiser of the year!





The Nigerian Institute of Soil Science (NISS) receiving the King Bhumibol World Soil Day 2021 Award by the Princess Maha Chakri-Sirindborn of Thailand. (LDDT)

Why is soil important?

Human well-being is dependent on soils which generate a flow of goods and services to support human welfare. The value of the Earth's natural capital is infinite, as it forms the human life-support system. Soil functions or ecosystem services are general capabilities of soils that are important for various agricultural, environmental, nature protection, landscape architectural and urban applications.

Soil functions are essential for the biosphere, and yet soil is perhaps the most difficult and least understood matrix. The main ecological functions of soil include nutrient cycling, carbon storage and turnover, water maintenance, soil structure arrangement, regulation of aboveground diversity, biotic regulation, buffering, and the transformation of potentially harmful elements and compounds. Soil ecosystem services are diverse, valuable, and underappreciated. They are classified as provisioning, regulating, supporting and cultural services.

The seven major soil functions or ecosystem services listed in the literature are:

Soil and plant growth

Soil is a medium for plant growth or the production of bio-materials, whereby it combines with the other soil functions to anchor roots, and allows for the transport of water and nutrients to the root/soil interface. As an anchor for plant roots and as a water-holding tank for moisture, soil provides a hospitable place for a plant to take root. Some of the soil properties affecting plant growth include: soil texture (coarse of fine), aggregate size, porosity, aeration (permeability), and water holding capacity. Several variable properties of the soil that affect plant growth include how fine or coarse the texture of the soil is, the degree of aeration, the proportion of organic matter, and the ability to retain moisture. A healthy soil, with sufficient moisture, a good balance of gases, and plenty of organic matter is the ideal medium for plants to grow in, and permaculture gardeners have a primary focus on making sure the soil is hospitable to the plants they wish to grow.

Soil is a natural filter and regulator of water flow

One of the key functions of soil is to act as a natural purification system. Soil has the ability to filter, absorb and transform substances. Chemical compounds that are deposited on or in the soil can be trapped, thus preventing them from reaching rivers, lakes or groundwater resources. Contaminates can also be degraded or otherwise made unavailable to plants through a range of biogeochemical processes. However, high levels of toxins or severe soil degradation can disrupt these processes, leading to a loss of this function.

Soil is a key regulator of water flow. Soil absorbs much of the rain that falls on it, but the amount varies according to texture, structure, organic matter content and vegetation cover. Some soils act like a sponge, absorbing as much as 40% of their volume. Soil also acts like a tap by storing and releasing water for plants when needed. Urban planners are increasingly realising the capacity of soil to mitigate flood peaks, and are developing soil-based solutions to reduce the rapid transfer of rainfall to river channels.



Some of the main services provided by soil are the provision of food, feed for animals, fibre for clothing and wood for fuel or construction. As shown in this photograph from Inner Mongolia, nomadic herders have grazed livestock on the vast grasslands of the Mongolian Steppe for thousands of years. Through the seasonal movements of their animals, herders have sustained the economic and well-being of their communities without degrading their ecosystems. Simultaneously, these soils regulate water supplies, offset industrial emissions of greenhouse gases and provide a unique habitat for life above and belowground. (FAO/AHC)

Soil and water

Infiltration is the physical process involving the movement of water through the soil surface. The ability of water to enter the soil is related to its **porosity** (a term that describes the amount of space within the soil) and **permeability** (the ease with which liquids can flow through the soil). In turn, these two factors are governed by the texture and structure of the soil (**see facing page and** page 12), the initial soil moisture content, and the type of minerals (e.g. the presence of clay minerals that can cause cracks in the soil to close). Water that has infiltrated the soil can later be released through evapotranspiration or subsurface flow.

Percolation is the movement of water though the soil by gravity and capillary forces. Water that is in contact with air in the soil is called vadose water. Where the voids or pores in the soil are full of water, this saturated zone is called groundwater. Groundwater can move in both vertical and horizontal directions. The boundary that separates the vadose and the saturation zones is called the water table.

A spring is a feature in the landscape where the soil water table reaches the surface. Groundwater discharges from the soil to form the base flow of streams and rivers. This is especially important for maintaining a minimum level of water in channels during dry periods.

Soil protects our cultural heritage

In some senses, soil is like a time capsule. Much of the evidence of human heritage remains buried within the soil, awaiting discovery and study by scientists that study the past (e.g. archaeologists and palaeoecologists). The degree of preservation of such remains depends very much on the local soil characteristics and conditions. Soils that are very acid, very alkaline or waterlogged with low levels of oxygen have very little microbial activity and



Soil is an important medium for the preservation of historical remains, which are often excavated by archeologists. This striking image shows the partially excavated site of the Terracotta Army, near Xi'an in China. A collection of lifesize clay sculptures depicting the armies of Qin Shi Huang, the first Emperor of China. They were buried with him around 210 BCE in very fine soil. (KMG)

provide an ideal environment for preserving organic remains. Archaeologists use these historical artefacts and the layers in which they are preserved to build a picture of the communities that produced them and the environments in which they lived. Any disturbance of these layers, such as by drainage or ploughing, changes these conditions and leads to the rapid decay and loss of the material. Soils also have cultural connotations to many societies and underpin certain landscapes that have high tourist appeal (and thus have economic significance).

Soil is a habitat that supports life

It is estimated that around a quarter of all living organisms on the Earth uses soil as a habitat. Some live on top of the soil (e.g. in leaf litter) while others live below the surface. A few hundred grams of fertile soil can contain billions of bacteria, kilometres of fungal hyphae, tens of thousands of protozoa, thousands of nematodes, several hundred insects, arachnids, a few worms, and hundreds of metres of plant roots. The biodiversity of soils vary according to climate, vegetation, land use and soil properties.

The biota turn the soil into a biological engine. Living creatures are involved in most of the key soil functions, driving fundamental nutrient-cycling processes, regulating plant communities, degrading pollutants and helping to stabilise soil structure. Soil organisms also represent a crucially important biotechnological resource, with many species of bacteria and actinomycetes providing sources of medicine such as antibiotics.



Soil functions are the inherent capabilities of the soil, which include the physical stability and support of plant systems that underpin food, fibre (i.e. agriculture) and energy (e.g. wood, biofuel) production, water dynamics, filtering and buffering of pollutants, the foundation of human infrastructure, the supply of raw materials, the provision of cultural heritage and the promotion of biodiversity and habitats. (FAO)

Soil provides raw materials and is the foundation upon which we base our dwellings and infrastructures

Soil provides the support for the vast majority of human infrastructure. It supports buildings by providing the foundation or footings for walls, which in turn depend on the dynamic properties of soil. Soils with a good structure and clay texture are more stable. Interestingly, as for growing crops, a mix of particle and pore sizes is best for engineering. It is also important that the soil is stable in wetting and drying cycles so that cracks do not form. Soil also hosts much of the infrastructure on which our daily lives depend. These include water and sewage pipes, electricity and communication cables.

Soil also provides a range of raw materials such as clay, sands, minerals and peat. Clay is used for making bricks for construction and pottery items (e.g. earthenware), and was an early writing medium (clay tablets). Sun-dried mud bricks, made of a mixture of clay, silt, sand and water, mixed with a binding material such as rice husks or straw, are a common building material in several countries.

Due to its impermeable properties, clay is used as a barrier to stop water seeping away, which is why many ponds, paddy fields, reservoirs and canals and landfill sites are lined with clay.

Sand and gravel deposits are heavily used in the construction industry as aggregates in the manufacture of concrete, while sand is the principal ingredient in glass production and is used in sand-blasting to clean buildings and in sandbags to stop flooding. Like sand, gravel has countless uses, including wastewater treatment. Many roads across Asia have a gravel surface.

There is growing concern about the environmental impact of peat exploitation, and people are increasingly looking for 'peat-friendly' alternatives.

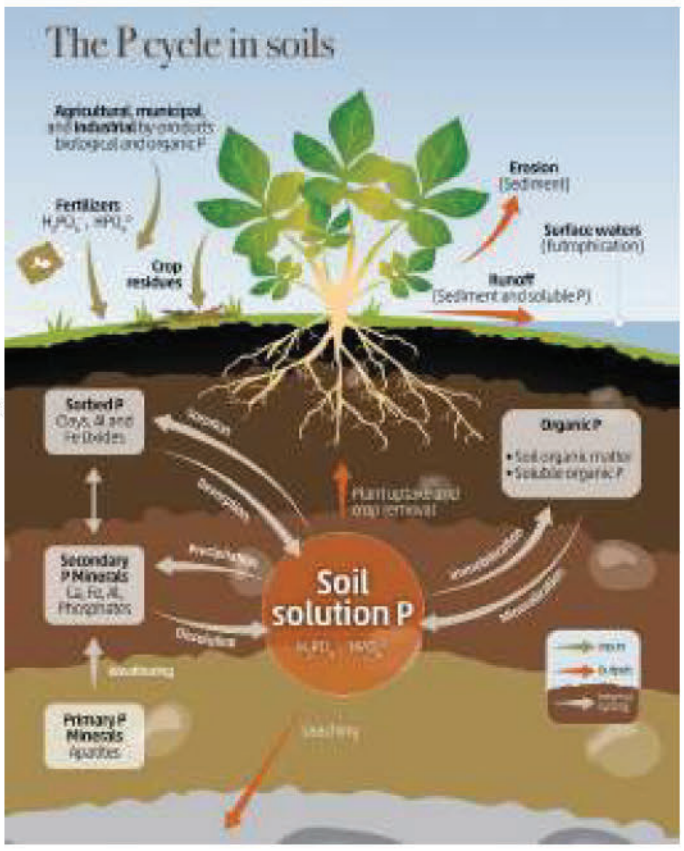


Ziggurats are massive pyramid-like structures that were built in ancient Mesopotamia (situated along the Tigris–Euphrates river system in Western Asia). Consisting of decreasingly sized terraces built on top of each other and accessed by ramps, they have a distinctive stepped appearance. The basic construction was a square or rectangular mud brick core, which was faced with thousands of glazed and baked mud bricks. Some ziggurats were more than 50 m in height. The picture shows the partially restored remains of a ziggurat from the ancient Babylonian city of Ur (now in Iraq). (H)

Soil and climate regulation

Soil is an important, yet often neglected, component of the climate system. It is the largest terrestrial store of carbon and only second after the oceans. In many parts of Asia, more carbon is stored in the soil than in vegetation. There is growing interest in the potential of soil to help mitigate climate change by offsetting industrial emissions through increased storage of carbon from the atmosphere. However, land-use change, in particular deforestation, is a major source of carbon dioxide emissions from the land. The most carbon-rich soils are peatlands, associated with wetlands. Grassland soils are also able to store a lot of carbon, while most soils in the hot and dry climate of Western Asia contain very low values.

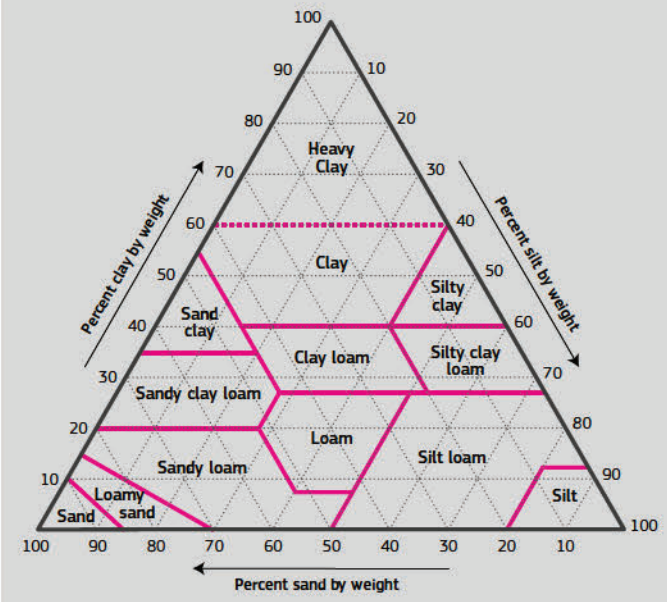
But the story is not just about carbon. Saturated peatland soils and flooded rice paddies are significant sources of methane gas, the second major greenhouse gas after carbon dioxide. Warming climates in the Himalayas and northern Mongolia are causing permanently frozen soils (permafrost) to thaw with resulting emissions of greenhouse gases. Finally, the over-application of nitrogen fertilisers can lead to increased emissions of nitrous oxide (N_2O), a potent and long-lasting greenhouse gas.



The phosphorus cycle in the soil-plant ecosystem. Phosphorus is found naturally in the environment from the weathering of rocks containing minerals such as apatite or in organic form from decaying plant remains and animal manure. On contact with water, it becomes soluble and can be taken up by plant roots to be transformed into organic compounds. When plants are eaten by herbivores and humans, the phosphorus then passes into their bodies. In the soil, phosphate ions (PO_4^{-}) can adsorp (or bind) to iron and aluminium oxides, clay particles and organic matter, making them unavailable to plants. It can also be lost due to leaching, runoff and erosion. In agricultural soils, phosphorus is added as a mineral fertiliser. Unlike other nutrients, the phosphorus cycle does not have a strong atmospheric component. Soil organisms regulate many processes within the cycle. (FAO/GSP)

Soil texture

Texture describes the proportion of different sized mineral particles that are found in a soil. The main particle size classes are broadly clay (< 0.002 mm), silt (0.02-0.63 mm) and sand (0.063-2.0 mm) [14]. Texture is measured by sieving, or by feeling the grains by rubbing the soil between your fingers. Particle size classifications may vary in different countries. Furthermore, large sand particles can be described as coarse, medium and fine.



Soil texture triangle – soils can be categorised according to their texture following particle-size analysis in a laboratory. Thus a soil with 40 % sand, 40 % silt and 20 % clay fractions will be categorised as loam. (FAO)



The Himalayas, the world's highest mountain range, is one of the most sensitive hotspots to global climate change. The Himalayan glaciers are the source of the Yangtze, Ganges, Indus and the Mekong rivers. Permanently frozen soil underlies much of the landscape. Thawing permafrost affects hydrology, vegetation, water chemistry, sediment loads and landslides, can strongly affect regional livelihoods and economies. (LG)

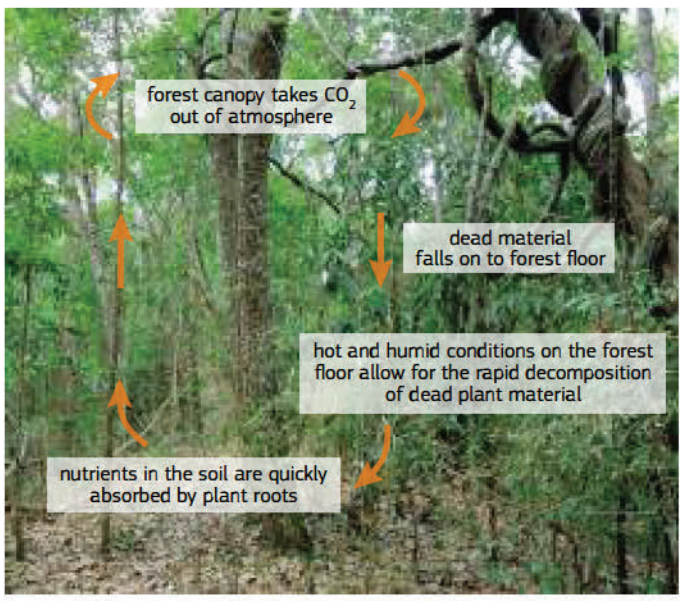
Soil as a regulator of the biogeochemical cycles

Soil plays a crucial role in a number of natural biological and chemical cycles that are essential for life. All chemical elements occurring in living organisms are part of one or more biogeochemical cycles. Nitrogen, carbon, phosphorus (see above), sulphur and a range of essential nutrients, are continuously recycled between the soil and plants, geological deposits, water and the atmosphere. The intensity and duration of these biogeochemical exchanges (fluxes) varies from place to place and is regulated by soil characteristics, land use and climate. The water cycle is also conditioned by soil.

The graphic below demonstrates nutrient cycling in humid tropical rainforests that are typical of large parts of southeast Asia. Hot, damp conditions on the forest floor aids the rapid decomposition of dead plant material. This provides nutrients to the soil that are then easily absorbed by plant roots. However, as these nutrients are in high demand from the rainforest's lush vegetation, they do not remain in the soil for long. This rapid consumption means that nutrients in the soil are concentrated near the surface. If the forest vegetation is removed, the flow of nutrients from the vegetation to the soil is interrupted causing the soils to quickly lose their fertility. The majority of cleared forest can only be used for agriculture if additional inputs of nutrients in the form of fertiliser, manure or compost are added.

Human activity is having a marked impact on the major nutrient cycles. Excessive amounts of phosphorus and nitrogen fertiliser can be detrimental to aquatic ecosystems while changes in land use affect the carbon cycle.

See pages 22-25 for more information about the main soil nutrient cycles.



As shown by this example from Northern Thailand, most carbon and essential nutrients in humid tropical rainforests are locked up in the living and decaying vegetation. Organic material is recycled so quickly that few nutrients remain in the soil. (A)

Soils and the provision of food, feed, fibre and fuel

One of the most widely recognised functions of soil is the medium in which most plants grow – although there are a few plants, such as orchids, that can grow without soil!

In turn, many of these plants are used by people directly as food. When systematically cultivated and harvested, such plants are referred to as crops. Other plants are not consumed by humans but are eaten by animals – these are often referred to as feed crops (e.g. grass). Other plants are cultivated for their fibres (e.g. cotton for cloth, wood as timber for construction). Many plants provide fuel for cooking and heating (e.g. trees, olives, sunflowers, etc.)

Food security is a key issue in many parts of Asia. While large areas have naturally productive soils, low soil fertility can contribute to rural poverty and poor nutrition. At the same time, increasing affluence, coupled with growing populations, gives rise to a demand for more protein-rich food and better nutrition.

This has enormous implications for agricultural productivity, which in turn drives the overexploitation of soils and pressure for land use change. Variations in soil-forming factors (see pages 32–41) mean that many soils in Asia have severe limitations for growing food crops because they are too shallow, too wet, too dry, too acidic or too salty. Other soils may be lacking in nutrients due to strong weathering processes. However, while some soils may be unproductive for food crops, they may support other sectors, such as rubber production.

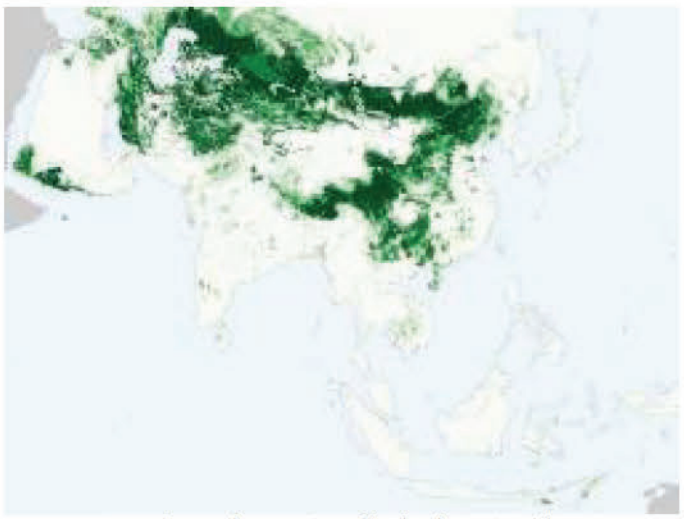


As shown by this landscape in Armenia, woodland covers around 18% of Asia (excluding the Russian Federation). They are an important source of fuel and construction materials. After the Russian Federation, the Lao People's Democratic Republic, Bhutan and Brunei have the most forest cover in Asia. (PM)

Food: Asiatic cuisine reflects the range of terrestrial plants that are grown in diverse landscapes across the continent. Rice is the principal staple food and some 90% of rice is produced and consumed in Asia [15]. Key rice-producing countries are China, India, Indonesia, Bangladesh, Viet Nam, Myanmar, Thailand and Philippines. Wheat and maize (corn) are the principle cereals after rice. Other minor cereals are barley, sorghum and millet. The continent produces nearly 40% of the world's sugar. China, accounts for more than 20% of the world potato harvest. Palm is widely grown in Western and Southeast Asia. South Asia is the largest consumer of pulses (beans, lentils and peas) in the world [16]. Some other important foodstuffs are: sugar crops: sugar beets, roots and tubers: potatoes, sweet potatoes, cassava and carrots, oilseeds: coconut, soybeans and rapeseed, fruits: citrus, bananas, apples and pears, mangoes and pineapples, vegetables: cucurbits, tomatoes, cabbages, eggplants, spinach and mushrooms, spices and condiments: onions, garlics, ginger, chilies and peppers, nuts: groundnuts or peanuts, and beverages: tea and coffee.

Feed: Across Asia, animals are a source of food (both meat and dairy), provide transport and, in some regions, a source of power (for tillage and processing crops). Demand for livestock products is growing rapidly although there are concerns in some sectors about the greenhouse gas emissions from industrial livestock production. The tern "fodder" is used to denote foods given to the animals as opposed to "forage", which is what they eat naturally for themselves. The former includes hay, straw, silage, pelleted feeds, oils, grains and legumes. It is estimated that cows and sheep need 8 kg of grain for every 1 kg of meat produced while chickens need only 1.6 kg of feed to produce 1 kg of meat. The implications are that large areas of soil are being prioritised to produce animal feedstocks.

Fibre: Soil supports plants that provide fibres that are used for textiles, cordage, paper making, packing, thatching, and the manufacture of baskets, mats, and wickerwork. Cotton is Asia's world's most widely used natural fibre. Cotton is used for textile and apparels and stuffing of pillows and cushions. Jute is grown in the Ganges and Brahmaputra valleys of India and Bangladesh and primarily produces coarse fabrics: burlap, twine, gunny bags, paper and insulation. Flax provides a finer fabric: linen cloth, canvas, carpets, threads, strong twine, cigarette paper and fine writing paper. Hemp was originally native to Asia and is widely used to produce cordage, paper, cloth, fishing nets, mattings, cot stringing, bags, ropes and coarse canvas. Hemp is used increasingly in agro-textiles, car panels and fibreboard. Bamboo produces laminated panels, boards, pulp, paper, mats, prefabricated houses and cloth. Silk is produced by silkworms that feed off the leaves of the mulberry, tassar, muga and eri. The world production of silk is heavily centred in China. Sisal is extracted from the leaves of the Agave cactus (*Agave sisalana*) and used in making ropes, mats, twines and nets.



Map showing the proportion of land under pasture (please compare with the map showing cropping on page 41). Dark shaded areas denote higher proportion of are under pasture. Note the low levels for eastern and central China, Russian Federation, southern and southeast Asia. (CIESIN/SEDAC)

Fuel: Soil provides fuel for cooking since millennia. Wood, charcoal, agricultural residues (straw, stalks, husks, bagasse, etc.), leaves, twigs, and grasses remain the primary source of fuel for cooking and heating in Asia. With 723 million m^3, Asia has the highest production of wood fuels, accounting for nearly 39% of global production [17]. Most of the biofuel (biodiesel and bioethanol) in Asia is produced from palm oil, coconut oil, used cooking oil or "gutter oil", corn, cassava, sugarcane and beet sugar. The momentum for biofuel production in Southeast Asian countries has slowed in recent years. China is the world's fourth largest ethanol producer and consumer.

What do we mean by fertile soils?

It is clear that healthy soils are at the heart of agriculture. However, most people are completely unaware of why a particular soil should be more productive than another or even how plants access the nutrients that are locked up in the soil.

The term 'soil fertility' refers to the inherent capacity of a soil to supply nutrients, minerals, water and air to the roots of plants in adequate amounts. Fertility should be viewed as a natural condition and reflects the main soil-forming factors and soil processes described in the next chapter. Soil structure and organic matter levels are critical controls of soil fertility.

The concept of productivity could be described as the ability of a soil to produce a crop. Artificial interventions to enhance fertility, such as the addition of fertilisers or drainage, may result in increased productivity or higher crop yields but at the same time may also upset the natural soil balance. This could include the rapid depletion of naturally available elements, the increased oxidation of organic matter or changes in biodiversity.

There is a general acceptance that plants require the presence of around fourteen elements in the soil to support healthy growth. These are broadly divided into macronutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, magnesium and potassium) which are required in relatively large amounts. Micronutrients or trace elements (e.g. iron, zinc, copper, boron, manganese, chlorine and molybdenum) are needed in much smaller quantities. This list is not exhaustive as plants also adsorb other elements such as sodium (essential for salt-tolerant plants), silicon (essential for some plants but beneficial for many), selenium (an essential element for animals) and cobalt (essential for the natural fixation of nitrogen by leguminous plants). Carbon, hydrogen and oxygen are generally very abundant and supplied as carbon dioxide (CO_2) and water (H_2O). With the exception of Cl and N, the major source of the other elements is mineralisation of organic matter and the breakdown of minerals in the soil.

See following pages for more details.

How do plants extract nutrients from the soil?

Plants take most nutrients from the soil by a process known as cation exchange which is dependent on soil moisture and sunlight. When plants are photo-synthesising, very fine hairs on their roots pump hydrogen ions (H^+) into water within the soil. These hydrogen ions displace positively charged cations (i.e. nutrients) that are attached to negatively charged soil and organic matter particles. Once these cations, and a few negatively charged nutrients (e.g. Cl^-) are present in the soil water solution, potential energy differences between soil water and roots move nutrients from a higher solute concentration (soil) to a lower solute concentration (plant). Low levels of certain elements can cause symptoms of deficiency in plants, while at a higher level the same element may cause toxicity. Conversely, an abundance of one nutrient may cause a deficiency of another nutrient.



Maintaining soil fertility is an important step in creating sustainable agriculture, food security and economic returns. In natural ecosystems soil nutrients more or less remain stable. However, the harvesting of crops removes some of the nutrients from the cycle thus, over time, depleting the soil. (PXFUEL)

Food Security

In recent years, the term 'food security' has been widely used by politicians and decision-makers to describe the availability of and access to food [18, 19]. A society is considered to be food-secure when its citizens do not live in hunger or fear of starvation. FAO estimates that the number of people without enough food to eat on a regular basis in 2021 is over 820 million, and increasing. Over 9% of the world's undernourished people live in Asia although this is projected to fall to just under 300 million people by 2030. Almost 25% of people living in Asia experience moderate (they face uncertainties about their ability to obtain food, have been forced to compromise on the quality of food) and severe (have run out of food or gone a day or more without food) insecurity. The 2021 FAO State of Food and Nutrition Report estimates that 30% of the population of Afghanistan and over half the population of the Democratic People's Republic of Korea are undernourished. [20].

Many factors influence this situation. Often not enough food is produced or imported to provide a satisfactory base for the diet. At other times, food distribution may be difficult due to poor infrastructure or conflicts. In the first case, efforts to enlarge the food supply are needed.

Increasing the productivity of arable soils can be achieved by increasing the number of crops grown each year or by increasing yields. However, both these approaches come with issues. Many parts of Asia suffer from soil nutrient depletion as the components which contribute to fertility are removed and not replaced and the conditions which support soil fertility are not maintained. This leads to poor crop yields. This is exacerbated in the tropics and sub-tropics where the nutrient content of soils is inherently low. Urbanisation and land take often consume productive soils forcing agriculture to move on to less productive, marginal land (most urban areas were originally located on fertile soils in order to ensure food security for their populations).

An additional, but often underestimated, element is food wastage. In 2022, a study produced for FAO and UNEP estimated that around 20% of the food is lost after harvest and before it reaches shops in Central and Southern Asia. A further 7% is wasted across Asia in retail and at the consumption level. [21].

Examples of soils and agriculture

Rice cultivation

Most people's perception of rice cultivation is an image of a paddy field, where young shoots of rice plants emerge from standing water. While rice can be cultivated in almost all types of soils, certain characteristics ensure higher productivity levels.

Generally, rice cultivation requires soils that are capable of holding water for long periods and can provide the crop with adequate levels of nutrients. Technically, this means soils with a good water retention capacity, which is usually provided by high amounts of clay and organic matter. A pH range of between 5.5 and 6.5 ensures the transfer of nutrients from the soil to the plant. This means that soils with a clay or clay loam texture are most suited for lowland rice cultivation.

As a result of the underlying geology, deep sandy soils are very common across Cambodia and especially the Lower Mekong Basin. Many of these soils, despite their high permeability, are increasingly used for rainfed rice production. These sandy soils are acidic, with low levels of nutrient, and due to their inherent hydraulic properties, standing water drain rapidly after rainfall. For rice cultivation, low water retention makes the rice susceptible to drought while the movement of water through the soil causes the leaching of nutrients, which impacts crop yields. In addition, hardsetting due to puddling can affect rooting depth.

Traditionally, sufficient rain fall is required to allow the initial cultivation of soils and for the accumulation of standing water in the fields, so that puddling and transplanting can proceed. Increasingly, direct seeding has replaced transplanting in many areas. Dry season crops can only be planted where sufficient soil-water or irrigation is available.

To combat these constraints, ensuring an integrated nutrient scheme while maintaining organic matter levels through the use of crop residues, manure or mulches are crucial. Data shows that most soils have low nitrogen and potassium levels. Studies have shown that the retention of rice straw at 2 $t\,ha^{-1}$ can boost lowland rainfed rice yields in Central and Southern Lao People's Democratic Republic by 50% while also maintaining potassium levels. Liming should be used to combat low pH. On the most marginal soils, rice is being replaced by dryland crops, trees, pasture or deep-rooted crops that could exploit more of the stored profile water than shallow-rooted rice crops, especially after the weakening of the plough pan. For more information, see [22].

As a postscript, a Cambodian rice, Phka Rumduol, was chosen as the "World's Best Rice" at several 'Rice Trader World Rice Conferences'.



Seed germination on the hardsetting surface of a sandy paddy soil in Cambodia having poor physical structure, low level of nutrients and low organic matter content. (SV)

Paddy fields

A paddy field is an enclosed piece of level land used for growing crops that can survive being flooded for a period during their growth cycle. The most well-known example is rice. Most dictionaries report that the word "paddy" comes from the Malay word padi, meaning rice plant. Contrary to popular belief, the cultivation of rice does not need a flooding stage. Instead, the water reduces the growth of less robust plants (weeds) that have no submerged growth state. Alternative methods of rice cultivation require different ways of adding soil nutrients as well as more weed and pest control during growth periods. Paddy fields require vast volumes of water, which is why that are generally located in floodplains or on terraces where water can flow due to gravity. When flooded, paddy fields are also sources of the greenhouse gas methane.

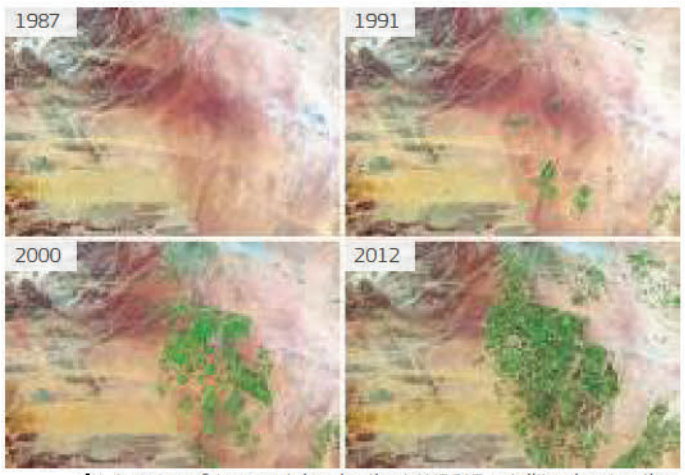
Farming in the desert

Outside the Fertile Crescent, farming in Western Asia, one of the most arid regions on earth, is a perpetual contest between man and nature. Rainfall is low, and much of it drains into the desert sands or quickly evaporates. In fact, over 25000000 square kilometres of the Arabian Peninsula contains almost no perennial rivers or streams, while its southern section is covered by one of the largest deserts in the world - the inhospitable "Empty Quarter."

Traditionally, agriculture in Saudi Arabia was confined to areas where water was found near the surface. This could be along dry river beds or close to natural springs. The presence of water supported intensive cultivation. In the 16th century, farmers in southwest Saudi Arabia began to grow coffee on terraced hillsides that stored rain water while date palms have been grown for centuries using springs from artesian water in oasis.

Since the early 1990s, there has been a surge in the development of centre pivot irrigation in Saudi Arabia (and other arid regions of the Earth). In this irrigation model, water is pumped from aquifers to the surface and then distributed to a crop via a sprinkler system that is fed by a pipe that rotates around a fixed point (hence the circular shape). These systems support a variety of agricultural crops such as wheat and forage crops (e.g. alfalfa).

While these green fields in the desert do permit agriculture in areas that otherwise would not be productive, there are concerns about the leaching of nutrients and risks of salinisation from the evaporation of irrigation water. In addition, these systems use non-renewable fossil water, which reflect precipitation that fell thousands of years ago. While water capture barriers and desalination plants are providing new inputs to the aquifers, there are questions regarding the long-term viability of such an approach.



A series of images taken by the LANDSAT satellite showing the expansion of pivot irrigation systems in arid land in Saudi Arabia between 1987 and 2012. In these images, healthy vegetation appears bright green while dry vegetation appears orange. Bare soils are white, yellow or dark pinks. Each agricultural field (circle) is about one kilometre across. It is clear that vegetation cannot grow in this area without irrigation. (NASA)



An example of a centre pivot irrigation system from the Tabuk region of Saudi Arabia. The picture clearly shows the sprinkler systems that are fed by a long pipe that extends from the central pivot point, which is connected to a water supply. (AA)

Cotton and the Aral Sea

Agriculture is a major feature of Central Asia and is highly relevant in regional development. According to the World Bank [23], agriculture accounts for more than 25% of the Gross Domestic Product (GDP) of both Tajikistan and Uzbekistan, while over 60% of the work force of Tajikistan are involved in agriculture. Overall, around 22 million people depend directly or indirectly on agriculture in these two countries. Land suitable for crop production accounts for only one-fifth of the total agricultural land of central Asia, with marked variations between countries (in Turkmenistan, only 4% of total land area is cultivated). Being largely arid, croplands in Central Asia are almost totally reliant on irrigation. In fact, more than 80% of cultivated land in Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan is irrigated.

The 20th Century saw a marked emphasis on intensive cotton cultivation in Uzbekistan, as well as parts of Kazakhstan, Tajikistan and Turkmenistan. The main requirements for cotton production are warm to hot weather, low humidity and long periods of sunshine (cotton needs around 180 very warm days to mature from seedlings to harvesting). Areas with such characteristics inevitably have a dry climate with high temperatures and low rainfall in the planting season. While cotton plants can grow in almost all well drained soils, higher yields are achieved in sandy loam soils that are rich in calcium carbonate (which means a pH > 7). In this regards, large parts of Central Asia have the correct combination of climate and soil, as well as a rural workforce, to support cotton cultivation. As a result, the region became one of the largest cotton exporters in the world.

Large amounts of water were extracted from the Amu Darya and Syr Darya rivers to support large-scale cotton cultivation. However, the diversion of water caused the Aral Sea to shrink. In 1960, the Aral Sea was the fourth largest lake in the world but since then, it has lost 75% of its volume while the coastline has advanced over 100 kilometres and is now divided into two sections.

In addition, excessive use of mineral fertilisers and pesticides disrupted the natural biological processes of soils. Excess phosphorous and nitrogen fertilisers were washed off the land to pollute rivers and aquifers. Poor land management practices has led to the build-up of salts in the soil (known as secondary salinisation), which is now estimated to affect more than half of the total irrigated land area. This is responsible for a decline in crop yields.

While entire communities have been established as a result of irrigation-based agriculture, alternative approaches are required as farming becomes increasingly difficult due to a decrease in soil health, failing irrigation infrastructure and reduced income from cotton.



Cotton is a soft, fluffy fibre that grows in a protective case around the seeds of the cotton plants of the genus Gossypium. Manual cotton harvesting, shown here in the Tashkent region of Uzbekistan, is slow but better preserves the cotton fibres. Manual harvesting is popular in small land holdings. (S)



Boats in Uzbekistan left stranded by the retreat of the Aral Sea. (MK)

Soil and nutrient cycles

As a recycler of raw materials, soil performs one of its greatest functions in the global ecosystem. In a simple sense, soil provides an environment to store, release and recycle substances. Of significance are substances that provide nourishment that is essential for the maintenance of life and for growth. These are known as nutrients. In this sense, soil an be considered as a sort of "Biogeochemical Reactor".

In addition to nutrients, the biological, chemical and physical processes also affect numerous other compounds that are found in soil. For example, these include the residues of pesticides, heavy metals, and other waste products. In this sense, soils can buffer people and the broader environment from the effects of harmful substances.

These biogeochemical processes, which are analogous to the water cycle, transform nutrients into forms that are easily available to plants. These processes can also lead to nutrients being leached to water bodies or treleased to air as gases. In some cases, these nutrients can be locked in the soil in a way that makes them unusable by plants.



Nutrients have a distinct 'life-cycle' in that they are created by a transformation process and stored in the soil. If conditions allow, certain elements are then consumed by organisms, which on their death, are returned to the soil so that the process can resume.

Each nutrient has a specific cycle but several elements appear in more than one cycle. Some cycles, such as those of nitrogen, carbon, oxygen and sulphur, involve transfers between the atmosphere, plants and soil while others may only involve movements belowground.

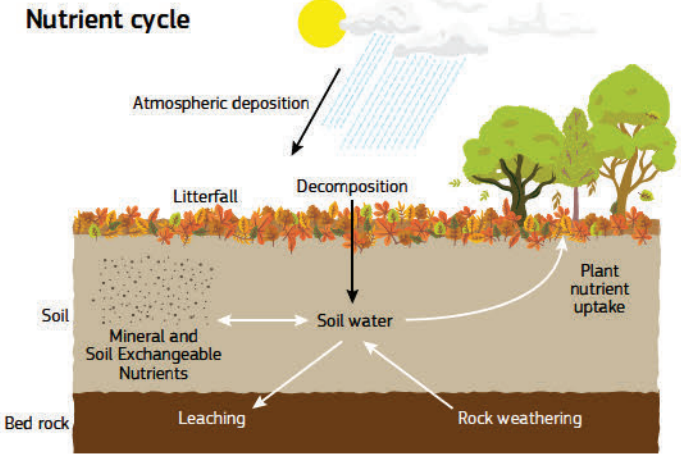
Generally, nutrients in soils can occur in two different forms: as organic, in combination with the element carbon (C) derived from living matter; or without carbon in an inorganic form. At the end, all nutrients become inorganic ions so that they can be taken by plants.

Storage in the soil in an inorganic form - during every growing season, plant roots only tap into a small fraction of the soil's inorganic store (e.g. Ca, P). These are derived from the weathering of minerals, rainfall or dust falling on the surface, the mineralisation of organic matter and the application of fertilisers. In these cases, the nutrients are made up of ions in the soil solution and exchangeable ions are electrostatically bound to clay minerals and organic matter;

Storage in living organisms below and above the ground – this involves nutrients stored in animals, plants and microorganisms. For elements with rapid cycles (e.g. K) the biomass store is very significant. On death, the remnants of living organisms are transferred to the organic pool;

Storage on and in the soil as residues of living organisms - this is the closing loop of the cycle and involves the decomposition of litter, manures and remains of organisms (see pages 28-29). The decomposition of the remains of dead plants, animals, and organisms by soil flora and fauna (e.g., bacteria, fungi, and insects) transforms their remains into simpler mineral forms, which are then utilised by other living plants, animals, and microorganisms in their creation of new living tissues.





Nutrients in soils may be derived from atmospheric deposition, plant decomposition and mineral weathering. Nutrients are retained by clay particles and organic matter where they can be slowly released into soil water solution for use by plants. However, nutrients may be lost from soils through leaching. (LJ, after CSS)

The main soil nutrient cycles and food production

The crucial role of soil in nutrient cycling can never be underestimated. The demand for food for the 4.5 billion people living in Asia (which makes up 60% of world population) is almost entirely met by land-based agricultural practices that depend on fertile soils. Crop yields in naturally fertile soils, where favorable chemical, physical and biological characteristics sustain plant growth, can be enhanced and maintained through the addition of nutrients. Usually this is done using organic and inorganic fertilisers.

Cropping systems in large parts of Asia are dominated by the cultivation of cereals. In the floodplains of Southern and Eastern Asia, the rice-wheat system is widely adopted. However, cereals are nutrient exhaustive crops. Proper nutrient replenishment is necessary for sustained food production. If practices such as returning crop residues or applications of manure or fertilisers are not applied in croplands, then intensive cultivation will slowly decrease the nutrient supply capacity of soil. In turn, the food production capacity will be lowered, thus increasing the risk of food insecurity.

As discussed above, soil is a nutrient reserve. Among the seventeen nutrients that are essential for plants (see facing page), fourteen are derived from soil (carbon, hydrogen and oxygen come from the atmosphere).

Nitrogen (N), phosphorous (P) and potassium (K) being the primary macro-nutrients, are most studied in terms of best management practices. Nitrogen is always a limiting nutrient and the mode of N transformation in soil can lead to some environmental problems. The global reserves of P are limited and its availability is greatly influenced by soil reaction. Potassium, a highly mobile element, is now slowly becoming a limited nutrient.

Calcium, magnesium, sulphur and range of micronutrients are equally important for biomass production. Besides these plant nutrients, soil is a huge reservoir of other elements as well. It harbours a huge mass of microbiome which make the soil a living entity, which is crucial in nutrient cycling. FAO projected a negative balance of soil nutrients (N, P_2O_5 and K_2O) in South Asia but a positive balance in Western Asia. Eastern Asia is likely to have positive balance in phosphorous and negative balance in nitrogen and potassium [24].

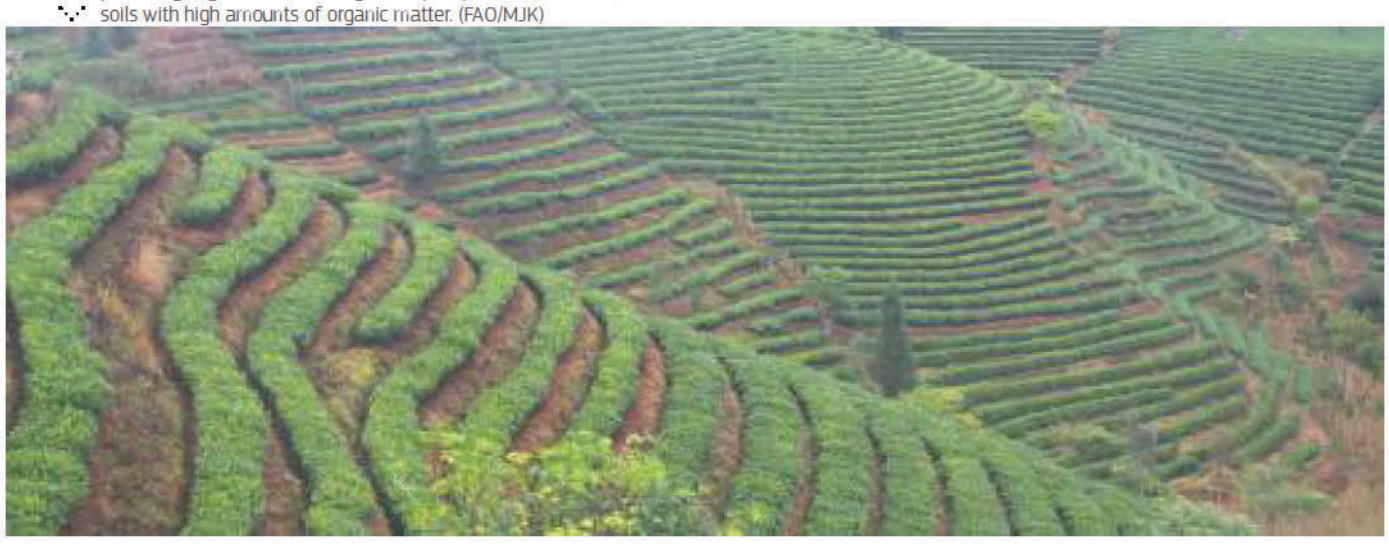
When the atmospheric N is fixed into to the soil, it is transformed to reactive N forms. Among which nitrate (NO_3^-) and ammonium (NH_4^+) can be utilised by plants. Only around 40% of stable nitrogen (N_2) is converted to reactive nitrogen that can be used by plants. The reminder is emitted to the atmosphere as the greenhouse gas nitrous oxide or transported to nearby water chanels or groundwater, with risk of pollution. There are various pools of phosphorous present in the soil. The greatest pool of P is occluded in primary or secondary minerals, while others are adsorbed by soil particles and in exchange by the soil solution, and present in the soil solution readily available for plant uptake.

East Asia (mainly China) has 5.4% of total global P reserve [25]. In 2016, Asia contributed to 50% of the total global production, with East Asia alone producing 42%. Similarly, East Asia consumes around 44% of of the world's phosphorous [26].

Potassium is the second most abundant plant nutrient after nitrogen in plant leaves [27], yet its application is often neglected in many Asian countries. Potassium is equally important as nitrogen and phosphorous but is slowly becoming a limiting nutrient for biomass production [28]. Worldwide, there is an estimated amount of 210 billion tonnes of potassium oxide reserve. Approximately 7.5% (16 billion tonnes) of K_2O can be recovered. In Asia, the Russian Federation and China have 11.4% and 10% of the global potash reserves, respectively [29]. The croplands of East, South East and Southern Asia have a negative balance of potassium [24].

Possible solutions to reduce negative nutrient balances involve maintaining natural levels through sustainable land management practices or combining organic manures with inorganic inputs. Other sources of inputs, such as organic household or agro-industrial waste, or nutrient-rich sewage and wastewater can be used, but care is needed to avoid contamination of soil from toxins and pollutants. Finally, a better understanding of the chemical and biological processes that render nutrients available to plants from soil could maximise the efficiency of their use.

Yunnan province in China is considered the world's oldest tea producing regions. Tea trees generally require well drained, acidic soils with high amounts of organic matter. (FAO/MJK)



The nitrogen cycle

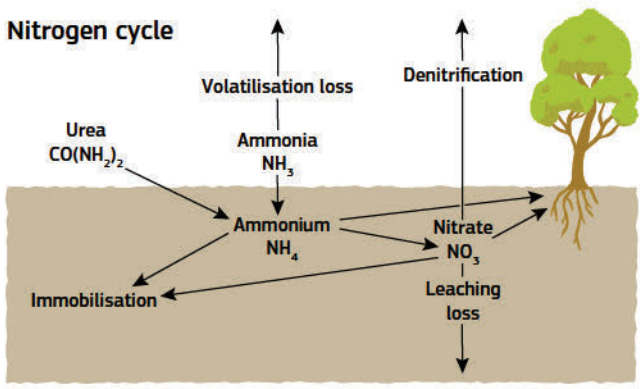
Nitrogen is a critical component of plants. It is a structural component of chlorophyll, nucleic acids (DNA, RNA) and proteins. Nitrogen in the atmosphere cannot be used directly by either plants or animals and must be converted into a usable state. Rainfall often contains substantial quantities of nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-). On contact with the soil, both ammonium and nitrate enter the soil solution easily and are absorbed by plant roots.

Another pathway is through the microbial decomposition of organic matter, which results in the mineralisation of organic nitrogen to release the NH_4^+ ion to the soil. Depending on temperature, moisture, the level of soil aeration and presence of some plant species, NH_4^+ is oxidised to NO_3^- , both of which are readily available to plants. Nitrogen may also occur in the soil as animal urine and through the application of mineral fertilisers.

Certain types of bacteria (e.g. Rhizobium) can convert atmospheric nitrogen (N_2) to ammonia (NH_3) through a symbiotic relationship with the root nodules of leguminous plants such as clover (*Trifolium*) or soybean (*Glycine max*). This process is known as nitrogen fixing. Plants convert the ammonia to nitrogen oxides and amino acids that form proteins and other molecules. In return, the plant provides sugars to the bacteria. In order to fix nitrogen, plants such as legumes maintain an oxygen-free (anaerobic) environment near their roots so that the bacteria can exist. Soil pH, organic matter levels and the availability of trace elements such as copper and cobalt can influence the distribution and activity of these specialised bacteria.

In natural ecosystems, plant growth is relatively slow and the annual uptake of nitrogen is comparatively low (e.g. 30 kg N ha^{-1}). Cultivated crops are much more demanding with nitrogen uptakes that are several orders of magnitude greater (e.g. 500 kg N ha^{-1}). In these cases, the natural nitrogen cycle is unable to maintain optimum growth and artificial inputs must be added to the soil.

Harvesting is a critical process as organic matter that would have normally decomposed on the soil surface is often physically removed from the field for processing. This means that there is an export of nitrogen and other elements from the soil to the marketplace. Corrections of N shortages through the addition of mineral fertilisers result in an increase in vegetative growth, much higher protein levels and greater yields of grain and fruit. However, excess amounts of N, above what can be used by plants, are often flushed out of the soil to accumulate in water bodies. Under the right conditions, nitrogen-driven bacterial growth can deplete the oxygen in nearby water bodies to the point that fish and other aquatic organisms die. This process is known as eutrophication.



The principle pathways and transformations of the nitrogen cycle. Nitrogen is important to all life. Nitrogen in the atmosphere or in the soil can go through many complex chemical and biological changes, be combined into living and non-living material, and return back to the soil or air in a continuing cycle. Animals and plants deposit organic nitrogen into the soil. Bacteria convert organic nitrogen to plant-usable ammonium and ammonium to plant-usable nitrates. Denitrification describes the bacterial decomposition of nitrate in the soil to atmospheric nitrogen while volatilisation turns urea fertilisers and manures on the soil surface into gases that go directly to the atmosphere. (LJ)

The Haber-Bosch process

Nitrogen, in a non-reactive form, accounts for 78% of the total gas proportions of the atmosphere. The Haber-Bosch process, named after its two German inventors, converts hydrogen and nitrogen to ammonia, which is the main source of nitrogen-based fertilisers. It has been argued, this is one of the most important industrial chemical reactions ever developed. The process made ammonia fertiliser widely available, and sparked a boom in crop yields. It is estimated that if crop yields had remained at 1900 levels, the crop harvest for the year 2000 would have required nearly four times more land than currently used. [31]

The phosphorus cycle

Phosphorus is another vital plant nutrient that forms the backbone of DNA and RNA molecules, forms cell membranes and regulates cell division, root development and protein formation.

Phosphorus deficiency can occur in areas of high rainfall, on acid, clayey or poor calcareous soils. Symptoms include poor growth and leaves that turn blue/green but not yellow. Due to the movement of phosphorus in plants, the oldest leaves are affected first. Fruits are small and taste acidic.

Due to its high reactivity, inorganic phosphorus is never found as a free element, and geologically occurs as phosphate rocks. In natural ecosystems, phosphorus is released by the decomposition of organic matter as compounds known as orthophosphates (e.g. $H_2PO_4^-$, HPO_4^-). These are rapidly adsorbed by soil particles or immobilised by phosphorus-consuming bacteria (e.g. *Aspergillus*). The pool of phosphorus that is readily available to plants is found in solution or loosely bound on to soil particles.

Because of low concentrations of P in soil solutions and the competition from soil microorganisms, many plants have developed a symbiotic relationships with mycorrhiza – a type of fungus – which in essence extend the root network and provide an improved pathway for the rapid transfer of phosphorus.

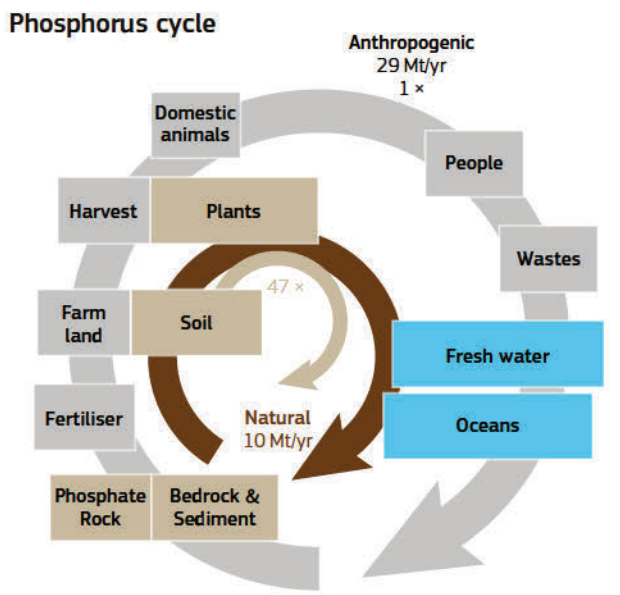
The highly weathered, iron-rich tropical soils of Asia tend to be deficient in plant-available phosphorus. The low pH together with high levels of iron and aluminium oxides, tend to immobilse phosphorus onto soil particles thus reducing its availability to plants. In such situations, large quantities of phosphorous fertiliser must be added to the soil to make a difference in crop yields. Lime-rich soils also imobilise phosphorus by precipitaiton of Ca-O minerals.

Among 34 Economic Co-operation and Development (OECD) countries, Korea and Japan had the highest P balances [30].

The future of phosphorus?

Due to the essential nature of phosphorus to living organisms, the low solubility of natural phosphorus-containing compounds and the slow natural cycle of phosphorus, the agricultural industry is heavily reliant on fertilisers containing concentrated phosphoric acids (H_3PO_4). About 50% of the global phosphorus reserves are in North Asia and the Middle East. Large deposits of phosphate-bearing apatite exist in China, Morocco, the Russian Federation and the United States of America.

Recent reports have suggested that production of phosphorus may have peaked, leading to the possibility of global shortages by 2040. However, some scientists now believe that a "phosphorus peak" will occur in 30 years and that reserves will be depleted in the next 50 to 100 years. [32]



Natural P cycle influenced by anthropogenic activities (adapted from [33]).

The role of soil elements in plant growth

Macronutrients

Macronutrients are elements that are essential to plant growth and are needed in significant amounts. For more details, see [34].

Phosphorus (P) is crucial to many plant functions, a key component of most fertilisers, and often lacking in non-fertilised soils. Phosphorus forms the backbone of DNA and RNA molecules and regulates cell division, root development and protein formation (see adjacent text). Phosphorus is responsible for crop yield increases.

Potassium (K) is also crucial to most plant functions including stomatal control, the maintenance of turgor pressure and charge balance during selective ion uptake across root membranes. It is also an enzyme in many biochemical reactions. Potassium is highly mobile and is easily leached from leaves to be taken up in high quantities by soil microorganisms and roots. In soil, potassium may be found in minerals such as micas and feldspars, secondary aluminium silicates (e.g. illite) and some salts. Potassium is available when attached to clay and humus colloids and easily available when in solution. Potassium dissolved in soil solution as an ion is highly leachable, although loses of potassium from runoff and erosion is not a significant problem.

Calcium (Ca) is used to build cell walls in plants. It helps keep P available in the root zone by binding it with other ions. Because it is bound within cell walls, it does not leach from leaves nor circulate within the plant. Calcium deficiency leads to stunted plant growth, the curling of young leaves and death of terminal buds. Calcium can be easily leached from the soil and is largely absent in the soils of central Asia.

Magnesium (Mg) is the central atom of the chlorophyll molecule and is an important enzyme. It is very mobile in plants. Magnesium deficiency in plants causes yellowing between leaf veins. Low soil pH decreases the availability of magnesium to plants.

Sulphur (S) is needed for the formation of amino acids, proteins, oils and chlorophyll formation. It promotes nodulation in legumes.

Micronutrients

Micronutrients are elements that are essential to plant growth but are required in very low concentrations (< 100 µg/g). They are generally metabolically active in plants as important enzymes.

Iron (Fe) primarily originates from chemical weathering of minerals and is not absorbed by plants in appreciable quantities; the amount found in plants is several orders of magnitude lower than the amount in the surrounding mineral soil. Iron serves as an electron carrier in enzymes. It also plays a role in nitrogen fixation and chlorophyll formation. Its movements in soil are due to chemical processes rather than an association with organic matter or uptake by plants. The presence of iron oxide gives a reddish tint to soil horizons.

Manganese (Mn) is critical to many plant functions, including photosynthesis, respiration, and nitrogen metabolism. Manganese is generally plentiful in acid soil and may reach toxic levels if pH is below 6.5. It generally leaches out of acidic soils.

Zinc (Zn) is a key component of growth control hormones in plants and is used in protein synthesis. Almost half of the world's cereal crops are deficient in zinc, leading to poor yields while zinc deficiency is the 5th leading risk factor for disease in developing countries. Zinc in soils is tightly bound to magnesium.

Copper (Cu) is especially plentiful in acidic, sandy soils and is an important enzyme activator found mostly in the chloroplasts of leaves.

Boron (B) supports cell wall formation and stability, maintenance of structural and functional integrity of biological membranes, movement of sugar or energy into growing parts of plants.

Molybdenum (Mo) supports the uptake of nitrates by plants.

Chloride (Cl^-), like potassium, helps with water regulation in plant cells leading to productive cells.

Nickel (Ni) is needed for the conversion of urea to ammonia (NH_3) that can be used by plants.

Toxic elements

Artificially high levels of all elements can have harmful or toxic effects. **Aluminium (Al)** is not used in significant amounts by plants. In soils, it immobilises phosphorus and generally increases the acidity and concentration of cations. As for most elements, aluminium becomes toxic to some plants above 1 ppm and to most plants above 15 ppm. **Lead (Pb)** binds with organic matter in the soil and accumulates in certain organic tissues of plants. In high enough concentrations, it can cause brain damage in humans.

Other elements, such as arsenic (As), cadmium (Cd), and sodium (Na), can be toxic to plants if concentrations are high enough.

Soil carbon cycle

The biological carbon cycle

One of the most important functions of soil is its role in the terrestrial carbon (C) cycle by facilitating the conversion of atmospheric carbon dioxide (CO_2) to living matter and then its breakdown and release to the environment.

Biology plays a critical role in the movement of carbon between the soil and atmosphere. Through photosynthesis, green plants use solar energy and water to turn atmospheric CO_2 into carbohydrates (i.e. sugars, starch and cellulose), the principle compounds that are necessary to build up biomass for plants or the bodies of animals. Most carbon leaves the biosphere through respiration or the decomposition of organic matter.

Where oxygen (O_2) is present, aerobic respiration occurs, which frees the energy contained in the sugars and transforms carbohydrate 'fuel' back into carbon dioxide, which is released back to the atmosphere.

When oxygen is lacking, for example in soil that is saturated with water due to poor drainage, then microbial communities (e.g. Methanobacterium, Methanosaeta and Methanosarcina) catalyse the breakdown of organic matter (anaerobically). In these conditions, organic matter is broken down to produce methane (CH_4) and CO_2. Carbon dioxide and methane are important greenhouse gases that affect the Earth's climate. This makes soil an important component in the study of climate change.

Soil organic matter and carbon

Organic matter is often described as the 'life-force' of the soil. It creates pores in the soil which help the roots of plants to develop and stores significant amounts of water thus increasing the soil's capacity to withstand drought conditions. Organic matter can attract the ions of essential nutrients, which reduces the risk of valuable plant food being leached away. The same process can occur with certain pollutants, which limits the potential contamination of soil and groundwater. Finally, the biochemical structure of organic matter can help to buffer excessive acid or alkaline soil conditions.

The amount of soil organic matter is determined by a balance between biological inputs and decomposition. Depending on the climate and land use, organic matter can remain stable in soil for long periods. However, the level of organic matter in soil can be manipulated. Several land management practices, such as the harvesting of crops or drainage, remove carbon from the soil. Minimal or no-till cultivation, mulching crop residues, crop rotation, and inter-cropping with perennials all enhance the formation and increased storage of organic matter in the soil. The drainage of peatlands leads to significant losses of organic matter and emissions of CO_2 to the atmosphere and should be avoided.

It is generally accepted that most soil organic matter contains between 40 to 60% C (by dry weight).

Soil carbon and soil type

It is clear from the earlier texts on soil-forming factors and soil processes that organic carbon content will vary according to the type of soil. Organic soils, known as Histosols (see page 62), can contain close to 100 kg of carbon per cubic meter while Gypsisols, found generally in very arid climates and containing high levels of gypsum (see page 62), typically contain only around 1 kg of carbon per cubic metre.

In addition, SOC varies with depth and soil type. In Leptosols (shallow soils over hard rock or gravel – see page 63) virtually all of the SOC is located in the uppermost 5-10 cm. In contrast, Histosols can be several metres thick.

Soil organic carbon and soil functions

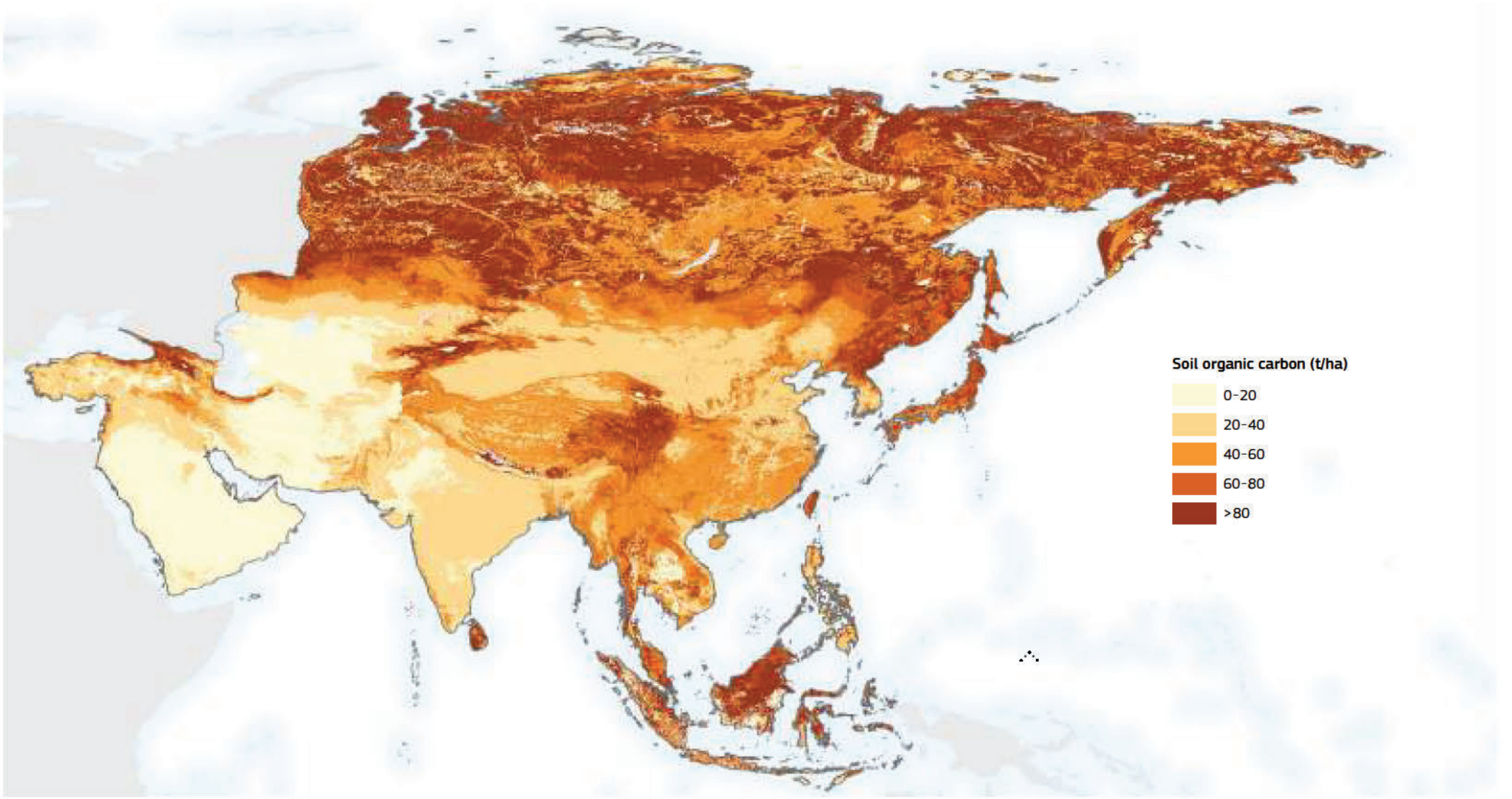
Low levels of organic carbon in the soil are generally detrimental to soil fertility and water retention capacity, and tend to increase vulnerability to soil compaction, which leads to increases in surface water run-off and erosion. Other effects of low organic carbon levels are a reduction in biodiversity and an increased susceptibility to acidification. Climatic conditions strongly influence both the trends and rates of accumulation and transformation of organic substances in the soil.





Upper right: An organic soil with high carbon content from peatland in Indonesia. The decomposition of organic matter has been slowed due to the saturation by water, which means that oxygen is not present. The photograph clearly shows the high moisture content and plant remains. (MA)

Lower right: Most mineral soils contain less than 3-5% organic carbon. In this profile of a shallow soil from Sri Lanka, almost all of the carbon is found in the uppermost 10 cm. (UV)



How much organic carbon is there in the soil of Asia?

From the Global Soil Organic Carbon Map, [35], soil carbon stocks for continental Asia have been calculated as 248 Gt C for the uppermost 30 cm of soil.

The peatlands of northern and southeast Asia hold the most soil organic carbon with lowest levels in the deserts of Western Asia.

Various estimates place the total terrestrial carbon pool of Asia (this includes above ground vegetation and also all soil organic carbon, not just that in the upper 1 m) at between 380-400 Gt. In this context, soil holds around 65% of the total Asian terrestrial carbon pool. However, this varies from almost 80% in northern boreal regions to around 50% in equatorial regions.

As shown by the Global Soil Organic Carbon Map on the facing page [35], one of the most striking feature of the soils of Asia is the huge range in values and the diversity in the distribution of soil organic carbon. The colours on the map correspond to the amount of organic carbon in the soil. Lighter tones indicate the lowest concentrations of organic carbon while darker tones indicate higher amounts.

The map presents the distribution of soil organic carbon stocks in Asia to a depth of 30 cm from the surface (0-30 cm) in tonnes of carbon per hectare (t C ha^{-1}). The resolution of the map is 1 km.

As discussed, soil organic carbon varies according to temperature, moisture, local soil conditions and land use. In this respects, four main zones stand out: the very low arid regions, temperate grasslands, tropical forests and grasslands and wetlands.

The largest amounts of SOC have been estimated to be stored in the peat soils of permafrost-affected regions of northern Asia, and the forests of southeast Asia. Here soils have more than 80 t C ha^{-1} the first 30 cm. Carbon accumulates in soils in huge quantities in the north due to low temperatures, which results in low biological activity and slow decomposition rates. In the equatorial regions, decomposition is reduced due to saturation by water. Organic soils are also found in the Caucasus, Kyrgyzstan, Japan and the Tibetan Plateau in China.

A roughly east-west trending band of soils with moderately high levels of organic carbon (i.e. 40-60 t C ha^{-1}) can be seen below the Boreal forests of northern Asia. This corresponds to the steppe zone where vast grasslands, receiving around 300 mm of annual precipitation, have resulted in the formation of zone of organic-rich soils stretching from the north of the Caspian Sea in the west, through Kazakhstan and Mongolia, to Manchuria in the east. Moderately highly soil organic carbon are also found in southeast Asia, eastern China, Japan, the Indus River and Sri Lanka.

Lower levels (i.e. 20-40 t C ha^{-1}), often reflecting semi-arid conditions, characterise almost all of India, central China and the Mediterranean region of western Asia.

In contrast, dry and hot regions, plant growth is naturally scarce, which means that very little carbon enters the soil. This gives rise to soils with low levels of soil carbon (i.e. < 20 t C ha^{-1}) in the deserts of the Arabian Peninsula, the Thar Desert, Iraq, Western Pakistan and much of Central Asia.

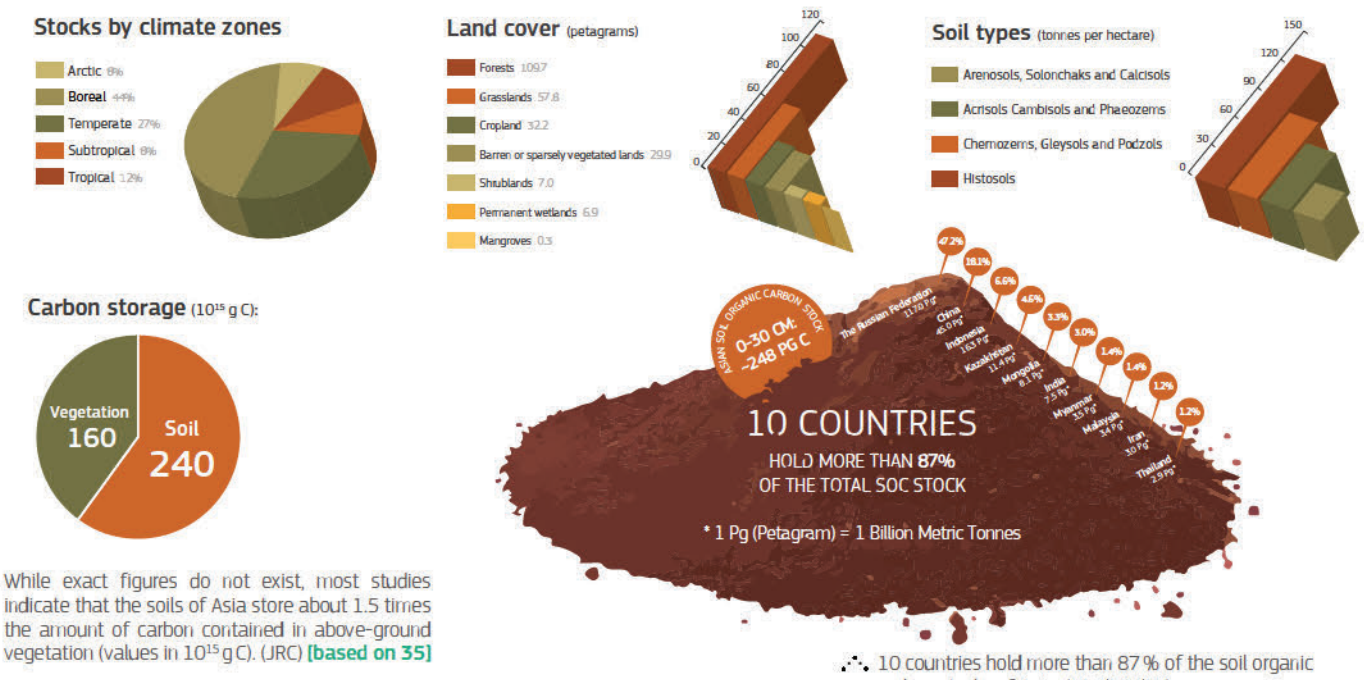
The reader should note that there are uncertainties in any estimate of soil carbon stocks at national and continental scales and the uncertainty of the information presented here is high. More confidence can be attached to information from regions with more detailed soil inventories.

Soil Carbon Sequestration

Sustainable soil management (SSM) practices centred on organic carbon sequestration are one of the most cost effective options for climate change adaptation and mitigation, for combating desertification, land degradation and food insecurity.

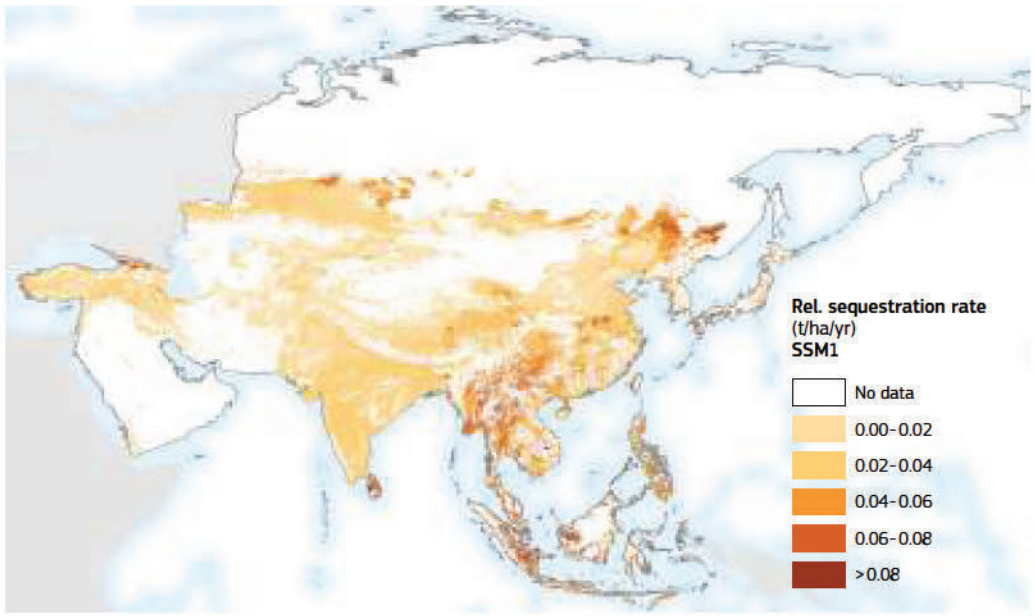
SOC sequestration is also an important strategy to improve soil health and the provision of ecosystem services. It is estimated that improved management of soils can offset between 5-20% of current global greenhouse gas (GHG) emissions. [36].

Data from the Global Soil Sequestration Potential (GSOCseq) Map [37] suggests that the soils of Asia have the potential to sequester a further 180 metric tonnes of carbon per year if high carbon-input sustainable soil management practices are adopted.

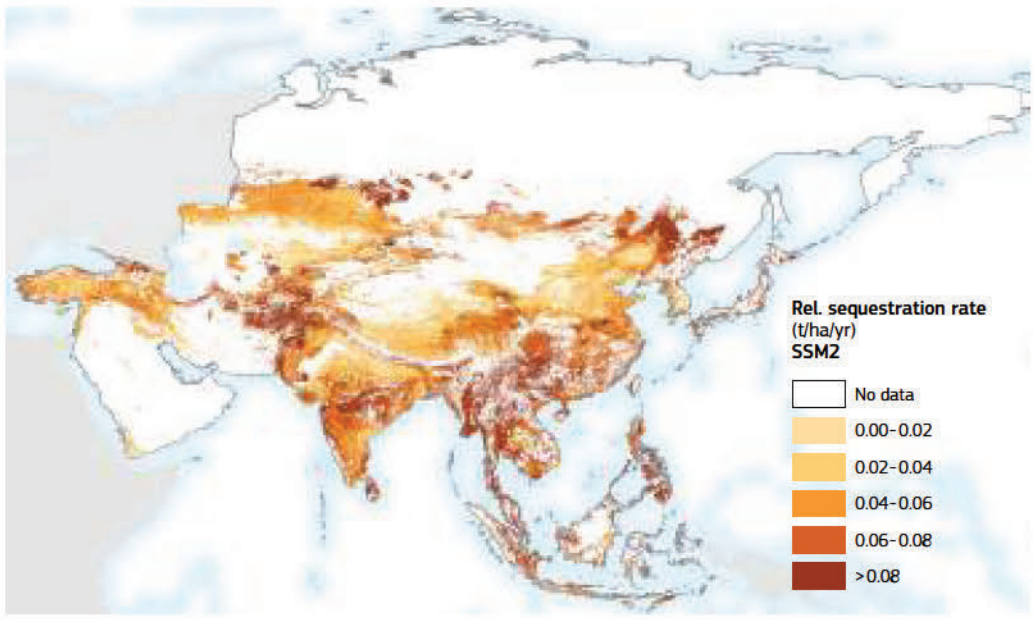


While exact figures do not exist, most studies indicate that the soils of Asia store about 1.5 times the amount of carbon contained in above-ground vegetation (values in 10^{15} g C). (JRC) **[based on 35]**

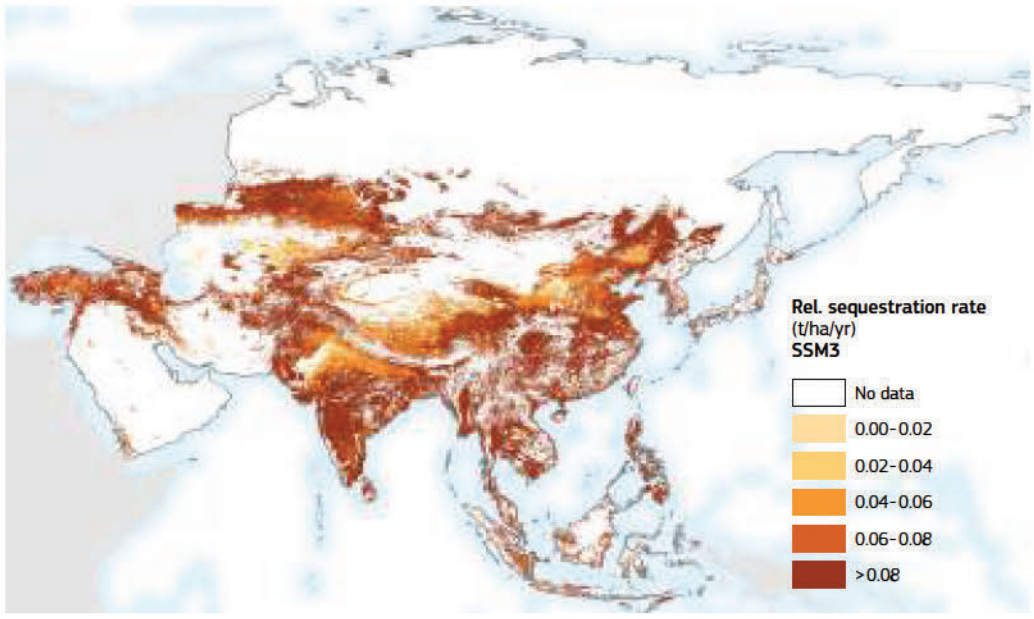
10 countries hold more than 87 % of the soil organic carbon stocks of Asia. (FAO/MM/YY)



a) Average annual rate of soil organic carbon stock change (tonnes/ha/year) after 20 years of implementation of sustainable soil management (SSM) practices that generate a **5%** increase in carbon inputs compared to business as usual (BAU) management, at a soil depth of 0-30 cm. **[37]** (FAO/MM/YY)



b) Average annual rate of soil organic carbon stock change (tonnes/ha/year) after 20 years of implementation of sustainable soil management (SSM) practices that generate a **10%** increase in carbon inputs compared to business as usual (BAU) management, at a soil depth of 0-30 cm. **[37]** (FAO/MM/YY)



c) Average annual rate of soil organic carbon stock change (tonnes/ha/year) after 20 years of implementation of sustainable soil management (SSM) practices that generate a **20%** increase in carbon inputs (SSM Scenario 1) compared to business as usual (BAU) management, at a soil depth of 0-30 cm. **[37]** (FAO/MM/YY)

Soil and the hydrological cycle

Soil acts as a hydrological buffer which stores and regulates the flow of water in the landscape. This allows various inorganic and biochemical compounds to be transported within and through soils.

The amount of water a soil can retain against the pull of gravity is called its water holding capacity. This property is closely related to the number of very small pores that are present in a soil that can excert capillary forces on water. Soil can regulate the drainage, flow and storage of water and solutes, which includes nitrogen, phosphorus, pesticides, and other nutrients and compounds dissolved in the water.

With proper functioning, soil partitions water for groundwater recharge and for use by plants and soil animals. Soil acts as a filter to protect the quality of water, air, and other resources. Toxic compounds or excess nutrients can be degraded or otherwise made unavailable to plants and animals. The water also acts as a solvent in which nutrients in the soil can be absorbed by plant roots. This ability of the soil to store moisture is particularly useful in locations where precipitation is intermittent. Increasing the water-holding capacity of your soil also helps preserve water, as less irrigation is needed. Planting ground cover crops reduces the rate of moisture evaporation from the surface of the soil, while contouring the land, by creating swales and other water-holding features, is another way to slow the movement of water off the land.

Water is held in the pore spaces of soil competitively and often concomitantly with air. Roughly speaking, water is assumed to occupy a quarter of total volume of soil in an average agricultural soil of top layers. Water influences many soil processes. Soil filters rainwater to supply fresh drinking water. Soil water serves as a resource pool for the growth of plants. It also supports soil fauna and biogeochemical processes occurring in soils. Soil water, especially near the soil surface, exhibits substantial variation in both time and space.

Entry, movement and retention of water in soils:

When water is supplied through rain or irrigation to a field, it seeps into the soil. This process of entering water into soil is called infiltration and the velocity at which water can seep into it is called infiltration rate. It is commonly quantified by the depth (in mm) of the water layer that the soil can absorb in an hour. The infiltration rate of a soil depends on various factors such as texture, structure, surface roughness and current moisture content. Coarse textured soils have higher infiltration rates than fine textured soils. Granular structured soils allow water to flow more rapidly in comparison to massive and compact structured soils. Rough soil surface traps water running over it and facilitates infiltration. Dry soils allow water to pass through more rapidly than wet soils.

The soil moisture content indicates the amount of water present in the soil. Soil moisture reaches the point of saturation when it is well drenched and all soil pores are filled with water. No air is left in the soil at this situation. If this saturated condition is prolonged, many crop plants may die. However, paddy crops can withstand such waterlogging state. When saturated soil is allowed to drain, water held in the larger pores, also known as gravitational water, percolates downward by virtue of gravitational force finding way towards groundwater. Water percolated below may either be retained in perched water layers or may reach aquifers or waterways. It may take some (2-3) days to drain water to reach field capacity.

Field capacity is the level of soil moisture when drainage has stopped and macropores of soils are filled with both air and water while the micropores are still full of water. Water remaining in the soil after gravitational water is drained out is called capillary water. Such moist and well aerated soil condition is considered to be ideal for crop growth. Gradually, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. When upper soil layers are drier, water can move upwards through the process called capillary rise. If additional supply of water to the soil is not available, it progressively dries out, leading to the state when plants start wilting. At a certain stage, plants cannot uptake water to meet their needs and ultimately die. Level of moisture at this point is called permanent wilting point. Although soils still contain some water, which is known as hygroscopic water, it is tightly attached to soil particles and plant roots are unable to take it.

Soil water availability to plants:

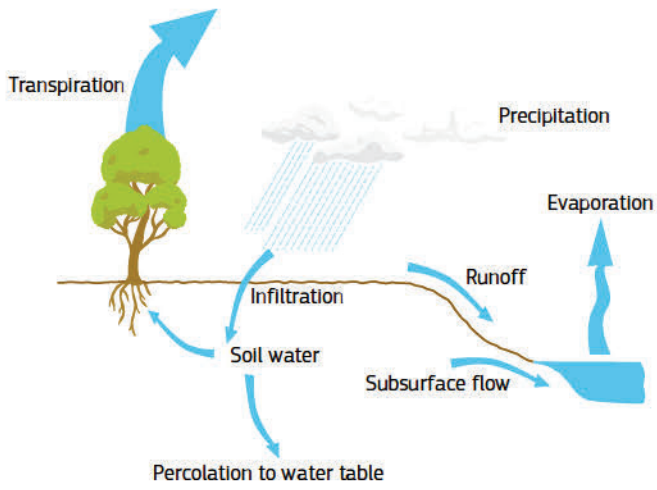
Soil is full of water when it is in saturated state. However, some water drains rapidly due to gravitational force of the earth and reaches below the root-zone before plants can use it. When the gravitational water drains away reaching field capacity, plant roots can draw water from the remaining water in the reservoir. When the soil dries out to reach permanent wilting point, the water remaining in the soil is no longer available to plants. Thus, the amount of water accessible to sustain plants is the difference between the amount of water stored at field capacity and the water that will remain in the soil at permanent wilting point. The amount of water held between field capacity and wilting point is referred to as the water holding capacity of the soil. Finer textured soils have more water holding capacity than coarser soils. As a general rule, plant available water is considered to be half of the water holding capacity of a soil. Organic matter in the soils may increase the water holding capacity and plant available water of soils.





These two profiles illustrate contrasting soil moisture conditions. The top profile, from China, is freely draining, well aerated, and situated on gently sloping land where excess water drains to the underlying rock and recharges the regional water tables (EM). The lower profile shows a typical low-lying, saturated wetland soil from Siberia where the water table is normally sitting around 20-30 cm below the surface. (SVL)

Hydrological cycle



Soil and the hydrological cycle. Soil acts like a giant sponge absorbing and storing water. The sealing of soil by artificial surfaces limits infiltration and restricts the ability of soil to mitigate against flood events by delaying the arrival of water to river channels. Sealed surfaces also facilitate the rapid transport of water to river systems, causing flood peaks to develop sooner. (CSS)

How do plants take water from soil?

Plants can use only the water that is in direct contact with their roots. For most crops in a deep uniform soil, the root distribution is concentrated near the soil surface. Plants such as grasses, with a high root density per unit volume of soil, may be able to absorb all available soil water. Conversely, vegetables, with a low root density, may not be able to obtain as much water from an equal volume of the same soil. As a result, vegetables are generally more sensitive to water stress than high root density agronomic crops such as corn, wheat and sunflowers. Over the course of a growing season, plants generally extract more water from the upper part of their root zone than from the lower part.

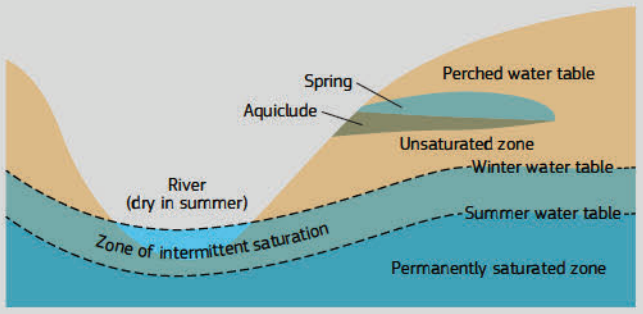
Water table, springs and watering holes

An important feature of the Asian landscape, especially in climates with low rainfall or distinct rainy seasons, are watering holes. Such features are important in supporting natural wildlife and grazing animals such as cows or goats.



A spring emerging from the ground in Azerbaijan. In addition to being the sources of rivers, springs are an important source of fresh water, especially in arid regions which have relatively little annual rainfall. (AQ)

Watering holes are depressions in the ground where water held by the soil comes to the surface. The upper limit or surface where the soil is saturated with water is known as the water table. The position of the water table reflects the surface relief but may vary due to topography, soil type and seasonal changes in precipitation or evapotranspiration. Springs, rivers, lakes and oases occur when the water table reaches the surface. Perched water tables occur above the regional water table when an impermeable barrier (aquiclude) prevents the downward flow of water through the ground. If a perched aquifer's flow intersects the land surface then the water is discharged as a spring.



Main components of the water table. (after WikiF/LJ)

Soil and land evaluation

Land evaluation

Decisions on how land is used have always been part of the evolution of human society. In the past, land use changes often came about by gradual evolution, as the result of many separate decisions taken by individuals. In the more crowded and complex world of today, the use of land is frequently dictated by government policies or economic factors. In Asia, many land use changes reflect the need to put environmental resources to new kinds of productive use or for developing previously unused (often marginal) lands. To ensure the suitability of any proposed change, there is a need for an effective and holistic evaluation or assessment process. Such actions are particularly important in the context of current debates on the competition for land.

The goal of land evaluation is to guide rational decisions on land use in such a way that the natural resources are put to the most beneficial use, while at the same time conserving fundamental ecosystem functions for the future. Such evaluations must be based on an understanding of both the natural environment and of the type of land use envisaged. There have been many examples of damage to natural resources and of unsuccessful land use enterprises through a failure to account for the mutual relationships between land and the uses to which it is put.

An important consideration is that land evaluation is concerned with an assessment of land performance for a specified purpose. For example, the suitability for a crop such as rice can be quite different to that for pineapples! FAO has developed a Framework for Land Evaluation which has been widely used throughout the world [38]. The approach involves understanding and interpreting the interactions between climate, soils, vegetation, topography and land use. To be of value in planning, land use considerations must be limited to those which are relevant within the physical, economic and social context of the area considered.

Soil characteristics and qualities in land evaluation

When land is mapped for resource exploitation, the areal units defined by the surveyor are normally described in terms of land characteristics (i.e. an attribute that can be measured or estimated). Examples include slope angle, rainfall, soil texture, available water capacity and biomass of the vegetation.

If land characteristics are employed directly in an evaluation, problems can arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not only by the angle of the slope but also by its length, vegetation cover, soil structure, rainfall intensity and other characteristics. Because of these interactions, it is recommended that the comparison of land with land use should be carried out in terms of composite indicators of land qualities.

In this context, a land quality indicator is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples include moisture availability, erosion resistance, flooding hazard, nutritional value of pastures and accessibility. Where data are available, aggregate land qualities may also be employed (e.g. crop yields, mean annual increments of timber species).

The soil assessment part of such an approach involves transforming soil characteristics into soil quality indicators before matching them with crop requirements.

Soil qualities and related soil characteristics

Soil qualities are highly relevant when it comes to the agricultural use of the soil and more specifically to specific crop requirements and tolerances. To illustrate the relationship, the above table outlines the soil characteristics needed to define the seven soil quality indices that are required to define land suitability.

Soil qualities		Soil characteristics
SQ1	Nutrient availability	Soil texture, soil organic carbon, soil pH, total exchangeable bases
SQ2	Nutrient retention capacity	Soil organic carbon, soil texture, base saturation, cation exchange capacity of soil and of clay fraction
SQ3	Rooting conditions	Soil textures, bulk density, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume
SQ4	Oxygen availability to roots	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts	Soil salinity, soil sodicity and soil phases influencing salt conditions
SQ6	Toxicity	Calcium carbonate and gypsum
SQ7	Workability (constraining field management)	Soil texture, effective soil depth/ volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans)

Assessing land suitability

The following text describes a typical land evaluation exercise. Seven key soil qualities have been identified as being relevant: nutrient availability, nutrient retention capacity, rooting conditions, oxygen availability to roots, excess salts, toxicities, and workability.

- Nutrient availability (SQ1) is decisive for successful low level and intermediate input farming. Important soil characteristics are soil texture, structure, organic carbon, pH and total exchangeable bases. For the subsoil (30–100 cm), organic carbon is less important.
- Nutrient retention capacity (SQ2) is important for the effectiveness of fertiliser applications and is therefore of special relevance for intermediate and high input level cropping conditions. Nutrient retention capacity refers to the ability of the soil to retain added nutrients against losses caused by leaching. Plant nutrients are held in the soil on the exchange sites provided by the clay fraction, organic matter and the clay-humus complex. Losses vary with the intensity of leaching which is determined by the rate of drainage of soil moisture through the soil profile. Soil texture affects nutrient retention capacity in two ways, through its effects on available exchange sites on the clay minerals and by soil permeability. The soil characteristics used to define this are organic carbon, texture, base saturation, cation exchange capacity, pH and cation exchange capacity of the clay fraction. Soil pH serves as an indicator for aluminium toxicity and for micro-nutrient deficiencies.
- Rooting conditions (SQ3) address various relationships between soil conditions of the rooting zone and crop growth. They include effective soil depth and effective soil volume and are related to the presence of factors that restrict the effective rooting depth or decreases the effective volume of soil that is accessible to roots. As soil depth/volume limitations affect root penetration and may constrain yield formation (roots and tubers), the following factors are considered:
  1. adequacy of foothold (i.e. sufficient soil depth for anchoring the crop);
  2. available soil volume and penetrability of the soil for roots to extract nutrients;
  3. space for root and tuber crops for expansion and economic yield in the soil; and absence of shrinking and swelling properties affecting root and tuber crops.

Relevant soil properties to be considered are soil depth, soil texture/structure, the presence of swelling clays, soil temperature and the presence of coarse fragments (stones) or surface crusts.

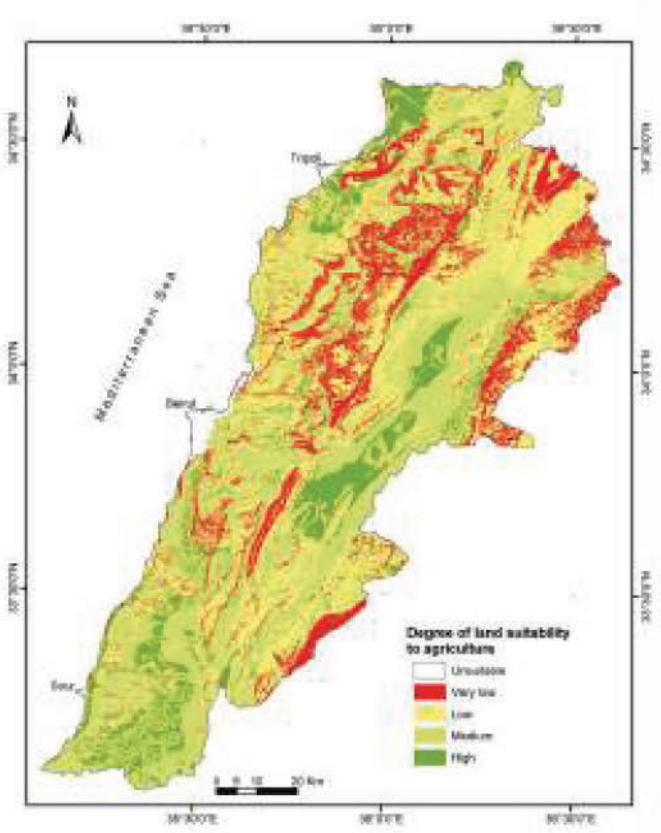
- Oxygen availability (SQ4) in soils is largely defined by the drainage characteristics of soils. The determination of soil drainage classes is based on soil type, soil texture, slope, movement of the groundwater table and the occurrence of waterlogging, periodic flooding or iron pans in the soil.
- Excess salts (SQ5), may cause salinity, is measured as electric conductivity (in dS/m) or as saturation of the exchange complex with sodium ions, which is referred to as sodicity or sodium alkalinity and is measured as exchangeable sodium percentage (ESP). Salinity affects crops by inhibiting the uptake of water. Moderate salinity affects growth and reduces yields; high salinity levels may kill the crop. Sodicity causes sodium toxicity and affects soil structure leading to a massive or coarse columnar structure with low permeability.
- Toxicities (SQ6). Low pH leads to acidity related toxicities (e.g. aluminium, iron, manganese toxicities) and deficiencies (e.g. phosphorus, molybdenum). Conversely, calcareous soils generally exhibit micronutrient deficiencies of iron, manganese and zinc and in some cases toxicity of molybdenum. Gypsum strongly limits available soil moisture. Tolerance of crops to calcium carbonate and gypsum varies widely. Low pH and high calcium carbonate and gypsum levels are mutually exclusive. Acidity related toxicities such as aluminium toxicities and micro-nutrient deficiencies are accounted for respectively in SQ1 and in SQ2.
- Workability (SQ7) or ease of tillage depends on several interrelated soil characteristics such as texture, structure, organic matter content, soil consistency/bulk density, the occurrence of gravel or stones in the profile or at the soil surface and the presence of rock outcrops or continuous hard rock at shallow depth. Some soils are easy to work independently of moisture conditions, other soils are only manageable at an adequate moisture status, especially for manual cultivation or light machinery. Constraints related to soil texture and structure affect low and intermediate input farming systems, while the constraints related to irregular soil depth, volume of stones and irregular soil depth affect mechanised land preparation and harvesting operations. Workability constraints are therefore handled differently for low/intermediate and high input agricultural systems. The workability soil quality includes physical hindrance to cultivation and limitations to cultivation imposed by texture/ clay mineralogy.

Agro-ecological zoning

FAO has developed the system of agro-ecological zones (AEZ) based on key characteristics of the climate, soils and topography [39]. For climate, the number of days during the year that rain-fed soil moisture is available when temperature conditions allow crop growth is calculated. This period is referred to as the reference length of growing period (LGP) and is derived from a water balance model. The soil quality indices described above can be calculated from local data, the Harmonized World Soil Database or SOILGRIDS – see page 136) while the topography and slope information can be derived from digital terrain models.

Calculation of land suitability index

Finally, the specific requirements for a particular crop can be compared against the agro-ecological parameters for each cell in the AEZ map. Land is scored from being very suitable to marginally suitable or not suitable at all. It is important to note that less suitable areas could become suitable on the basis of changes in land management practices, the introduction of farming technologies and climate change.



Land Capability Map of Lebanon. (TD)

Soil biodiversity

The United Nations Convention on Biological Diversity defines biological diversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" [40]. In this sense, we can define soil biodiversity 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.

Soil is literally teeming with living organisms of various sizes (see adjacent figure). It is estimated that between 25 to 40% of living organisms in terrestrial ecosystems are associated directly with soils at some stage during their life-cycle. These range from large, easily visible plant roots and animals, mites and insects, microorganisms that are so tiny you need a microscope to see them (e.g. bacteria and fungi).

Microorganisms are the primary decomposers of the soil, and perform much of the work of transforming and recycling old, dead materials into the raw materials needed for growth of new plants and organisms. Soil supports the growth of a variety of plants, animals, and microorganisms, usually by providing a diverse physical, chemical, and biological habitat.

Like the majority of life, soil microorganisms require some basic things to live, namely air, food, water and a habitat. A healthy soil provides all these and enables the organisms to survive and thrive. Organic matter provides the organisms with carbon, which they convert into energy, so keeping an abundant supply of organic matter on the soil, through composting and mulching, increase soil biodiversity and habitat for organisms. Soil is sometimes referred to as a biomantle, emphasising the fact that soil is a product, to a large extent, of biological activity. The majority of the vital soil functions described in the previous pages depend on the diversity of life that exists within it [41, 42].

Asian soils contain an extraordinary range of taxa and species with varying body sizes, populations and activity. Some animals that lack size often make up for it in numbers. Soil may benefit animals in a variety of ways. It provides shelter, a breeding ground, waste dump, source of food (animal and vegetable), dietary supplement (geophagy) and means of hygiene (dust and mud baths). In their use of soil, animals can change its characteristics. The mixing of soil particles (bioturbation), decomposition of organic matter and nutrient cycling are heavily dependent on biological activity.

By burrowing and nesting, animals such as termites, ants, earthworms, moles, rodents, mongoose, birds and even large herbivores, mix and aerate soil layers. They create passages that aid the infiltration of rain and hasten the recycling and mineralisation of nutrients, both by direct digestion, and by disturbing litter. In fact, many creatures bring organic matter from the surface and deposit it deep in the soil. The consequences for soil porosity, aeration, water storage, drainage, bulk density, erodibility and nutrient status are profoundly important, both ecologically and economically. Indeed, thriving populations of invertebrates and microorganisms are regarded as a cornerstone of soil health.

Soil fauna depends for their energy and nutrients on plants, which in turn depend on soils in the first place. Ground burrowing birds and mammals, together with moles, earthworms, and fungus-culturing termites (which make large earth mounds), could be regarded as 'ecosystem engineers'.

Understanding the relationships between soil biology and aboveground habitaits can have enormous practical significance. For example, conservation farming methods may need to consider the need to achieve a healthy population of organisms capable of effecting bio-tillage.

While soil biota may be out of sight (and possibly out of mind), taking steps to protect them may be doubly useful as efforts to protect soil communities are very likely to help conserve better-known endangered plants and animals that live aboveground.

For more information on soil biodiversity, please see the Global Soil Biodiversity Atlas [42] and the State of knowledge of soil biodiversity [43].

Organism size	Group	Known species	Estimated species	% described
	Vascular plants	350700	400000	88 %
	Macrofauna			
	Earthworms	7000*	30000*	23 %
	Ants	14000	25000 - 30000	60 - 50 %
	Termites	2700	3100	87 %
	Mesofauna			
	Mites	40000*	100000	55 %
	Collembolans	8500*	50000	17 %
	Microfauna ad microorganisms			
	Nematodes	20000 - 25000*	1000000 - 10000000*	0.2 - 2.5 %
	Protists	21000*	7000000 - 70000000*	0.03 - 0.3 %
	Fungi	97000	1500000 - 5100000	1.9 - 6.5 %
	Bacteria	15000	>1000000	< 1.5 %

Known and estimated number of species of soil organisms and vascular plants organised according to size. Values of estimated diversity comply with the published literature, and are supported by expert judgement. Asterisks indicate numbers of species that live in the soil (updated from [44]).



Indian Tiger Centipedes (*Scolopendra hardwickei*) can reach lengths of 16 cm whose body consists of bright and contrastingly coloured segments. Commonly found in southern India, it is a ferocious predator and its bite can cause swelling and drowsiness in humans! (HSB)



Fungi are an important part of soil biodiversity. This diverse group of organisms support aboveground vegetation and are closely interlinked with carbon and nutrient cycling. This 1964 postage stamp from Mongolia shows the mushroom of *Ixocomus granulatus*, a symbyotic fungus generally found in pine forests. (AS)



Termite mounds, such as this example in Southern India, ensure that the underlying nest maintains a constant temperature and humidity to support fungal gardens. Termites eat these fungi in order to help them digest the wood fibres that they consume. (SK)



Mangroves are a threatened habitat in many parts of Asia. They are home to many soil dwelling organisms, such as this this Mangrove crab,. In addition to bringing organic matter in to the soil, their burrows alter the topography and grain size, which allows more air to circulate within the soil. Removing crabs from an area causes significant increases in concentrations of sulphides and ammonium, which in turn affects the productivity of the mangrove forest. This suggests that mangrove crabs are a keystone species. (KS)

Soil is alive!

- Soil biodiversity reflects the mix of living organisms in the soil. These organisms interact with one another and with plants and aboveground animals, thus forming a web of biological activity.
- Soil biodiversity varies greatly across Asia as the species numbers, composition and diversity of a given soil depend on factors such as air, temperature, acidity, moisture, nutrient content and organic matter.
- Soils are conditioned by climate, altitude, soil parent material, land use and the presence of living organisms (especially humans).
- Soils provide an amazing habitat and may contain more than 10000 species per square metre.
- A single gramme of soil may contain millions of individual cells and thousands of species of bacteria. Bacterial biomass can amount to 1-2 tonnes per hectare in temperate grasslands.
- Soil organisms maintain critical processes, such as carbon storage, nutrient cycling and plant species diversity, and play a key role in maintaining soil fertility.
- Earthworms, termites and other soil organisms enhance soil productivity by mixing the upper soil layers, which redistributes nutrients, aerates the soil and increases surface water infiltration. Earthworms increase crop yields by 25%, on average.
- Japan and China has established a national eDNA Project to assess soil biodiversity.
- China is developing microbial-based bioformulations to improve soil quality and reduce soilborne diseases.

While there is a lack of data on the distribution of many groups of soil-dwelling organisms at global scale, what is available can be used to develop a simple index describing the potential level of diversity living in soils on our planet. The **uppermost map** to the right is an initial attempt from the Global Soil Biodiversity Atlas to denote global soil biodiversity levels based on the:

- distribution of microbial soil carbon [45]. This dataset was used as a proxy for soil microbial diversity
- distribution of the main groups of soil macrofauna [46]. This dataset was used as a proxy for soil fauna diversity.

The two datasets were then harmonised to a 0-1 scale and summed. The total scores were categorised into an index ranging from low (i.e. low levels of soil biodiversity richness) to high (i.e. significant level of soil biodiversity richness).

For Asia, the highest levels of soil biodiversity are predicted for the tropical soils of southeast Asia, western India and the eastern coast of the Bay of Bengal reflecting both humid-temperate and humid-tropical soils. Lower levels are found in cooler and drier soils (such as boreal and steppe climates). Where extremes in temperature and precipitation levels are found, soil organisms are generally limited (see western Asia, Gobi Desert).

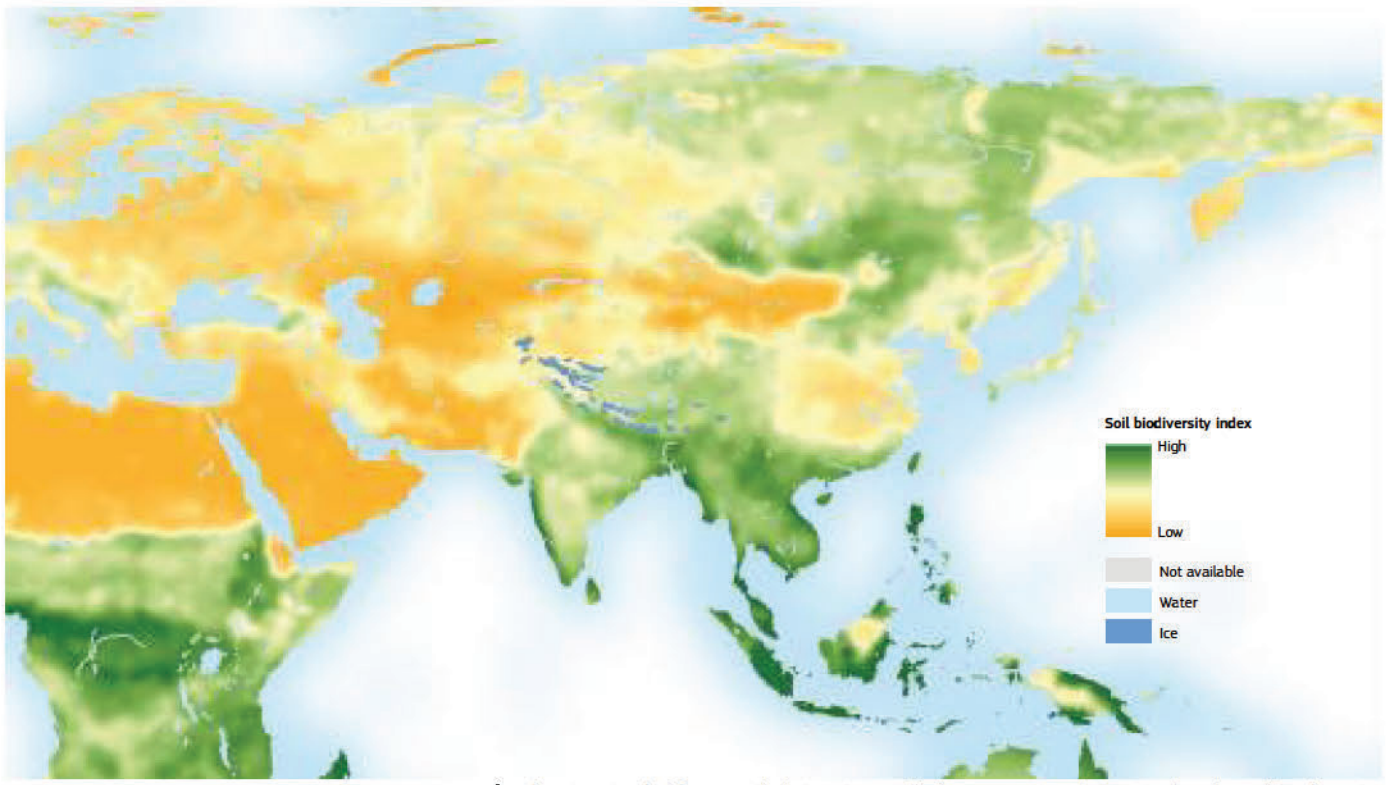
It is important to note that this is a simplistic exercise, based on two datasets, shows the distribution of only a few groups (proxies) of soil organisms. Further refinement could be provided by including soil microfauna (e.g. nematodes) and mesofauna (e.g. collembolans and mites). This map also gives a clear message of the need for significantly more research and data collection.

Furthermore, as numerous factors influence the spatial patterns of soil biodiversity, it is not easy to give a static representation of soil biota distribution on a map. For all these reasons, it is difficult to obtain a reliable large-scale map showing the distribution of all soil biodiversity.

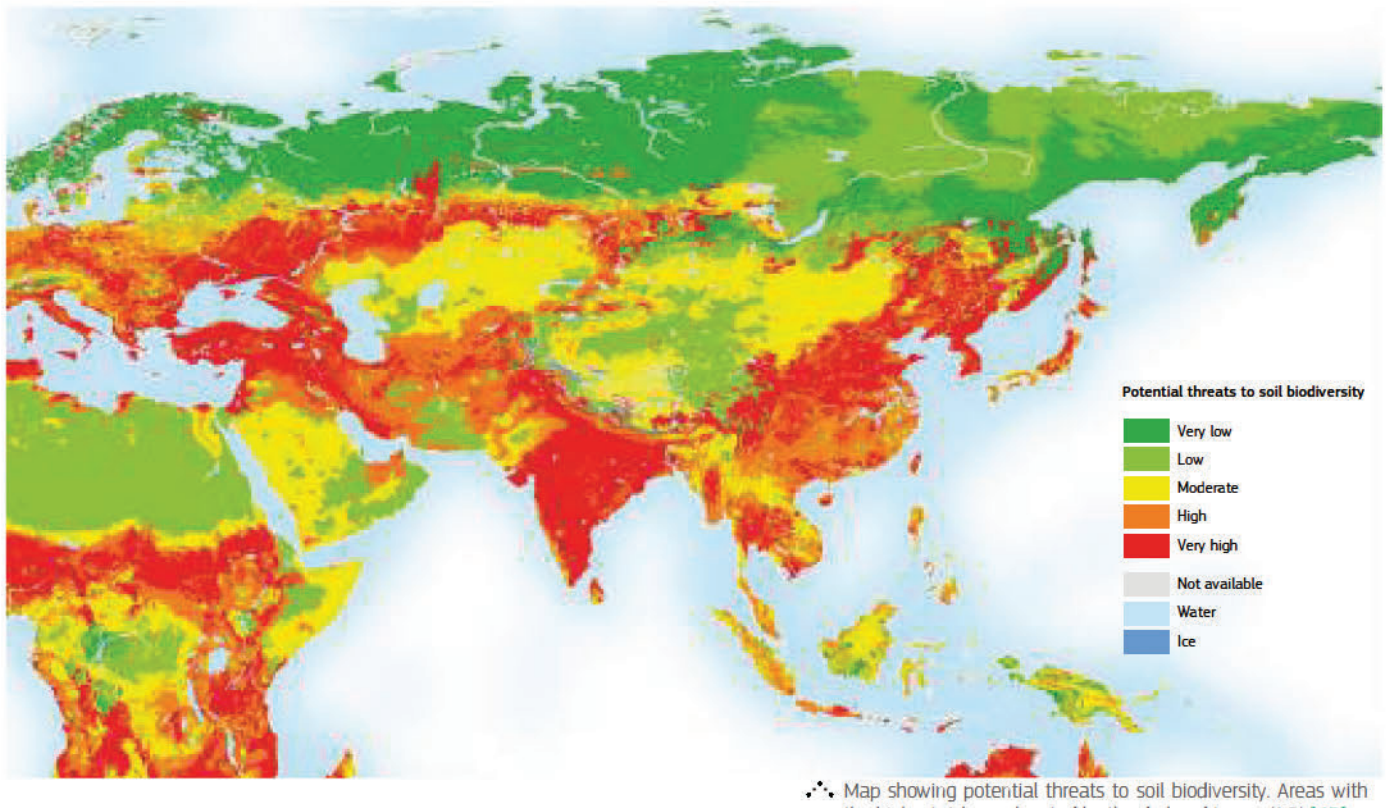
The map in the **centre-right** is the result of an initial attempt to denote levels of potential risk to soil biodiversity at a global scale. The pattern reflects the main potential threats to soil life (see pages 176-187). The areas with the lowest level of risk (green tones) are mainly concentrated in northern Asia, which is generally less affected by both direct (e.g. agriculture) and indirect anthropogenic effects.

At the opposite end of the scale, the areas with highest risk (red tones) are those with the greatest exposure to human activities.

An important point to highlight is the nature of risk shown in the map. As indicated, the potential rather than the actual level of threat has been mapped. This means that in the areas with high or very high levels of risk, soil organisms may not necessarily be in real danger. However, these areas present a combination of factors that lead their soils, and thus the organisms living in them, to be more sensitive to risk.



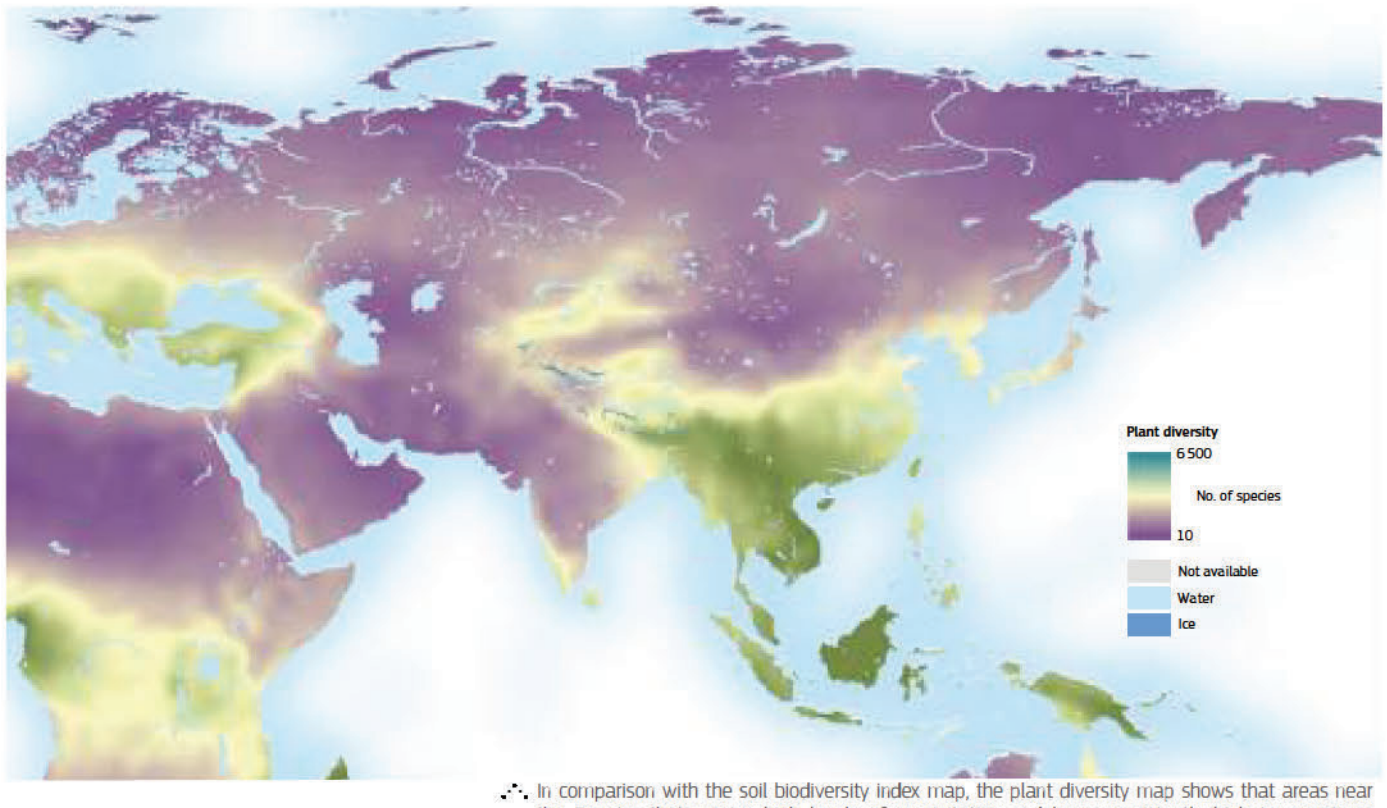
There's not only life on Earth, but in it as well. This map is an attempt to describe soil biodiversity across Asia. Darker green tones denote the likelihood of higher soil biodiversity while dark orange tones highlight low biodiversity. Note the striking contrast between western and eastern Asia. (AO) [42]



Map showing potential threats to soil biodiversity. Areas with the highest risk are denoted by the dark red tones. (AO) [42]



A single teaspoon of fertile soil may contain thousands of species, millions of individuals and hundreds of metres of fungal networks. (FAO) [42]



In comparison with the soil biodiversity index map, the plant diversity map shows that areas near the Equator that receive high levels of precipitation and have consistently high temperatures have the highest plant biodiversity. Outside of southeast Asia, plant diversity decreases in low in cold and dry conditions. It should be noted that higher levels are also found in countries facing the Mediterranean and Sri Lanka where temperatures are moderated by the vicinity to the ocean, seasonal precipitation and varied topography which create micro-ecoregions. (AO) [derived from 47]

Soil and society

Preservation of cultural heritage and landscapes

The soils of Asia are full of heritage [48]. Soil stores and protects much of our cultural heritage, including archaeological remains and landscapes. Over long periods of time, indigenous communities have moved across the landscape, making use of its resources and by their activities modifying the environment. These communities have left signs and products of their activities across the continent, buried in the soil. Objects preserved in soil have been used to understand history, often when no other evidence remains. The remains of dwellings can be identified from the outlines of ditches, foundation trenches and postholes in soil through changes in texture and colour. The presence of charcoal from hearths can be dated while the remains of animal bones, settlement debris and plant remains can give an insight into past environments. A glimpse into society and beliefs can be obtained by investigating burial practices, grave artefacts and fragments of pottery or art.

Soil characteristics are critical in determining the preservation of an object. Being of organic origin, wood normally decays under combined biological and chemical attack when buried in the ground or submerged in water. However, it can survive for very prolonged periods in very dry or a completely waterlogged environments. In the same manner, organic matter decomposes rapidly in well-drained soils where, in contrast, metal objects (metal weapons, ornaments, jewellery and coins) tend to survive. Acid soils are rather aggressive in decomposing artefacts, especially iron. Pottery, ceramics and glass tend to survive in most soil conditions.

In addition, soil conditions often shape distinctive habitats or, together with specific land management practices, produce specific habitats and characteristic landscapes that are valued by society at large. For example, the wetlands of Indonesia or the open grasslands of the Steppe regions are products of specific soil-climate interactions in the same manner as the tropical rain forests and oases in the deserts. Fertile soils give rise to agricultural landscapes such as the vineyards of Georgia or the olive groves of the Mediterranean region. It should be remembered that the location of most urban sites were selected because they also provided a stable food supply to their resident populations.

It is important that soils with high or potential cultural heritage aspects are managed in a manner that preserves these features. Cultivation practices should be controlled, for example, by avoiding deep ploughing if archaeological remains are in the topsoil. Similarly, the risk of erosion, acidity/alkalinity levels and desiccation should be controlled if possible. Cultural 'erosion' of such traditional knowledge about soil is still responsible for the loss of a significant number of languages and their unique information, knowledge and conceptual systems about humans and nature, often acquired through experiential and insight learning.

Culture originally meant cultivating the soil and raising crops. Soil is closely connected to the culture and civilisation of an ethnic group living in a given place, including their religion, thoughts, livelihood and health. Throughout history, soil has given birth to and fostered a variety of cultures, civilisations and livelihoods.

Fujiwara [49] wrote, "Because soil is the embodiment of the environment, I believe that cultures come into being with soil as the underlying factor". Fujiwara categorised the following types of cultures, each of which has soil at their core.

1. Rice paddy soil cultures: Cultures in which people flood soil to grow wet rice and other paddy crops. This includes ethnic groups in India, Thailand and China (e.g. Yue and Wu).
2. Loess cultures: Cultures built on loess, which is an alkaline soil. China's Han ethnic group is one example, producing crops such as barley, wheat and millet.
3. Oasis soil cultures: Cultures that live in extremely dry oases where soils are alkaline and saline. They include the Uighur, who cultivate fruit trees and vegetables.
4. Grassland soil cultures: Cultures based primarily on livestock farming, which is viable on dry grasslands. Soils are neutral or alkaline. This group includes nomadic Turkish and Mongolian groups.
5. Coral limestone soil cultures: Cultures built on red soil consisting basically of the limestone distributed along the southern edges of continents and on islands. This group includes the Austronesian cultures that produce coconut palms, breadfruit trees, banana trees and similar products
6. Laterite soil cultures: Cultures arising on acidic terra rossa from moist tropical rain forests to savannah regions. This group includes Austroasian sedentary farming cultures that produce crops such as sorghum, cassava, taro and yams.
7. Red-yellow soil cultures: Cultures arising on the acidic red-yellow soil of moist warm-temperate or subtropical regions. These South-East Asian cultures engage in slash-and-burn agriculture, and ethnic groups such as the Yao, Lahu and Lisu plant crops including dry rice, millet and mulberries.
8. Brown forest soil cultures, volcanic ash soil cultures: Cultures built on acidic brown forest soils arising in moist temperate-zone regions. This group engages in slash-and-burn agriculture in South-East Asia and includes Tungusic peoples who opened broadleaf deciduous forests. Crops include buckwheat and Japanese barnyard millet.
9. Podzol cultures: Cultures arising in lands with highly acidic podsols in moist cool-temperate zones and subpolar zones. This group includes the hunting and fishing cultures of Siberian ethnic groups, such as the Buryats and Tuvans, who speak Altaic languages.



Fruit cultivation system in the Kyoutou Region, Yamanashi, Japan which was officially designated as an Agricultural Heritage system in 2022. A key element is the maintenance of permanent soil coverage where native vegetation ground cover keeps the soil surface covered, which prevents soil erosion and leaching of nutrients. Grass roots provide deep aeration and absorb excess moisture. (FAO/Promotion Association for the Kyoutou Area)



Soil that has developed on aeolian sediments in Northern Jordan has protected the remains of an ancient hilltop archaeological site in a limestone environment. (BL)

It is important for people to protect the soil, their agriculture and the environment because the collapse of soil leads to the collapse of human culture, civilisation, livelihood and health. Soil is the basis of life, culture, civilisation, livelihood and health. If humanity cannot pass healthy soil to the next generation, human cultures cannot be passed on and will surely perish. We do not inherit the land from our parents; we borrow it from our children. If people do not have an ethic for the environment, including the soil, the water and the air, as we have ethics for people and society, the world will surely start to retaliate against humanity.



Globally Important Agricultural Heritage Systems (GIAHS)

The Globally Important Agricultural Heritage Systems (GIAHS) are agroecosystems inhabited by communities that live in an intricate relationship with their territory. These evolving sites are resilient systems characterised by remarkable agrobiodiversity, traditional knowledge, invaluable cultures and landscapes, sustainably managed soils that contribute to the livelihoods and food security of their communities. FAO has designated over 60 sites around the world as GIAHS.

For further information, please visit [50].

Farmers in some parts of Bangladesh that are affected by frequent and prolonged floods have developed a system of floating gardens made of water hyacinth. These provide an opportunity for the cultivation of vegetables and spices (okra, red amaranth, cucumber, Indian spinach, turmeric) during the monsoon months, when most of the land is flooded. Balls made from well decomposed water hyacinth plants, known locally as "Tema" or "Mada", are used for the germination of seeds and growing seedlings. (BS)

Soil as a source of raw materials

Construction

Soil is a foundation. It provides the physical stability for plants to skyscrapers. Soil has the ability to maintain its porous structure to allow passage of air and water, withstand erosive forces, and provide a medium for plant roots. Building foundations need to be on stable and strong soils. But soils range in strength - some are able to hold up a skyscraper, while others are unable to support the weight of a person. If the soil under a building is not stable, the foundation of the building will crack or sink, causing the building to collapse.

Various types of houses are built by using soil as a construction material. Soil is used for roofing and thatching houses in arid and semi-arid areas of Asia where other thatching material is unavailable. Houses with soil or green roofs are heat and cold absorbers and make the dwellings more comfortable to live in.

Clay is used to make bricks of different sizes, colours and shapes. Clay roofing has been used as roofing material for a very long time. Bricks made of clay are used for walls in modern and as well as ancient buildings. The Arg-e Bam (Bam Citadel) in the Islamic Republic of Iran is one of the the largest adobe building in the world. Brick-walled houses are very strong and again absorb heat and cold. Brick-walled houses are also durable, provided that timely maintenance is carried out. Plinthite, an iron-rich mixture of clay and quartz that hardens to ironstone on exposure to air is widely used as bricks in Southern and Southeast Asia (see page 65).

Loamy to clay soils are used for plastering straw houses while sand is used for mixing with cement for rendering, mortar and concrete making. Many dwellings in rural areas are plastered with soils mixed with crop straw to make it resistant to cracking.

Pisolithic gravel is used widely for roads and air strips. Rocky soil is used as final fill in roads, in most cases the outer cover of dam walls is made from sandy loam soils while the cores of dam walls are often made from Vertisols or other soils containing swelling clays.

Finally, many roads in rural Asia are unsurfaced with vehicles being driven on the soil surface. In wet conditions, traffic can cause the surface to deteriorate, making the road impassable.

Utensils

Many rural inhabitants throughout Asia use clay, especially kaolinitie, to make a range of pots, cups, kettles and pans. In fact, earthenware is one of the oldest materials produced by humans. While less strong, less durable and more porous than stoneware, earthenware is also less expensive to produce and much easier to work. Due to its higher porosity, earthenware containers must usually be glazed or baked in order to be watertight. Soils with very high kaolinite clay contents are thus seen as a valuable local resource. Many kinds of food and drink are prepared using such utensils while earthenware jars are also used to store grain or liquids.

Some researchers believe that glass was accidently discovered after large fires for metalworking were lit on sandy soils. Archaeological evidence suggests that the first synthetic glass was made in Lebanon and Syrian Arab Republic some 7 000 years ago. Some communities still make drinking glasses from sandy soil. Bags filled with sand are often used to slow the thawing of frozen items.

Ornaments and ritual/spiritual objects

Soil is used to make ornamental or decorative objects. Cosmetics for painting faces are often soil-based. Soil-made items are used for celebrating traditional beliefs and also serve as objects of worship. Clay tablets of Babylonian astronomical records (found in the lower Euphrates river in southern Iraq) date back to around 1 800 BCE and denote the regular passing of comments.



The Arg-e Bam (Bam Citadel) UNESCO World Heritage Site is the largest brick building in the world. The building was originally a large fortress on a crossroads along the Silk Road. It was almost completely destroyed by an earthquake in 2003. (AAL)

Recreation and tourism

Topsoil is used for levelling and filling gardens and lawns while sport turf is grown on selected soil types. Coarse sand is used for building golf greens and sand 'hazards'. In India, there is an understanding thar the use of red or black soils for cricket pitches will determine the bounce of the ball. Soils are critical in underpinning aboveground habitats and biomes, which draw visitors from all over the world. Most tourists are unaware that the distinctive habitats of giant pandas (*Ailuropoda melanoleuca*) in northeast China depends on a dark, organic-rich soil (a Chernozem). Referred locally as 'panda soil', it contains high levels of potassium that is vital to the growth and metabolism of giant pandas and its staple food, bamboo [51].

Medicinal and food/nutrients

Despite the incredible diversity in soils, very little is known about the genetic resources available. Many of the organisms that produce antimicrobial and other bioactive compounds that benefit human health are abundant and diverse in soils. Plant beneficial organisms collected from soils are being added to crops to improve plant productivity. One of the most successful advances in pest-resistant crops comes from an insect toxin found in soil bacteria.



Clay pots in Myanmar being covered with straw to protect them from the nightime dew before being fired in the kiln in the background. (TF)

Soil health

The underlying principles of "soil health" are that soil is not just a growing medium, rather it is a living, dynamic and ever-so-subtely changing environment. Analagous to human health, a healthy soil can be considered as:

- being in a balanced state of well-being in terms of biological, chemical and physical properties;
- not being diseased (i.e. not degraded, nor degrading), nor causing negative off-site impacts;
- functioning interactively with each of its qualities to reach its full potential and resist degradation;
- providing a full range of functions (especially nutrient, carbon and water cycling) and in such a way that it maintains this capacity into the future.

The term soil health is used to express the ability of a soil to:

- sustain plant and animal productivity and diversity;
- maintain or enhance water and air quality;
- support human health and habitation.

Different soils have different levels of health conditions depending on the inherited qualities and on the environmental settings. Soil health can be measured in terms of individual ecosystem services provided relative to a particular site. Specific aspects used to evaluate soil health include CO_2 release, humus levels, microbial activity and available calcium.

Factors adversely affecting soil health include issues such as deforestation, absence of soil cover, overgrazing, monocropping, inappropriate tillage, soil nutrient mining and pollution.

Good practices to maintain and/or improve soil health include permanent soil cover (conservation agriculture), integrated plant - animal production, crop rotation/association, controlled grazing, controlled carbon levels (relatively close to the limits set by soil type and climate), integrated nutrient management, maintenance of biological productivity (relatively close to the limits set by the soil environment), contour tillage and terracing to reduce erosion and a limitation/reduction on the level of contaminants.



Soils can be deemed to be healthy when their physical, chemical and biological characteristics are in good condition so that they can support a broad range of ecosystem services. This vivid photograph from Inner Mongolia, China, is an example of the sustainable management of soils in dryland grazing lands. (GIAHS - Aohan Dryland Farming System)

What is soil?

All of us have come into contact with soil at some time in our lives and most people are familiar with such terms as clay, silt, sand or even peat. In reality, soil is of a mixture of mineral and organic particles. Minerals are the products of weathering and related biochemical processes (see page 34) where rocks are eventually broken down into individual grains of sand, silt and clay. In parallel, plant remains, soil dwelling organisms and substances discharged by roots, are transformed into soil organic matter that binds to the mineral particles. Unlike hard rock, soil is full of spaces known as pores that can hold air and water. In certain situations, pores can completely fill with water, displacing all the air, which can cause plants to wilt or die.

Soils are divided into two groups: mineral and organic. Mineral soils are derived from weathered rocks and contain a limited amount of organic matter. Conversely, organic soils are composed predominantly of plant remains and contain very little mineral matter. Some organic soils are referred to as peat.

The soil in profile

If we dig a hole into the soil and look at the vertical section on display, we can observe different layers laying roughly parallel to the land surface. These layers are known as 'horizons' and are the result of a range of physical, chemical and biological processes that have acted upon the parent material over the lifetime of the soil. Relatively young soils, such as those on river sediments, sand dunes, or volcanic ash, may have indistinct or even lack horizons. As the age of the soil increases, horizons are generally much more apparent (there are exceptions such as in deeply weathered soils of the humid tropics or in permafrost-affected areas).

Most soils usually exhibit two or three horizons (there can be more or less) that are generally described by colour, texture, structure, organic matter content, pH and the presence of carbonates. More detailed characteristics can be measured in the laboratory. Some soils show a gradual change from one horizon to another while others may possess horizons with markedly different characteristics.

Know Your A, B, C...

The identification and quantitative description of horizons are an important aspect of studying soils. Most soils conform to a similar general pattern of horizons. In soil science, major horizons are denoted by a capital letter as a means of shorthand and easy communication (typically followed by several alphanumerical characters to denote a characteristic feature).

The uppermost layer normally contains the undecomposed or slightly decomposed remains of plants lying on the surface of the soil. This layer is called an organic horizon and is referred to by the letter 'O'. The O horizon is usually not saturated by water for prolonged periods and its mineral content is very low. Where the accumulations of organic material on the soil's surface are waterlogged (saturated by water) for prolonged periods, this is referred to as an H horizon. Organic matter in both the O and H horizons may be further divided into i) slightly decomposed where plant remains are visible to the naked eye; ii) an intermediate phase where decomposition is greater but plant remains are still visible; iii) completely decomposed organic layer on top of the mineral soil.

Beneath the O horizon, a dark horizon containing a mixture of organic and mineral material can be recognised which is referred to by the letter 'A'. The A horizon is the topsoil, which contains most of the organic material within the soil, hence its darker colour. It is the engine room of the soil where most of it's biological and chemical activities occur (e.g. biomass growth, dead litter and root decay and release of nutrients, formation of organic acids and their reactions with minerals, etc.). If the topsoil layer is removed by erosion or human activity, most of the soil's ecological potential goes with it. While the topsoil layer will regenerate over time, if left undisturbed, it may take hundreds of years for its full original potential to be restored.

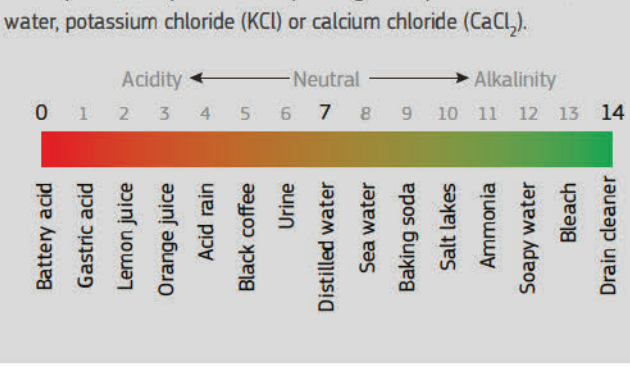
Below the topsoil (O and A horizons) is the mineral subsoil containing one or more brighter coloured layers that are referred to by the letter 'B'. Apart from Podzols (see page 47), the B horizons contain much less organic material than topsoil (making them different in colour) but they are still exploited by plant roots and soil animals which use the water, air and nutrients stored in them. Brownish, yellow or reddish colours originate from iron or aluminium oxides formed by weathering in the soil, whereas

What is meant by heavy or light soil?

Soils are sometimes referred to as heavy or light. This is the ease with which they can be worked or tilled and depends on their texture (see box on page 19). Heavy soils contain greater proportions of clay or silt particles and retain much more moisture than soils with larger particles, such as sand. Consequently, they are heavier to dig into and turn over than light sandy soils.

What is pH?

The pH scale (from 0 to 14) indicates the degree of acidity based on the concentration of hydrogen ions in a solution. Soils typically fall between pH 4 to pH 11, with a neutral soil having a pH of 7. Soils are often described as having a certain pH value or being acid or alkaline. Acid soils will have a pH below 7 while alkaline soils have a pH greater than 7. The pH is usually measured by mixing a sample of soil with deionised water, potassium chloride (KCl) or calcium chloride ($CaCl_2$).



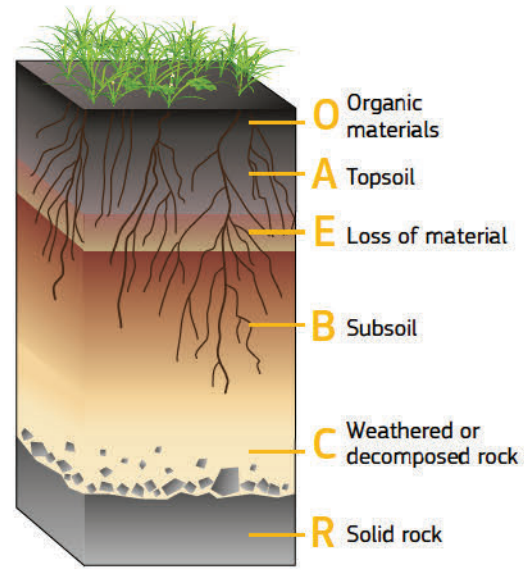
greyish tones result from chemical reaction in waterlogged conditions. Towards the base of the subsoil, the soil structure gradually becomes less apparent as the factors affecting its development decrease in influence.

In some cases, it is possible to distinguish an E or Eluvial horizon under an A horizon and above a B horizon. An E horizon indicates that materials such as clay, iron and aluminium, have been destroyed or flushed to deeper layers by percolating water. E horizons are usually lighter in colour (but not always) and have a coarser texture. An E horizon is usually differentiated by a change in colour or coarser texture and generally contains less organic matter than the A horizon. E horizons can be found within the within the B horizon.

Eventually, a layer is reached where the influence of soil-forming processes is less apparent. This layer is referred to by the letter 'C'. This horizon lies above hard bedrock. The characteristics are usually very different to the A and B horizons and may contain weathered blocks of the underlying geological substrate.

The R horizon basically denotes the layer of hard bedrock underneath the soil. Soils formed in situ will exhibit strong similarities to this layer.

Soil horizons can change within relatively short distances. Digging another hole in the same field can often reveal a very different arrangement of horizons and soil properties. These differences are due to variations in soil-forming factors and processes.



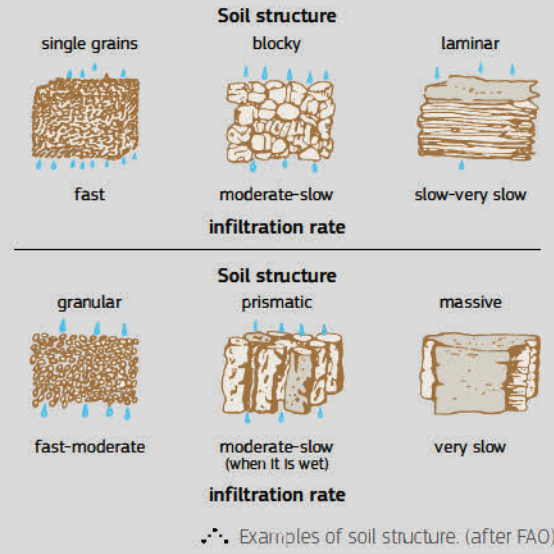
A hypothetical profile showing the main soil horizons and their relation to parent material, root development and soil-forming processes. Other possible horizon codes are L (sediments deposited in a body of water) and W (presence of water layers). (LJ)

What is meant by heavy or light soil?

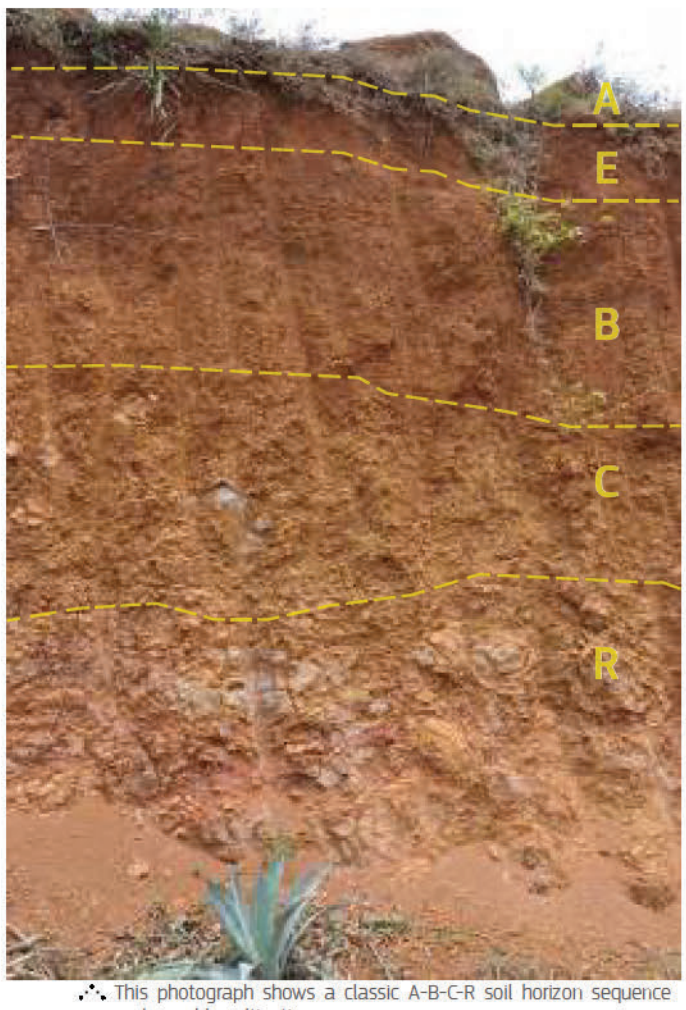
Structure refers to the natural arrangement of soil particles (also called aggregates) and the space between them. Soil structure has a major influence on root growth and the movement of water and air within the soil. Structure depends on factors such as the parent material, the chemistry and structure of minerals, biological activity and environmental conditions (such as shrinking the presence of swelling clays or freezing and thawing). Soil structure is affected and damaged by different land management practices such as tillage, wheel traffic and animal stocking density. Structure can be improved through the addition of organic matter (such as compost), crop rotations or avoiding tillage, especially in wet conditions.

Soil structure is usually described in terms of the degree of aggregation (from structureless to strong, size (very fine to very thick) and shape of aggregates (e.g. granular or crumb, blocky or subangular, prismatic or columnar, platy).

Soils with a good structure will have lots of spaces or pores between aggregates. Soils with few pores and fissures are said to be compacted. Soils with a high clay or organic matter content tend to have a more stable soil structure than those that are mostly sand or silt. The presence of sodium salts in the soil can cause the structure to collapse.



Examples of soil structure. (after FAO)



This photograph shows a classic A-B-C-R soil horizon sequence under arable cultivation.

The hard bedrock (**R**) has weathered to form a stony **C horizon**, which is the **parent material** for the development of the A-E-B horizons above. A shallow **A horizon** is slightly darker in colour due to a higher level of organic matter. Below is a well structured **E horizon** where clays have been lost and deposited by percolating water in the **B horizon** below. High amounts of iron oxides and clay, as a result of weathering and soil-forming processes, give the soil a distinctive red colour.

Plant roots and burrows are clearly visible in both the A and B horizons. (EM/JRC/LJ)

Where do the soils of Asia come from?

Soil-forming factors

As we can see from the pictures on this page, the appearance and characteristics of soils can vary considerably from place to place. The next few pages will describe the main factors that govern soil formation and illustrate how they dictate the properties of a particular soil.

The Russian Vasily Vasil'evich Dokuchaev is commonly regarded as the father of pedology or soil science. He was the first person to articulate that geographical variations in soil characteristics were related to climatic conditions, position in the landscape and geological factors (parent material). His ideas were developed by a number of soil scientists, including Hans Jenny who, in 1941 [52], established a mathematical relationship which states that the observed properties of soil are the result of the interaction of five variables, the most important of which are:

Parent material

Topography or position in the landscape

Climate

Living organisms, especially vegetation

Human activities

Time

Jenny expressed this relationship through a formula:

soil = f (climate, organisms, topography, parent material, time)

According to this formula, variations in parent material, climate or the age of the soil will result in specific soil characteristics.

For example, the weathering of solid bedrock through processes such as heating-cooling or freeze-thaw cycles (determined by topography and climate) produces a matrix of rock fragments (also known as regolith). Further, weathering leads to the production of finer particles containing crystalline minerals that have been liberated from the rock. These fine-texture materials provide the conditions for seeds to germinate and plants such as lichens and mosses to become established. The growth of vegetation is supported by the transformation of minerals into simple molecules or compounds that act as plant nutrients. As plants become established, dead leaves will fall on the surface and decay to form thin organic layers, which in turn, support the next cycle of plant growth by returning the nutrients to the soil. Over time, the parent material becomes covered and buried by more and more organic matter allowing larger plants to grow. The slope or aspect of the site may determine growing conditions but also the drainage and movement of materials. In this way, a soil will form with characteristics that reflect the interplay between the various factors.

A changing climate may alter the weathering processes and thus halt the supply of parent material and the release of minerals. Alternatively, climate change may favour a more luxurious vegetation community, leading to the production of more plant matter, resulting in deeper organic layers. In both cases, the soil characteristics will be different from the initial condition.

Many people argue that these soil-forming factors are not truly independent. Climate has an obvious bearing on living organisms while at the same time, the (micro)-climate at the surface of the soil may be very different to the general regional climate. This micro-climate may itself be controlled by topography which, in turn, is the result of the interaction between the underlying geology (in many cases the parent material) and the regional climate.

Nevertheless, the underlying principles of soil formation have been shown to be sound. An additional important factor that should not be ignored is the influence of human activities. Soil processes and characteristics can be significantly altered by the way that the land is used or managed. Drainage, the addition of fertilisers or the removal of natural vegetation are only a few examples of how soil characteristics can be changed artificially.

Much more information on soil-forming processes can be found in most general soil text books such as [34, 53].



The three photographs on this page illustrate the variety of soil characteristics, which in turn are driven by the interplay of soil-forming factors. This photograph shows a deep, coarse-textured soil that has developed in old sand dune deposits. The darker band just below the surface is the result of ploughing, which mixes organic matter from the surface. (EM)



A fine-textured soil with high levels of swelling and shrinking clay minerals. Initially derived from the weathering of basic rocks such as basalt, the clays were later redeposited in still water conditions. The dark colour reflects the presence of manganese and dark iron oxides. Note the cracks and smooth surfaces of sheer planes which are evidence of churning within the soil as a result of shrinking and swelling in wet and dry conditions. (EM)



A profile of a soil in Indonesia that has developed in materials ejected during a volcanic eruption. Such soils are highly porous, generally dark-coloured, and have high aluminium content. (EM)

Where is the continent of Asia?

Asia is flanked by the Pacific Ocean on the east, the Indian Ocean on the south and the Arctic Ocean on the north.

The border of Asia with Europe is rather arbitrary but in this atlas, we have adopted the commonly accepted definition that it runs along the crest of the Ural Mountains and the Ural River into the Caspian Sea, then along the crest line of the Caucasus Mountains into the Black Sea before passing through the Dardanelles into the Mediterranean. After skirting the southern coast of Cyprus to southern Türkiye, the western side of the Arabian Plate follows the coastline of Syrian Arab Republic and Lebanon then the Dead Sea Transform Fault System down through the Gulf of Aqaba into the Red Sea and the Indian Ocean (see page 77).

The border between Asia and Oceania is usually placed to the south and east of the Maluku Islands in Indonesia with the island of New Guinea being regarded as part of Oceania. [54]

The most northerly point of Asia is Cape Fligely on Prince Rudolf Island, part of the Russian Federation Franz Josef Land Archipelago (81°52'N), the most southerly point (11°00'S) is Pamana Island located in Indonesia's Lesser Sunda Islands. The westernmost point is Cape Baba, Türkiye (26°04'E) while the easternmost point, Big Diomede, Island (169°03'W), lies in the Bering Straits and is technically also the westernmost point as it lies 1 km west of the International Date Line! The coastline of Asia is estimated to be around 63 000 km long.



Map showing the generally accepted extent of Asia, the world's largest and most populous continent. Asia covers an area of 44 579 000 km^2, which is about 30% of the Earth's total land area and has a population of almost 4.7 billion people, roughly 60% of the world's population. [55] (LJ after S).

At 8849 metres above sea level, Mount Everest on the border between Nepal and China is both the highest mountain in Asia and in the world. The lowest point is the Dead Sea at almost 400 m below sea level, which is also the lowest point on Earth! While large parts of Asia are relatively low elevation (< 250 m), the average altitude of Nepal and Bhutan is over 3000 m.

According to the United Nations, there are forty-eight countries in Asia. The Russian Federation and China are by far the largest, making up around half of the geographical area. The smallest (and with the lowest elevation) is the Maldives. The smallest nation on the continental mainland is Bahrain, just marginally larger than the island of Singapore. There are twelve landlocked countries in Asia, the largest of which, Kazakhstan, is also the largest landlocked country in the world and the 9th biggest country in the world.

With a total length of over 6300 km, the Yangtze is the world's third longest river, while the Yenisey, Yellow and Ob are all over 5000 km long while much of Western Asia has no permanent rivers!

The term Eurasia refers to the a combined continental landmass of Europe and Asia. While geologically, Eurasia is a single continent, the concepts of Europe and Asia as distinct continents reflects cultural and historical concepts rather than geological principles. [56]

Asia – the name!

While the origin of the word "Asia" is uncertain, there is a school of thought that believes it to date back to Ancient Greece or Mesopotamia, which makes reference to the east and the direction of the rising sun. This is comparable to the etymology of Europe, which is thought to signify the setting sun.

Soil-forming factor 1: Parent material

Parent material refers to substance in which the soil has developed. In most cases, it is of geological origin (see page 24 for more on organic soils). In a sense, parent material can be considered as the primary product on which all other soil-forming factors will act. The nature of the parent material is often mirrored in the soil and can have a profound influence on its characteristics. For example, the mineralogy of the parent material determine the weathering process, control natural vegetation compositions, soil fertility, pH, salinity levels and internal water flows. For example, lime-rich soils are derived from calcareous rocks (e.g. limestone, chalk) or sediments derived from such deposits. In turn, such soils can offset the development of acidic conditions but may not support plants that are not tolerant of alkaline soil conditions (e.g. rhododendrons).

Two types of parent material are recognised: a) weathered materials directly overlying the consolidated hard rock from which they originate and b) unconsolidated deposits or loose sediments that have been transported by ice, water, wind or gravity. In both cases, the eventual parent material can be weathered through physical destruction of rock or chemical reactions. Weathered minerals can themselves undergo further changes that cause the formation of so-called secondary minerals.

Although a relatively new continent in its current extent, Asia is rather complex from a geological perspective. Three key aspects can be summarised:

- several major tectonic events giving rise to extensive mountain ranges and high plateaus, most notably the Himalayas which are the result of the Indian Plate crashing into Asia about 50 million years ago. Current tectonic activity manifests itself as volcanoes in western Asia and along the Pacific Ocean;
- parts of the land surface (e.g. Arabia, India) have been geologically stable for millions of years and in the form of plains and tablelands that often exhibit low relief;
- extensive accumulation of wind blown deposits and water borne sediments, mostly associated with the erosion of uplifted land.

As highlighted by the adjacent map, the lithology (the mineral composition) of parent materials is an important factor and has a high bearing on soil characteristics and properties.

Basic and acid igneous rocks began life as molten rock (known as magma) which cooled and crystallised into minerals. Geologists classify igneous rocks on the basis of crystal size, chemical composition and the presence of the mineral quartz. Examples include basalt and granite. Igneous rocks that reach the surface are referred to as extrusive volcanic while those that cool inside the lithosphere are called plutonic. In a sense, they are the source of all other rocks.

Sedimentary rocks are formed by the deposition of weathered material by wind or water. Carbonates indicate parent material such as limestone, dolomite and chalk, which are rich in calcium or magnesium carbonate (CO_3) and are created through the precipitation of calcium carbonate from solution. Non-carbonate sedimentary rocks encompass a great variety of mineral composition, texture, and other properties and include shales and mudstones (deposited on ocean floors), sandstones, conglomerates (composed of resistant fragments of other rocks), ironstones, evaporites (rock salt, gypsum, and other salts) and siliceous rocks (cherts).

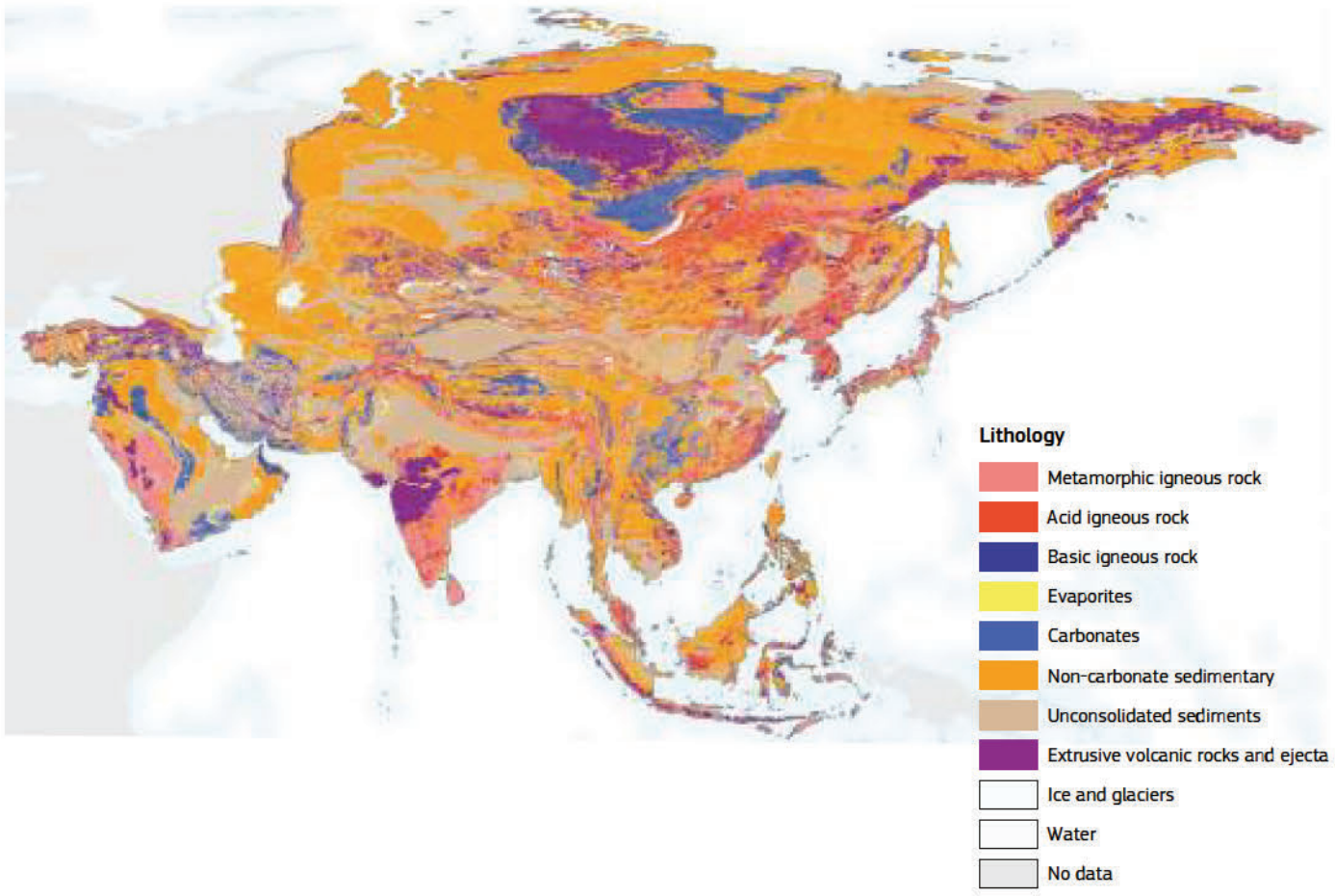
The term metamorphic denote rocks that have been subjected to high pressures and temperatures within the crust and upper mantle of the Earth causing a change the chemical make up of the rock. Different combinations of temperature and pressure will cause very different metamorphic products from the same source (if the temperatures would have been sufficient to melt the rock, a new igneous rock would have formed). Examples of sedimentary metamorphism include slate, quartzite and marbles while metamorphic igneous rocks include greenschist, epidosite and felsite. Schists and gneisses can form from either igneous or sedimentary rocks.

Organic soils (peat deposits) are formed in wetlands, cold climates and mangrove areas, where environmental conditions slow the decay of vegetation remains.

A thorough summary of the geology of Asia is given in [57].



Soil formations on continuous, hard bedrock in Yemen (**left;** MHAM) and transported sediments in the United Arab Emirates (**right;** BA), in this case, of wind deposition in the background dunes while in saline sediments in the foreground. Where consolidated parent material lies close to the surface, the depth of soil is generally shallow and horizon development is weak. In some areas, unconsolidated sediments can completely mask the characteristics of the underlying bedrock (e.g. blown sands over a limestone).



The map shows the lithological properties of the surface geology of Asia. Lithology describes the mineral composition and structure of geological material which is based on rock formation (i.e. whether it is igneous, sedimentary, metamorphic) and mineralogy (e.g. carbonate, silicic, mafic). This map is a good proxy for soil parent material as it only reflects surface conditions and not the underlying bedrock. It should be noted that the general nature of this map means that at a local level, the conditions may be quite different to that shown. Please note that the age of material is not indicated. The preponderance of unconsolidated sediments (generally reflecting floodplains and deserts) and volcanic rocks across Asia is striking. Please consult the glossary at the end of the atlas and the adjacent text box for an explanation of the geological terms. (JRC/FAO) [58]

Alluvium and colluvium

Alluvium (from the Latin *alluere*, which means to wash against) is used to describe any material deposited by rivers. It can range from fine silt or clay particles to larger sand or gravel particles, and is generally well sorted. Alluvium is usually found on floodplains or deltas, but may be deposited at any point where the river overflows its banks or where the velocity of a river is checked when it runs into a lake.

In contrast, **colluvium** (from the Latin for washing) is material that has accumulated at the base of slopes or in depressions. It consists of material that has rolled, slid or fallen down the slope under the influence of gravity, soil creep, or overland flow. It is often poorly sorted.

Acidic or Basic Rocks

The terms acidic and basic are often used to describe rocks or the parent material of soils and does not refer to the pH of the material. In geology, it refers to the amount of silica in proportion to Mg, Fe and Ca.

Magmatic rocks that contain significant amounts of silica (at least 66% SiO_2 by mass, which normally occurs as quartz minerals) are referred to as acid. Examples include granite and rhyolite.

Conversely, the term basic is applied to rocks containing minerals such as feldspar and biotite but relatively low amounts of silica. Examples include basalt, dolerite and gabbro. The term mafic is increasingly used in place of basic.

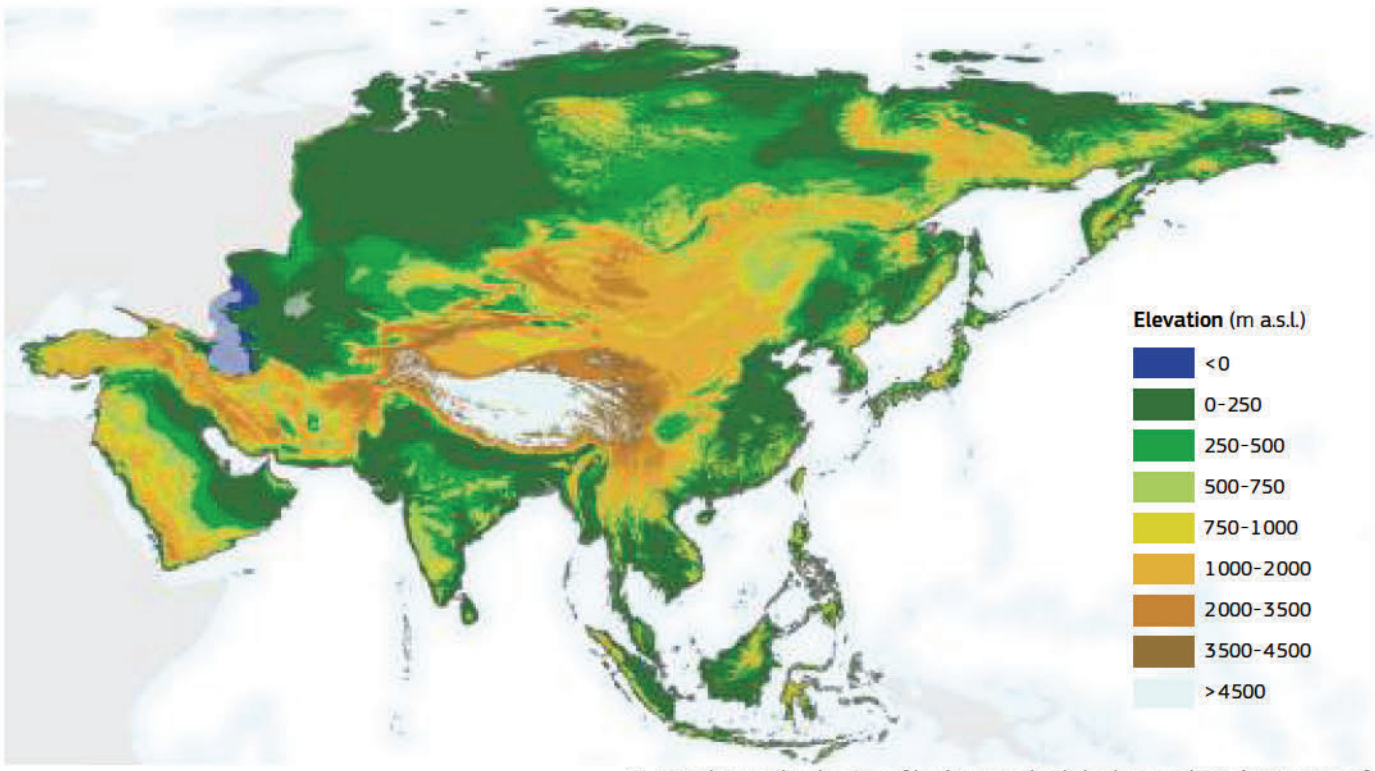
Soil-forming factor 2: Topography

The shape of the land surface, also referred to as relief or topography, is a key soil-forming factor as it has an important influence on local climate, vegetation type and the movement of water. Mountains can affect the amount and intensity of precipitation and vegetation growth while locally, the slope of the ground controls drainage and the movement of material. Even small variations in elevation can be important in flat lands. River terraces or small depressions can lead to improved drainage or waterlogging, respectively, with a single field. Micro-topography can be particularly important if saline groundwater occurs close to the surface as it will affect evaporation rates.

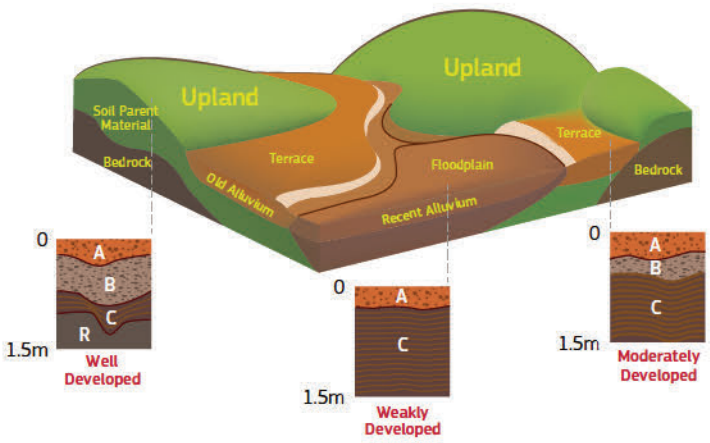
The position in the landscape is very important. Generally, soils found at the top of a slope are generally freely draining while those at the foot of a slope or on the valley floor often have impeded drainage. In some cases, the water table may be near or at the surface (see page 26). In this situation, different soils may form on the same parent material, climate and even vegetation type (e.g. a grass-covered slope). Soils occurring on the middle of slopes receive sediment and solutions from higher up but at the same time lose material to soils below. In these cases, the actual shape of the slope is important as smooth, irregular, convex or concave slopes will result in different soil characteristics.

It is clear from the map on the **right** [59] that Asia is a rather elevated continent where most of the land is more than 200m above sea-level and a very significant part is very mountainous. In fact, the highest elevations in the region (light blue) are found in the Tibetan Plateau of the Himalayas where Mount Everest, the tallest peak in the world, reaches a height of 8849metres above sea-level. Bhutan, Nepal, Tajikistan and Kyrgyzstan all have an average elevation of over 3000m, while China and western Asia have high elevations over much of the territory. In fact, Mount Elbrus in the Caucasus (5642m - technically the highest mountain in Europe and the tenth most prominent peak in the world), Mount Damavand in the Islamic Republic of Iran (5609m and the highest volcanic mountain in Asia), and the snow-capped dormant volcano of Mount Ağrı (Ararat) in eastern Türkiye (5137m), all reach significant altitudes.

Conversely, the turquoise and dark green colours represent areas below or just above sea-level respectively: the low-lying area around the Caspian Sea in western Asia is particularly evident (the current water level is about 28m below sea-level, however, the bed of the lake is more than 1000m below sea-level). At 430.5m below sea-level, the surface and shores of the Dead Sea is the lowest elevation on the Earth's surface (the lake itself is an additional 304m deep).



Map showing the elevation of land in Asia. The darker brown colours denote areas of higher elevation while the green areas are below 500m. The map clearly shows that than most of the continent is above 500m, with large tracts of land above 1000m. In many places, the high lands come right up to the coast. The map is based on measurements made by a specially modified radar sensor carried on board the Space Shuttle as it orbited the planet. [59] (LJ/FAO)



The position of a soil in the landscape is important in determining its characteristics. The graphic on the **left** illustrates the conceptual differences in the development of soil profile according to a generalised topographic setting in humid climates. (LJ after UM/TC)

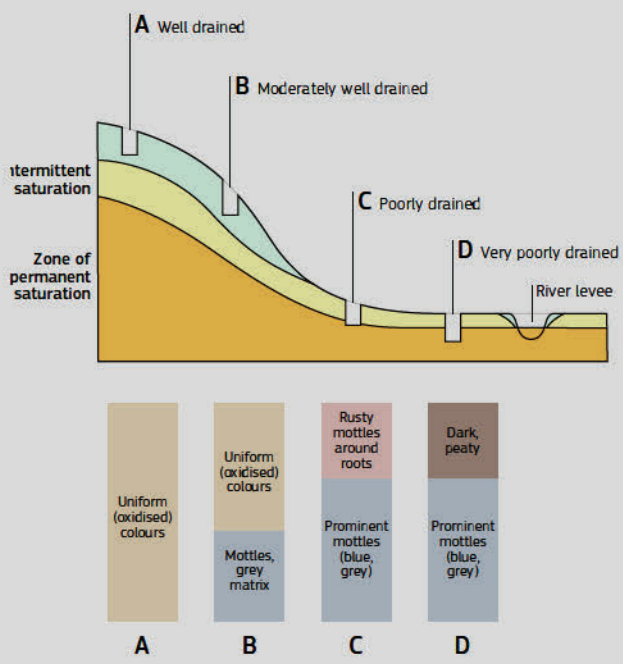
Conversely, the diagram **below** shows a generalised 3-D representation of a typical piedmont setting in an arid climate. Physical erosion of the mountain front leads to the accumulation of coarse sediments in the form of scree or talus slopes along the foot of the higher ground (this is known as a pediment). Flash floods leads to the development of alluvial fans than become finer grained towards the basin floor, which are generally composed of silt and clay-rich soils as well as salt pans (often referred to as a playa - however, the terms takyr, sabkha and kavir are common in Western and Central Asia. (LJ after UWM)

The light green areas show the extent of low relief landscapes such as the plains of Central Asia, which are generally flat or gently undulating, the coastal plains of Arabian Peninsula and southeast Asia, and the lower floodplains of major rivers (such as the Indus, Ganges, Mekong, Yellow and the Tigris. Light pink denotes the higher plains where the landscape begins to show evidence of soil erosion on steeper slopes. The orange colours signify upland regions which in some places give way to mountains (dark brown).

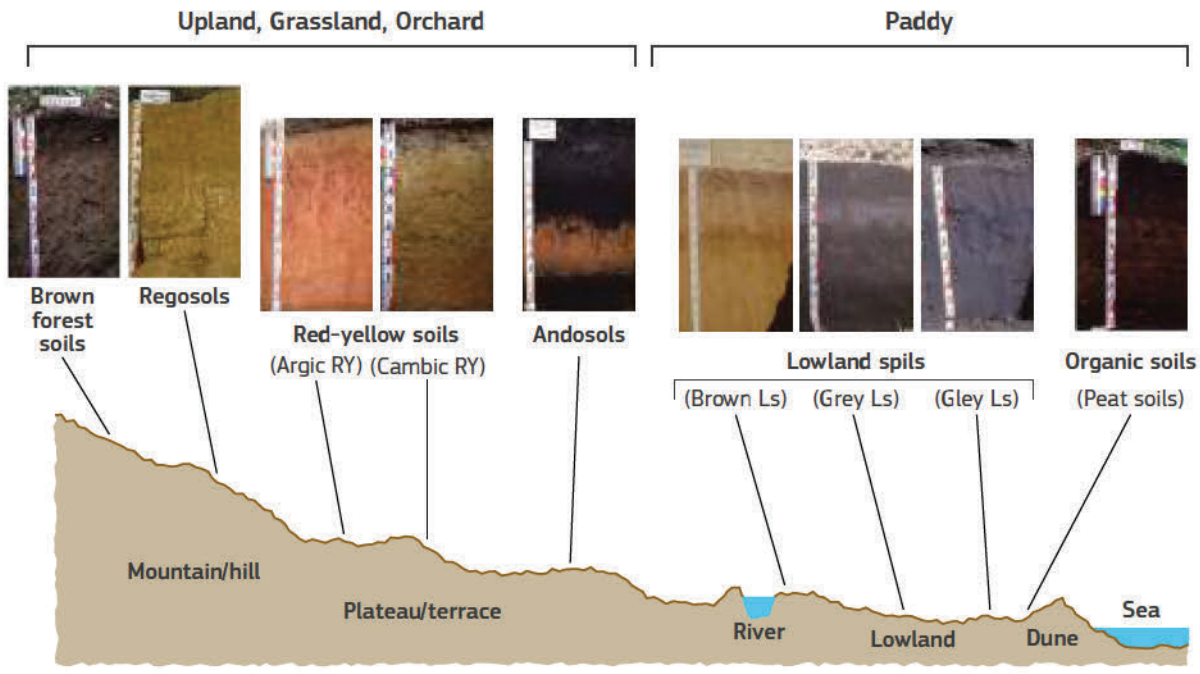


The Catena

From the Latin word for chain, the catena is a term that describes the sequence of soils occurring on slopes, where the parent material is common. In this case, the influence of relief dominates other soil-forming factors. The theory of the catena originates from a soil reconnaissance survey that was carried out in Africa in the 1930s [60] but is now widely recognised.



Soils occurring at the foot of slopes receive greater amounts of water and sediment compared to those on higher ground. Soil at the highest location (A) will be well drained while waterlogging or saturated ground may be common on the valley floor (D). The vertical blocks denote typical soil characteristics resulting from the degree of drainage. (LJ after JHI)



Examples of changes in soil profile characteristics on weathered granite along a catena in Korea. The graphic also describes the drainage class and the main land use. Soils on forested land on higher ground are excessively drained and leached while those on the flat floodplain are poorly drained Gleysols under rice cultivation. (YM)

Soil-forming factor 3: Climate

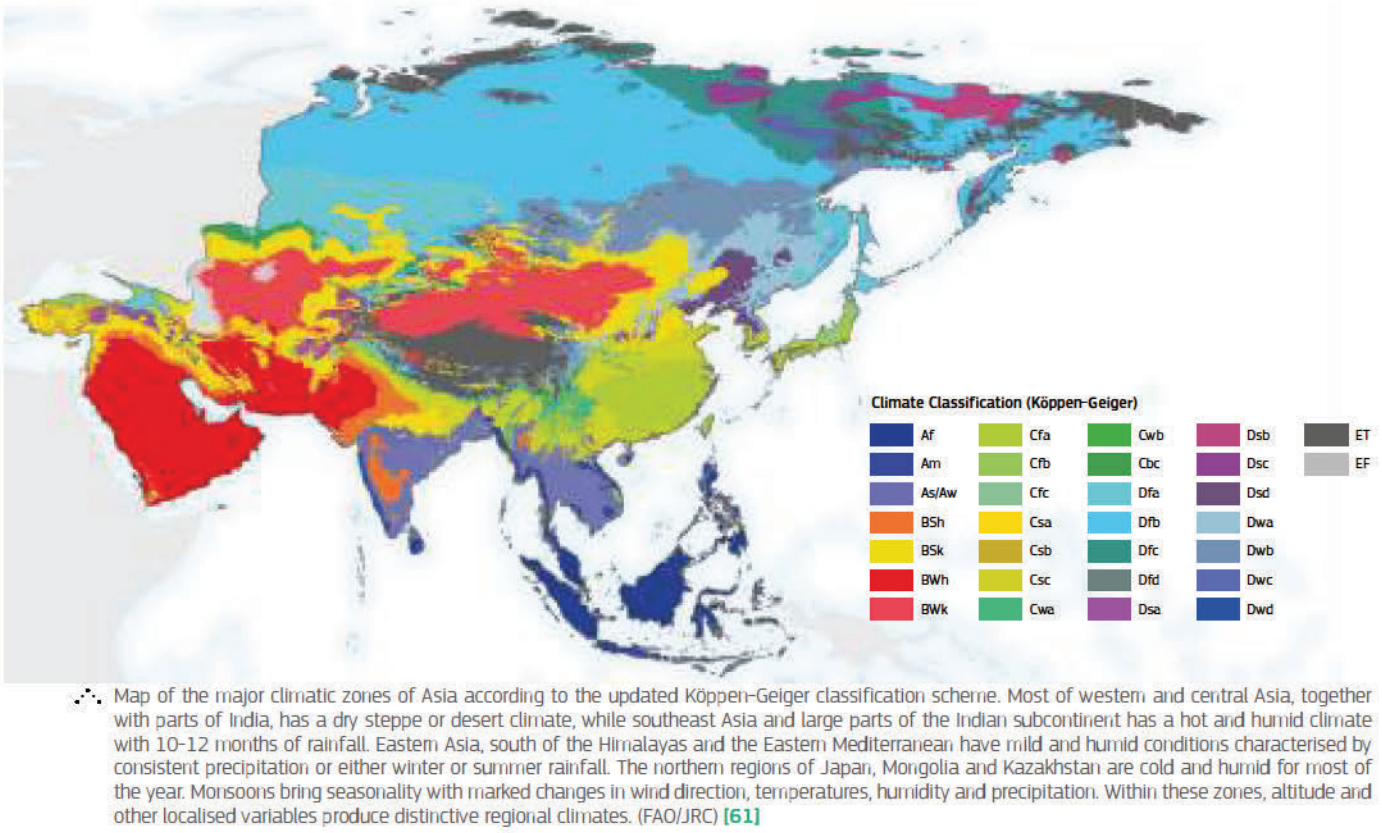
Climatic zones

Climate is the summary of weather patterns over a period of time, generally thirty years. Climate is a key factor is soil formation as temperature and moisture levels determine weathering processes and biological activity. For example, both hot desert and very cold climates tend to facilitate physical weathering while chemical weathering is most active in areas with high temperatures and high humidity. In parallel, climate dictates many soil-forming processes (see pages 44-51) such as leaching, salt formation and the accumulation of organic matter.

Asia is a continent of climatic extremes, encompassing all of the planet's climatic zones. Much of Asia is characterised by a continental climate of hot summers and where the southwards movement of the Arctic Polar Front brings very cold winds from Siberia during the northern latitude winter.

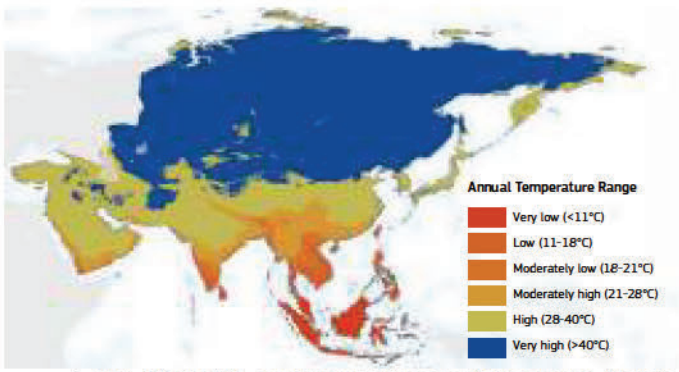
Rain shadows and distance from the oceans results in low precipitation in central Asia. In the west, a hot and arid climates predominate, with large expanses of semi-arid conditions throughout central Asia. In the south and east, more humid conditions can be found, the northern extent of which is blocked by the mountains of the Himalayas. The equatorial regions of southeast Asia are hot and humid all year round. An important feature of the region are the monsoons (see box below). While the extensive mountain chains of Asia often serve as climatic barriers, their altitude gives rise to several climatic belts along their slopes. Six broad climatic zones can be distinguished [61]:

- **Hot and humid zone** generally found around the Equator (e.g. Indonesia, Malaysia, Philippines, southern Sri Lanka). It is hot and humid throughout the year and average monthly rainfall exceeds 60 mm. Away from the equator, mean annual temperatures are still high but monsoonal conditions give western Thailand, western Myanmar and the eastern coast of India a short dry season. Southern Viet Nam, the Lao People's Democratic Republic, northern Thailand, eastern Myanmar, Bangladesh and eastern India) have markedly drier winters, with the driest month having less than 60 mm precipitation.



Map of the major climatic zones of Asia according to the updated Köppen-Geiger classification scheme. Most of western and central Asia, together with parts of India, has a dry steppe or desert climate, while southeast Asia and large parts of the Indian subcontinent has a hot and humid climate with 10-12 months of rainfall. Eastern Asia, south of the Himalayas and the Eastern Mediterranean have mild and humid conditions characterised by consistent precipitation or either winter or summer rainfall. The northern regions of Japan, Mongolia and Kazakhstan are cold and humid for most of the year. Monsoons bring seasonality with marked changes in wind direction, temperatures, humidity and precipitation. Within these zones, altitude and other localised variables produce distinctive regional climates. (FAO/JRC) [61]

- A **mild and humid zone**. Northern Myanmar, northern Viet Nam, southeast China, and southern Japan are characterised by a humid subtropical climate with hot humid summers and cooler winters. Mean temperatures in the coldest month are between 0 °C and 18 °C while the mean temperatures in the warmest month are at least 22 °C. Precipitation is generally high (> 1 000 mm), occurring mostly in the summer, often as thunderstorms. Northeastern India and large parts of Bangladesh have hot dry summers followed by a cooler monsoon period that brings heavy rain on a daily basis. A derivative is the Mediterranean climate, with hot, dry summers and cool, wet winter months (Eastern Mediterranean, the flanks of the Caucasus Mountains, the northwest of the Islamic Republic of Iran and parts of Pakistan).
- **Hot and dry zone**. This occupies virtually all of the Arabian Peninsula, southern Iraq, and southern parts of the Islamic Republic of Iran, Afghanistan and Uzbekistan. The Thar Desert forms a natural boundary between India and Pakistan. Annual rainfall is erratic, generally less than 200 mm, often much less. Daily and seasonal extremes of temperatures are large with the average summer temperature above 35°C. These regions are flanked by hot semi-arid climates (western and central India, and south of the Caucasus Mountains) with hot summers and warm or cool winters, and higher levels of precipitation.
- A **cold desert zone** stretches from the eastern shore of the Caspian Sea through southern Kazakhstan, Uzbekistan, Turkmenistan, Afghanistan, northern Pakistan and India, northwestern China into Mongolia. Summers are hot and dry (although not as warm as hot desert climates). Winters are cold and dry. The Gobi and Karakum are both examples of cold deserts. These conditions are the result of the rain shadows from the land mass of Western Europe and the Himalayas, which restrict precipitation. These regions are bordered by cold semi-arid steppe climates characterised by cold winters (often with snow) and slightly higher precipitation. This covers large parts of central Asia (bordering the Gobi and Karakum Deserts), the central part of the Islamic Republic of Iran and the mountains of the Middle East.
- Northern Kazakhstan, central and northeastern China, the Korean Peninsula and northern Japan are characterised by a **humid continental climate with large seasonal temperature differences** due to warm or hot summers and cold winters. Precipitation is usually distributed throughout the year although in China it tends to fall in the winter.
- A **cold zone**. A subarctic climate, covering much of northern Mongolia, Nepal and the highlands of central China, is characterised by very cold winters (−40 °C), short cool summers and low annual precipitation (generally < 400 mm). It is also found in small pockets at high elevations in the Islamic Republic of Iran, Kyrgyzstan, Tajikistan and Türkiye. Cold conditions also denote the high peaks of the Himalayas and Caucasus where the temperature never exceeds 0 °C resulting in permafrost (permanently frozen ground), ice sheets and glaciers.



Map showing the annual temperature amplitude or range for Asia based on the difference between the mean temperature of the warmest and coldest months. The low annual range around the equator, the Himalayas and parts of the Arabian Peninsula is in sharp contrast to large parts of Asia that experiences annual temperature ranges in excess of 30 °C. (FAO/JRC) [62]

Annual temperature range

Temperature and fluctuations in temperature have important bearings on soil-forming processes. The map above shows the difference between the average temperature of the warmest and coldest months. This change depends on the annual cycle of incoming solar radiation, which in turn reflects latitude and elevation, and proximity to the ocean. Clearly, Asia exhibits tremendous variations in annual temperature ranges. The region with the least variation is the equatorial zone. The island of Borneo has an average annual temperature of 22.9 °C, with a high of 23.9 °C in March and a low in November of 22.0 °C. In contrast, the Himalayas and the coasts of Oman and Yemen stand out as being consistently cold and hot respectively! Away from the Equator, annual temperate ranges increases with distinct seasons. Northern and western Asia exhibit annual temperature ranges in excess of 30 °C reflecting the climate of the arid deserts and the proximity of the Arctic.

Monsoons

One of the main drivers of climate in southern and eastern Asia is a feature known as the monsoon, a seasonal change in atmospheric circulation and precipitation associated with the uneven heating of land and sea (analogous to coastal sea breezes). The heating of land in summer causes air to rise which is replaced by air from cooler regions (usually the oceans). In winter, the processes is reversed as the oceans are warmer than the land. Asia has two major monsoon systems:

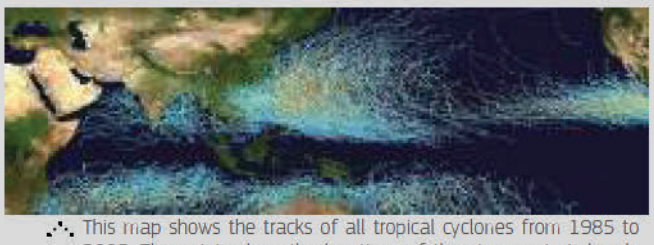
- The **Indian Subcontinental Monsoon**, affecting the Indian subcontinent and surrounding regions, has two components. The Southwestern Summer Monsoon, from June to September, is driven by heat from the Thar Desert which draws moisture-laden air from the Indian Ocean into the subcontinent. When it meets the Himalayas, it is forced to rise and precipitation occurs. The Northeast Winter Monsoon, which runs from December to March, reflects the cooling of the Indian subcontinent with respect to the Indian Ocean, causing cold air to move from the Himalayas, bringing rain to southern India and Sri Lanka.
- The **East Asian Monsoon** affects large parts of China, the Philippines, the Korean Peninsula and Japan. It consists of warm, rainy southeasterly winds in summer and cold, dry northeasterly winds in winter. Rain occurs in an east-west belt that moves northwards in the spring and retreats southwards in the autumn. The winter monsoon brings significant dust deposition that is though to be the responsible for the formation of the Loess Plateau of China.



A striking photograph from the coast of Viet Nam showing rain bearing clouds associated with the East Asian Summer Monsoon. (JMH)

Typhoons

Another important feature of the climate of southeastern Asia are typhoons. This is the name given to strong circular tropical storms that originate over the warm waters of the western Pacific, especially to the east of the Philippines and in the South and East China Seas, during late summer and early autumn. They are characterised by low atmospheric pressure, high wind speeds and heavy rain. In the Atlantic, such storms they are known as hurricanes.

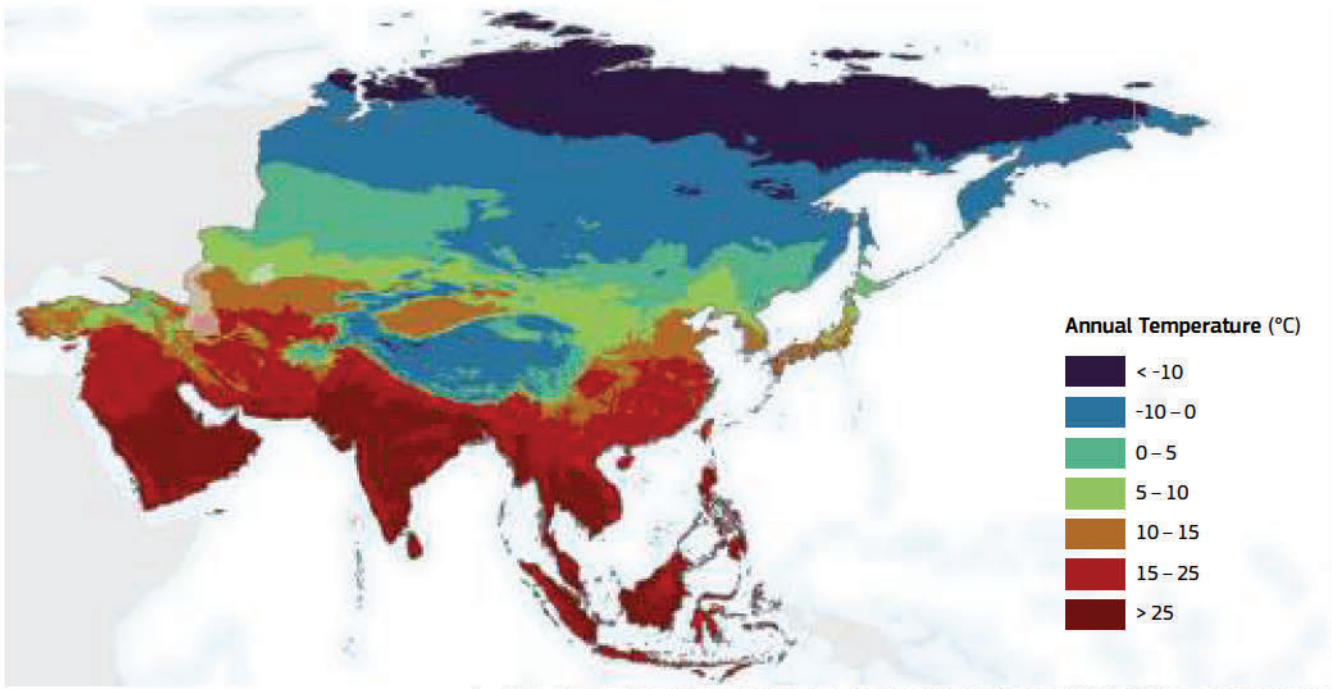


This map shows the tracks of all tropical cyclones from 1985 to 2005. The points show the locations of the storms at six-hourly intervals. Blue denotes storms and depressions while yellow and red colours demote more intense events. (PD)

Temperature

Temperature is one of the key climate variables that drive soil formation. As well as being one of the controllers of biological processes, high temperatures or fluctuations in daily or seasonal temperatures is a major factor in physical weathering (see page 44). The patterns on the adjacent map show variations in mean annual air temperature for Asia. A striking north-south divide, roughly following the 30°N latitude, has cooler conditions to the north and much warmer temperatures to the south. While Asia's highest temperatures (dark purple colour) occur along the Red Sea coast of Saudi Arabia and Yemen, extensive parts of the continent (including almost all of the Indian subcontinent and the islands of the equatorial zone) have average annual temperatures in excess of 25°C. Western Asia experiences very high daily and seasonal temperature ranges. More temperate conditions tend to be associated with higher elevations and proximity to the ocean (e.g. east Asia, Mediterranean countries)

Most of central and northern Asia is markedly cooler with the coldest regions (blue colours) located in regions of Mongolia on the Tibetan Plateau and northeastern China. While the coldest temperature ever recorded in Asia was −67.8 °C at Verkhoyansk in Siberia, Ulaanbaatar in Mongolia is often described as the coldest capital city in the world with temperatures often dropping to -40 °C in the winter. Ice fields and glaciers exist in the Himalayas.

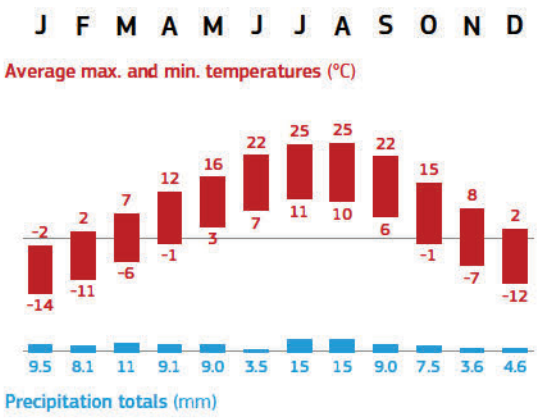


Map showing the pattern of mean annual temperatures for Asia. Most of the continent has a mean temperature of above 20°C while the subtropical areas are significantly hotter. Central Asia and north of the Himalayas are much cooler with permanently frozen ground in parts of Mongolia and Tibet. During the past twenty years, many parts of Asia have experienced record high temperatures (e.g. Cambodia: 42.6 °C in April 2016, China: 50.5 °C in July 2017, India: 51.0 °C) raising fears about the increased frequency of heatwaves due climate change. (FAO/JRC) [62]

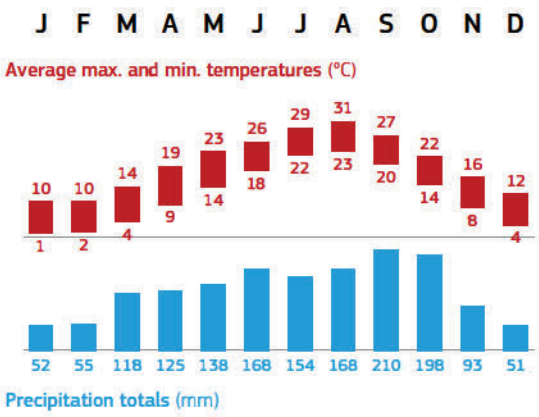
Precipitation

Climate charts for selected cities

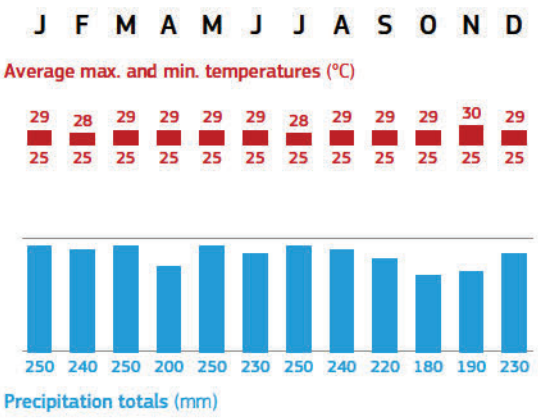
Leh, Northern India (cold desert climate)



Tokyo, Japan (humid subtropical climate)

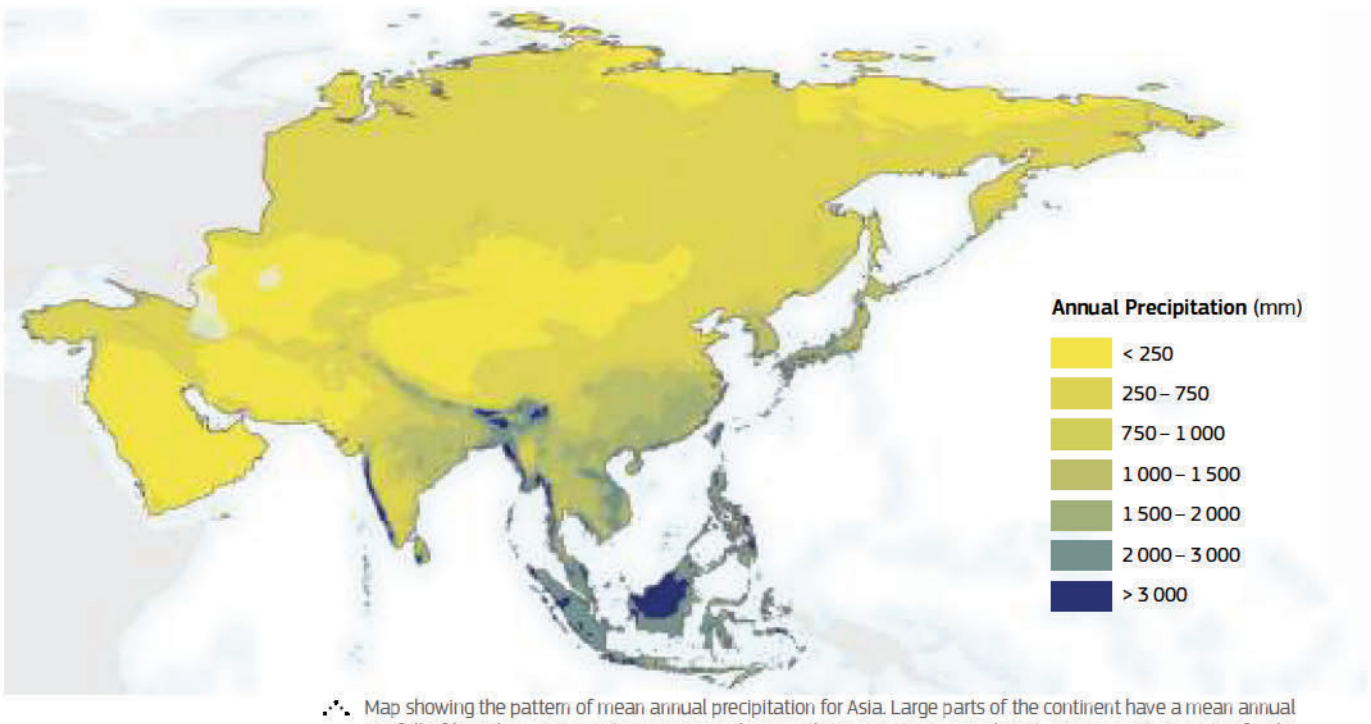


Biak, Indonesia (equatorial rainforest climate)



Climate graphs provide an overview of the climate in a particular place. Over the course of the year and are important to highlight that temperature and precipitation can vary within an individual climate zone. The letters at the top row indicate the months of the year (J = January, F= February, etc.). The red bars and numbers convey the average daily high and low temperatures for each month, and the red bars represent the average daily temperature span for each month. The blue bars represent the amount of precipitation that falls in each month in millimetres. For reference, the thin gray line is 0°C. The left chart from Leh in Northern India describes a **cold desert climate** with long, cold winters from November to early March, with minimum temperatures well below freezing for most of the winter. Average annual rainfall is only 102 mm. The middle chart shows the situation in Tokyo, Japan, which has a **humid subtropical climate** with hot, humid summers and generally cool winters with cold spells although the minimum rarely drops below freezing. The warmest month is August with summer temperatures reaching 30 °C. Annual rainfall averages nearly 1 530 mm with a wetter summer and a drier winter. The right chart from Biak in Indonesia shows an **equatorial rainforest climate** where the average annual temperature is 26 °C with almost no variation throughout the year. Precipitation in significant in every month, averaging around 2 816 mm annually. The driest months are October and November, but they still average close to 200 mm of rain per month. [63]

The amount of water in the environment is perhaps one of the main factors in soil formation. Very low precipitation will inhibit biological activity but give rise to the development of crusts and the accumulation of salts. Conversely, humid conditions lead to more chemical weathering, higher levels of minerals and organic matter. Heavy or prolonged rain can lead to soil erosion and saturated soils.



Map showing the pattern of mean annual precipitation for Asia. Large parts of the continent have a mean annual rainfall of less than 750 mm (see correspondence with temperature map above). However, some parts of India and southeast Asia receive more than 5 m of precipitation every year and are among the wettest places in the world. In fact, the highest ever recorded rainfall in a single year was 22 987 mm at Cherrapunji in northeastern India in 1861. However, it should be noted that climate change is likely to result in increased droughts and water shortages in some parts of Asia (see pages 184-185). (FAO/JRC) [62]

The map on the left shows the pattern of mean annual precipitation (millimetres of rainfall and the water equivalent of snowfall). As for temperature, Asia displays two distinct areas. Broadly speaking, western, central and northern regions receive less than 750 mm of rainfall annually. The light yellow colour corresponds to the desert belt running eastwards from the Arabian Peninsula to the Gobi and the Taklamakan Deserts. This area receives less than 250 mm of precipitation a year and in some parts rain may not fall for several consecutive years.

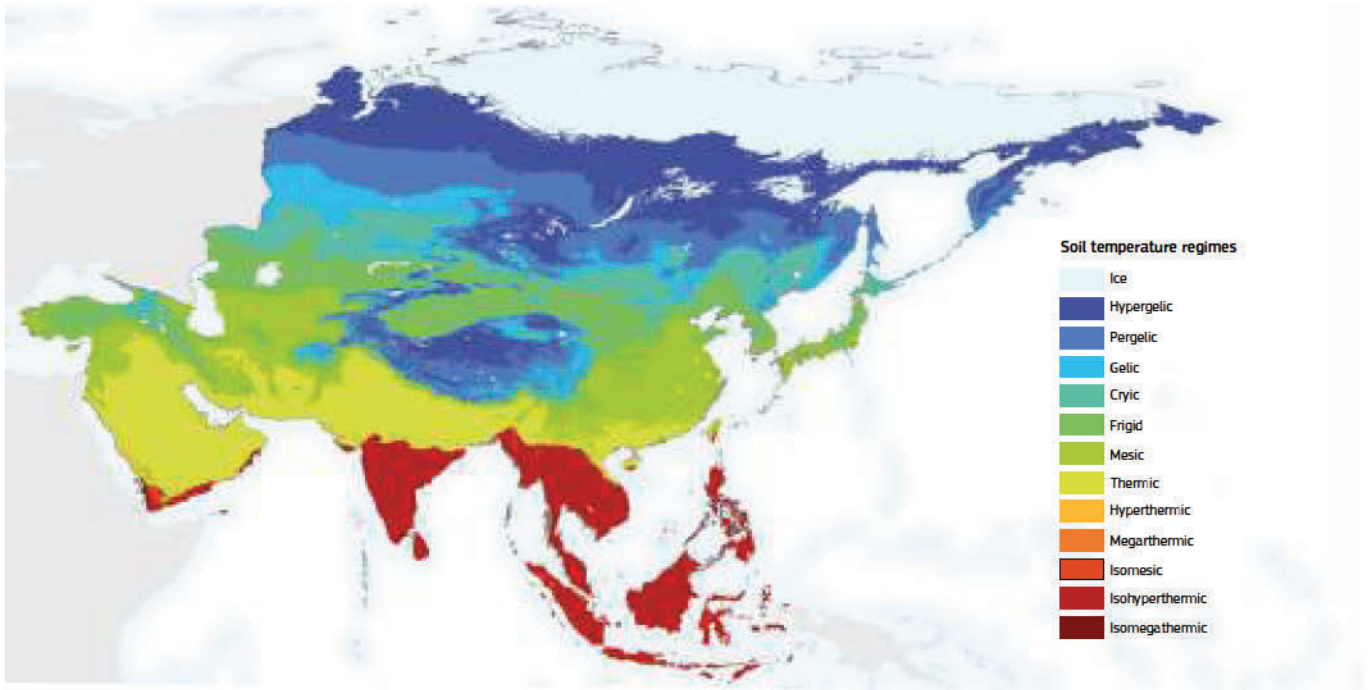
Alternatively, south and southeast Asia are much more humid, reflecting the monsoon conditions. Rain falls throughout the year in the equatorial zone ensuring more than 1 500 mm of precipitation annually, which can be significantly higher in many places. Parts of India, together with the islands of Borneo and New Guinea, are some of the wettest places on Earth, with many places having an average annual rainfall of 3 000 mm or more. Other rainfall maxima are found on the Himalayas, the Caucasus Mountains and on the Mediterranean coast. Away from the equator, precipitation becomes increasingly seasonal, often separated by dry periods.

Soil temperature regimes

Soil temperature is an important attribute and key environmental factor in determining soil-forming processes, the natural distribution of plants and controls biological processes in the soil. Soil temperatures above or below critical limits severely inhibit seed germination, even if there is adequate soil moisture. The life cycles of many soil-borne pests and diseases are controlled by soil temperature. Soil temperature at a depth of 50 cm lags behind air temperature, commonly by one or two months. The length of lag depends on climate, shade, aspect, the thickness of organic layer and the thermal conductivity and heat capacity of the soil (governed by factors such as mineralogy and porosity).

The map on the right shows the main soil temperature regions of Asia [64]. The explanation of the legend is provided below. The classes denote increasing temperatures while the term 'Iso' implies similar summer and winter temperatures.

- Hypergelic, Pergelic and Gelic: These are very cold soils affected by very low temperatures. Mean annual soil temperatures are <-10 °C, -4°C to -10°C, and 1°C to -4°C, respectfully. Broadly coressponds to areas affected by permafrost.
- Cryic: Soils affected by very low temperatures and cold summers. Mean annual soil temperatures <8°C but no permafrost).
- Mesic: Mean annual soil temperature is 8°C or higher but lower than 15°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Isomesic: Mean annual soil temperature ≥ 8°C but lower than 15°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Thermic: Mean annual soil temperature ≥ 15°C but lower than 22°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Isothermic : Mean annual soil temperature ≥ 15°C but lower than 22°C,difference between mean summer and winter soil temperatures ≥ 5°C.
- Hyperthermic: Mean annual soil temperature ≥ 22°C and difference between mean summer and winter soil temperatures ≥ 5°C.
- Isohyperthermic: Mean annual soil temperature ≥ 22°C, difference between mean summer and winter soil temperatures ≥ 5°C.
- Megathermic: Mean annual soil temperature ≥ 28°C.
- Isomegathermic: Mean annual soil temperature ≥ 28°C, difference between the mean summer and mean winter soil temperatures ≥ 5°C.

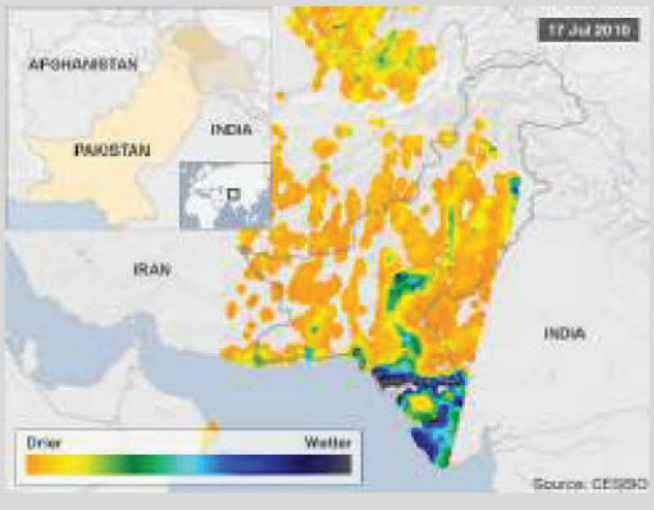


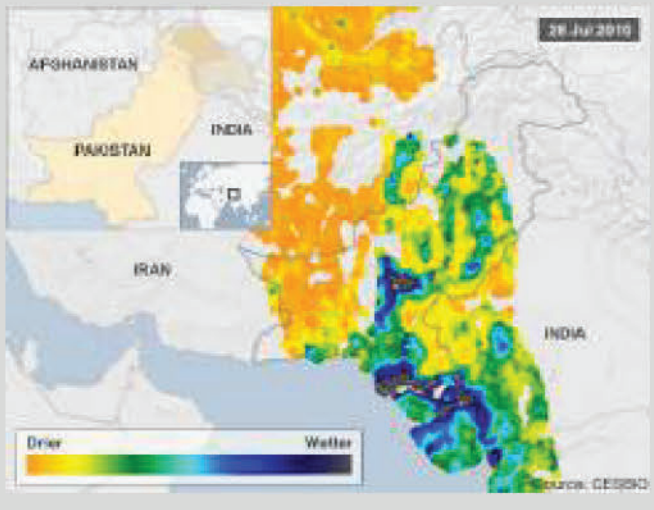
Map showing the pattern of soil temperature regimes for Asia, an important factor in determining soil-forming processes and biological processes operating in the soil. (FAO/JRC) [64]

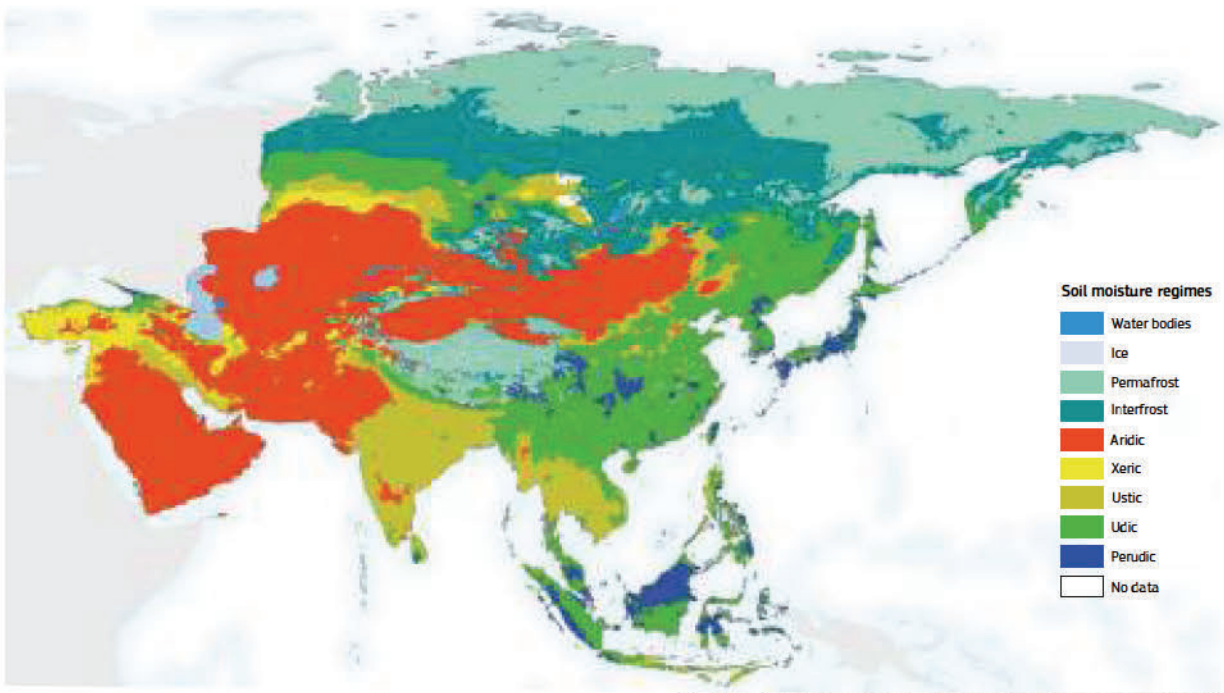
Soil moisture from satellites

In recent years, increasingly accurate assessments of actual soil moisture conditions have been provided by sensors on-board satellites. The image below shows soil moisture levels for Pakistan as mapped by the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) mission. The orange and yellow colours denote dry soil conditions while the green and blue colours indicate increasing moisture levels.

These maps from 2010 were produced during one of the worst floods in recent times and show the increasing extent of flooded areas (blue colours). Approximately 20 million people and 160 000 km^2 of land (20% of the country) were affected. (ESA/CESBIO) [66]







Map showing the pattern of soil moisture regimes for Asia. While the permafrost class may not be visible at this scale, permanent snow and ice exist on the summit of Asia's highest mountains. (FAO/JRC) [65]

Soil moisture regimes

Soil moisture regimes are based on the watertable level and the presence or absence of water that can be used by plants. Soil moisture regimes affect soil formation and the use or management of soils. Soil moisture regime classes include:

- Aridic: arid climate, usually dry. Irrigation required for crop production. Dry soils for significant periods.
- Xeric: semi-arid or Mediterranean climate. Dryland crop possible from stored soil water. Soils can be wet in winter but dry in summer.
- Ustic: semi-arid climate. Rain falls during the growing season. Generally dry in summer.
- Udic: humid climate. Soils usually moist and so irrigation is not generally required for crop production.
- Perudic: precipitation exceeds evapotranspiration in all months, but soil is not saturated for long periods.
- Aquic: soil is saturated by water long enough to cause anaerobic conditions (not visible on the map).

Soil-forming factor 4: Living organisms

All plants and animals (from microorganisms to humans) affect soil formation. Living organisms add organic matter - a key component of soil - through the breakdown of litter and the decomposition of roots. Microorganisms, such as fungi and bacteria, facilitate chemical exchanges between roots and the soil to produce essential nutrients. Both animals and plants allow moisture and gases to seep into deeper layers along burrows and root channels. Humans can impact soil formation through land management practices that disturb natural processes and change the chemical and physical characteristics of the soil. Cultivation practices and burrowing animals mix soil from different horizons, especially from the organic-rich surface layers. The nature of biological activity in the soil is governed by climate, topography and soil characteristics such as depth, texture, structure and chemistry (e.g. pH, salinity).

Ecoregions and biomes

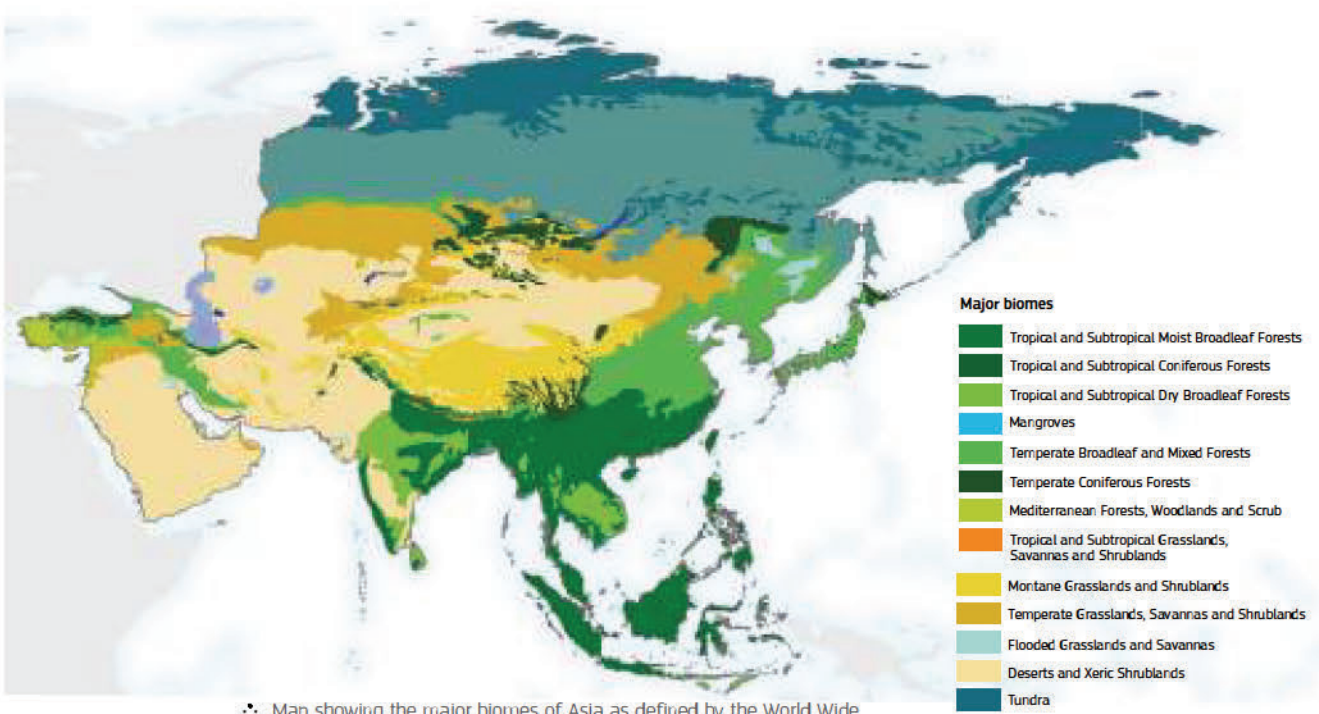
Ecoregions can be defined as relatively large units of land or water containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change [67]. The limits of ecoregions generally follow continental boundaries or major barriers to plant and animal distribution (such as the Himalayas or coastlines). With the exception of southern and southeast Asia (which lie in the Indo-Malay ecoregion), most of Asia lies in the Palearctic ecoregion apart from eastern Indonesia, which is in the Australasia ecoregion.

The Palearctic consists of several bioregions, including the Euro-Siberian region, the Mediterranean Basin, the Arabian Deserts (and also the Sahara), as well as Western, Central and East Asia. In contrast, the Indo-Malay ecoregion cover the Indian subcontinent, Indochina, the Sunda Shelf and the Philippines.

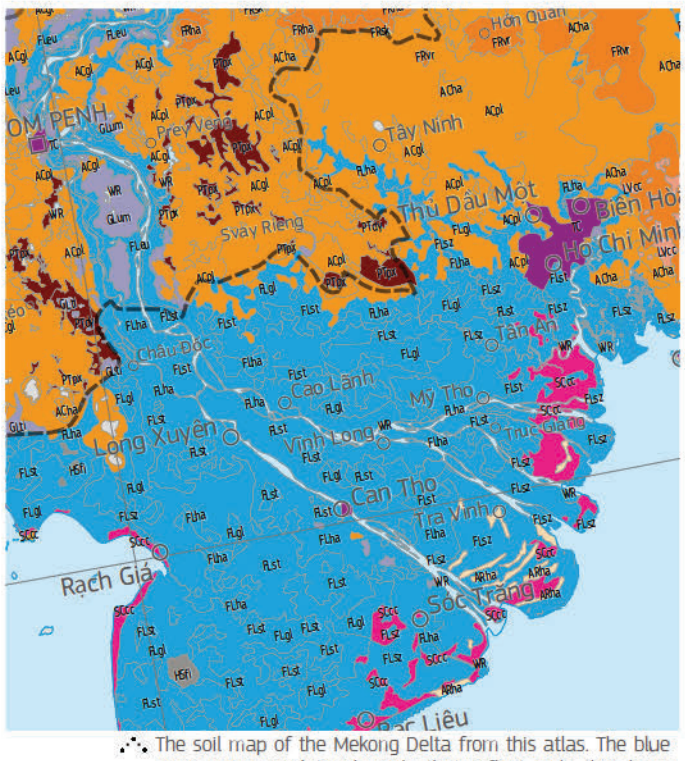
It is worth noting that the Hindu Kush, Karakoram, and Himalaya mountains are a major biogeographic boundary between the subtropical and tropical flora and fauna of the Indian subcontinent and the temperate-climate Palearctic realm.

Similarly, the Wallace Line is a faunal boundary drawn in 1859 by the British naturalist Alfred Russel Wallace that separates the biogeographical realms of Asia and Australia. Asiatic species are found to the west while to the east, a mixture of species of Asian and Australian origins is present. The line runs between the island of Borneo/Kalimatan and Sulawesi (Celebes) and between Bali and Lombok.

Ecoregions are classified by the presence of biomes, which are major plant communities determined by rainfall and climate [67]. Forests, grasslands (including savannah and shrubland) and deserts are distinguished by climate (e.g. tropical, subtropical, temperate) and water conditions. In addition, forests are divided into conifers, broadleafed or mixed.



Map showing the major biomes of Asia as defined by the World Wide Fund for Nature (WWF). The continent is largely characterised by vast expanses of deserts and savannah, with boreal forest and tundra to the north, and tropical and subtropical forests to the south and east. (FAO/JRC) [67].



The soil map of the Mekong Delta from this atlas. The blue areas correspond to Fluvisols that reflect soils that have developed in materials that have been deposited by rivers. The pink areas near the coast denote salt-affected soils. The floodplain of the Mekong towards Phnom Phen is clearly visible and distinct from the soils of higher ground. (JRC/FAO/LJ)

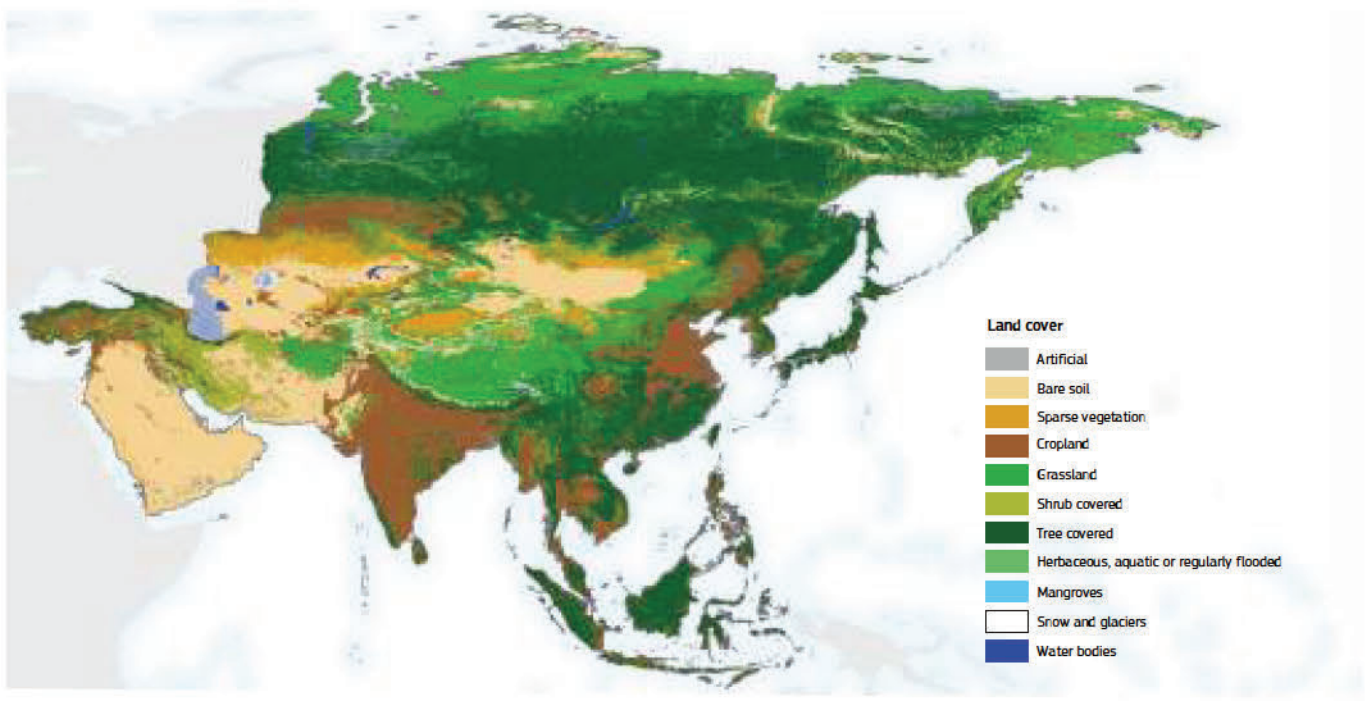


The Mekong Delta in southern Viet Nam, as seen from the European Space Agency's ENVISAT satellite. The Mekong River splits into nine arms, with all flowing into the sea. Because of this, the Vietnamese refer to it as Cuu Long, 'the nine-tailed dragon'. At the end of its course, the tropical wetlands of the Mekong Delta are supplied with rich alluvial deposits that have been eroded, which can be clearly seen flowing out into the sea. The soil of the Mekong Delta is highly fertile. The intense green colour corresponds to cultivated rice paddies. The thin lines running perpendicular to the main rivers are irrigation and drainage canals. (ESA)

Land cover

The term 'land cover' is used to describe the vegetation covering the surface of the planet (which can also be bare ground or unvegetated). It is important to distinguish between the terms 'land cover' and 'land use'. For example, a land cover of mixed shrubs and grass could be a park, an orchard or savanna.

This map on the lower-right shows the principal land cover types of Asia for the year 2010 as mapped by sensors on-board satellites orbiting the Earth [68]. The map shows that the northern, eastern and southeastern regions are covered by extensive forests (dark green) which merge with grasslands (tundra to the north and steppe in the south). The brown areas denote cropland, which indicates the human alteration of natural vegetation patterns. With increasing aridity, the sparse grasslands and shrublands become more evident (yellow colours). Where water is scarce, the bare soils of the deserts are clearly evident (light brown). At the scale of this map, only the extensive mangrove areas in the Bay of Bengal are visible. Blue areas are large lakes.

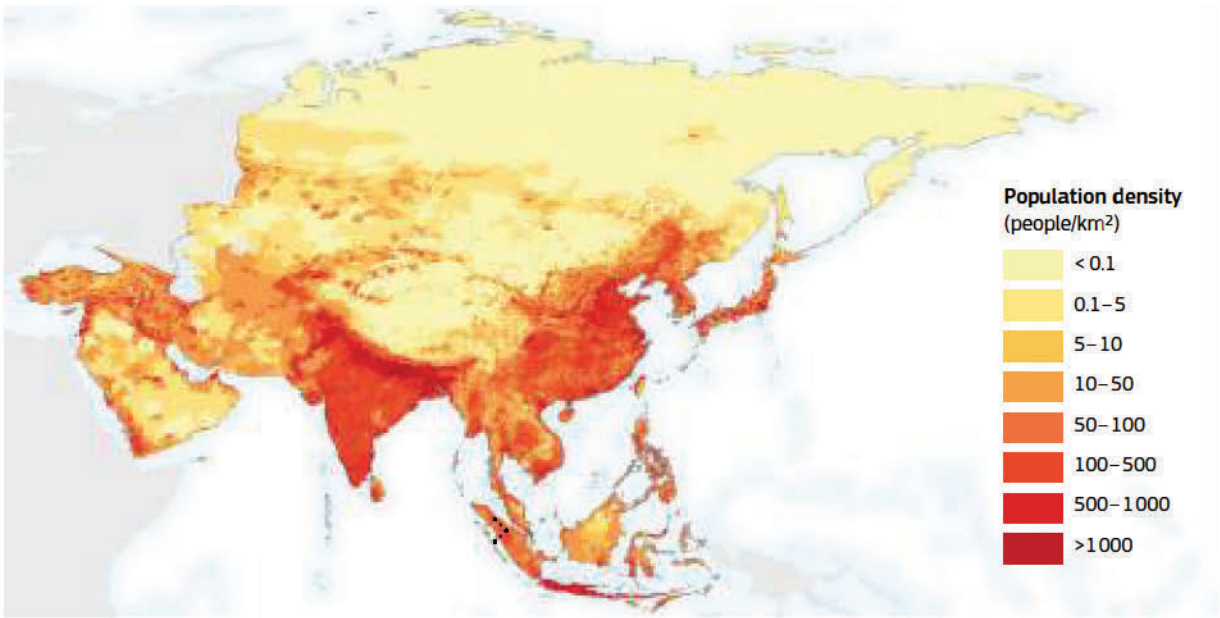


Land cover map of Asia. This map was produced for the year 2010 using data collected by sensors on satellites. (FAO/JRC) [68]

Soil-forming factor 5: Human activities

Originally, human settlement was closely dependent on climate, the availability of water, the length of the growing season and the presence of fertile soils for crops, fodder, timber and fuel. As a consequence, the urban pattern and infrastructure network that is visible today reflects the areas that match these conditions. The map on the right shows population density for Asia (technically this is the estimated number of people living within one square kilometre). This map denotes where people are concentrated [68]; from the less populated (white) areas to the densely populated red and purple regions.

The overall population density for Asia is 150 people per km^2, with 51% living in urban areas. However, this figure reflects the fact that population density is less than 1 person per km^2 in most of the cold tundra regions of Siberia and the Tibetan Plateau while less than 5 for the hot and arid parts of the Arabian Peninsula and most of Central Asia, the southern part of the Russian Federation, Western China and Mongolia. High population densities are evident for India, eastern China and parts of southeast Asia (e.g. the island of Java). The most densely populated country is Bahrain with 2239 people/km^2 while Mongolia is only 2! Population density in Macao in China is over 21500 people / km^2.



Map showing the population density of Asia. Values denote the number of people living in one square kilometre. Large populous cities can be identified as dark dots (e.g. Baghdad, Colombo, Hanoi, Mumbai) while the main urban sprawls of Eastern China, Java in Indonesia and the Ganges-Brahmaputra floodplains are clearly evident. It is worth reflecting that urban populations rely almost entirely on third-parties for food production, which in turn puts increasing pressure on rural soils. (FAO/JRC) [69]



Asian society is rapidly changing from rural to urban, with cities and towns expanding dramatically, in terms of both population growth and extent. The sealing of rural land, agriculturally productive soils and contamination are major issues associated with urbanisation. (ZM)



This striking image shows lights that are visible at night from the Earth's surface. The large bright areas are large cities, which often develop along the coasts (e.g. Amristar, Bangkok, New Delhi, Seoul, Shanghai). While the image is a proxy for urban development and soil sealing, it is striking that vast parts of Asia are thinly populated and unlit. (NASA) [70]

Soil-forming factor 6: Time

While soils are formed through the combined effect of physical, chemical and biological processes which operate over hundreds or thousands of years, these factors rarely remain constant. Time determines the duration for which a set of factors is active. Over geological timescales, new sources of parent material can be introduced to the landscape while changes in global climate patterns are usually accompanied by changes in sea-level, erosion and deposition regimes, vegetation patterns and the shape of the landscape.

Over much shorter timescales (100–1000 years), major changes can occur in the amount and nature of biological activity or hydrological conditions within a soil. Even annual fluctuations in weather patterns (e.g. drought versus above-average rainfall) or changes in the use of the land (conversion of forest to arable farming) can affect soils.

Dramatic changes in soil-forming factors can either lead to an increase in the rate of soil formation or to the destruction, or even complete removal, of the soil. Given constant environmental conditions, all soils must eventually tend towards a state of equilibrium or maturity where the rate of soil formation is equal to the rate of soil loss. However, situations may arise naturally where the rate of destructive processes exceed the rate of accumulation and retention of materials from weathering, plant growth and aerial deposition. At this point, the soil becomes vulnerable to degradation processes such as wind and water erosion.

Young soils

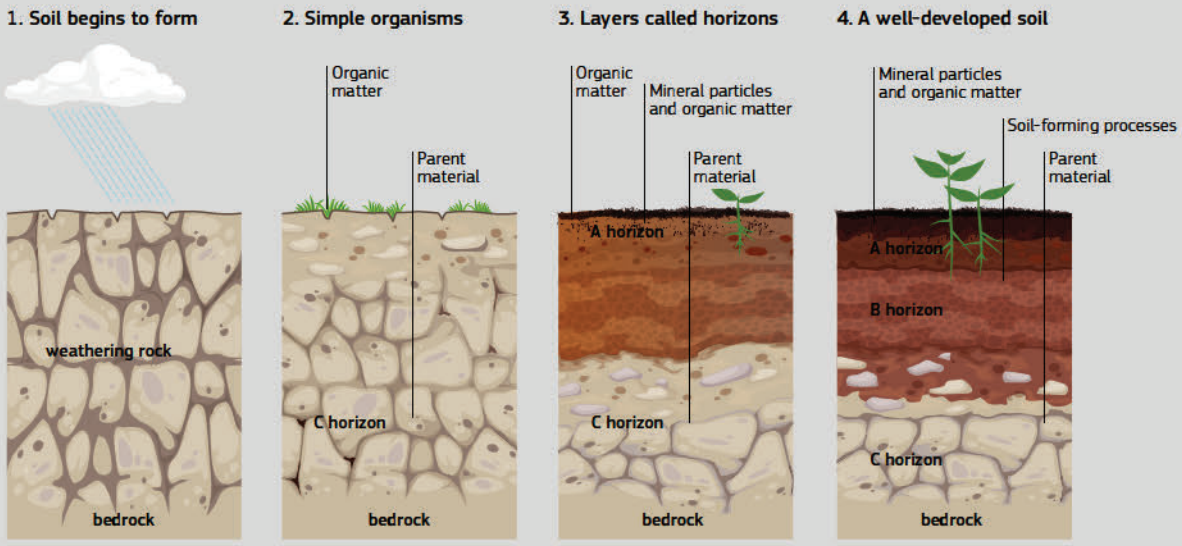
In arid or mountainous areas, clear evidence of any ongoing soil-forming processes, other than the weathering of the parent material, may be difficult to find. Profile development can be negligible as a consequence of the young age and/or slow rate of pedogenic processes because of unfavourable climatic conditions for plant growth (e.g. prolonged drought, low temperatures). The paucity of altered products means that the characteristics (i.e. colour, chemistry) of the soil are very similar to those of the parent material. The development of a thin, unstratified surface horizon or subtle changes in the colour and/or structure below the surface horizon are sometimes the first steps towards the development of an A horizon. With time or changing conditions, the expression of horizons becomes stronger and the soil properties begin to differ markedly from that of the C horizon.

How old are soils?

Working out the age of soils is difficult as evidence of earlier soils may have been destroyed by a continuous cycle of soil-forming processes. Ancient human artefacts can be used to date horizons as long as the material has not been buried by people! Organic matter can be dated based on the natural radioactivity present in all living material while the last time the sun shone on a crystal can also be measured.

Studies have shown that the rate of soil formation varies from around 100 years for 2–5 cm on volcanic ash in the warm, humid tropics (rapid) to 1 cm in 5000 years) on hard rocks in cool temperate climates (slow). A commonly quoted value is 100 years for 1 cm of soil development under permanent grasslands in temperate climates.

There is much debate as to the age of soils in the equatorial region of Asia. Many scientists believe that some soils reflect stable land surfaces that are millions of years old, where deep, highly weathered, iron-rich soils require a very long time to develop. Countering this argument is the view that soil-forming factors operate only at the surface. In this way, deeply weathered sediments are dominated by soil-forming factors driven by current climate and vegetation conditions.



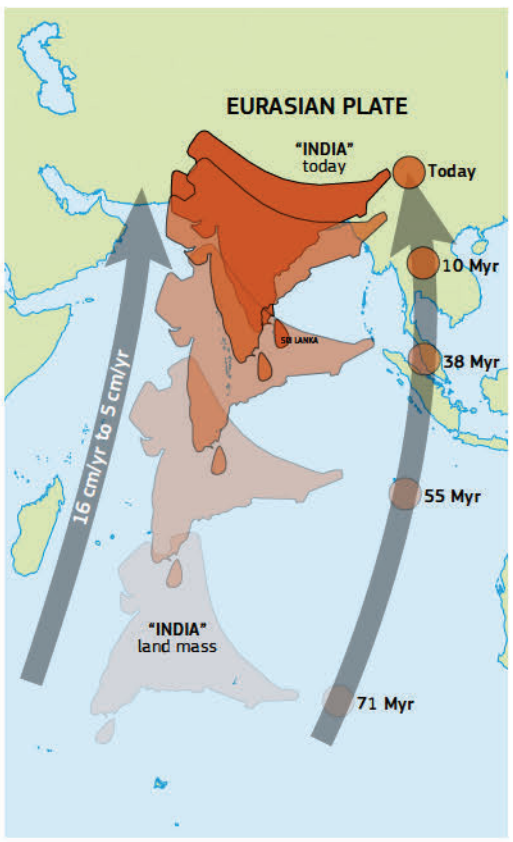
The figure shows the development of a typical mineral soil profile over time in a humid environment. Rocks are broken down to smaller and smaller fragments as a result of weathering. Mosses and lichens leads to the accumulation and decomposition of organic matter on the surface, which eventually leads to the development of an A horizon where organic matter and mineral particles are mixed. Over time, various processes will lead to the development of a B Horizon, reflecting the movement and destruction of materials. (LJ after KRA)

Additional information

The Himalayas





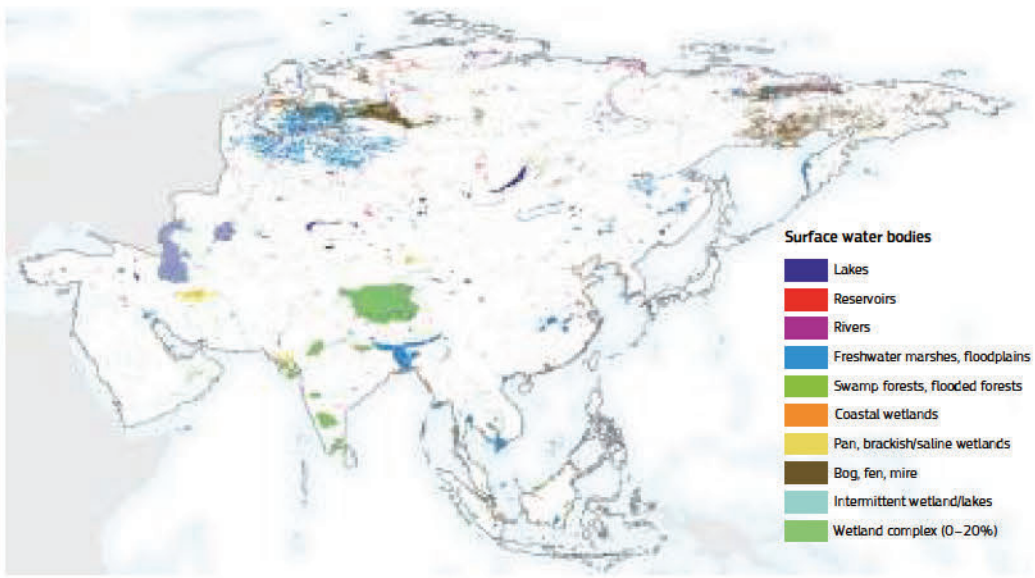


Top left: The Himalayas forms a 2 500 km arc of the world's highest mountains, separating the plains of the Indian subcontinent from the Tibetan Plateau. In the northwest, they merge into the Karakoram and Hindu Kush ranges. This satellite image taken by the MERIS instrument on the Envisat satellite shows the snowy peaks of the Himalayas as white areas running from northern Myanmar in the right to Central Asia in the upper left corner. To the south, the green colours denote the presence of vegetation, which is strikingly apparent on the S-shaped floodplain of the Indus River in the west. To the north, the land becomes increasingly dry and bare. (ESA)

Bottom left: The Himalayas controls the main climatic patterns of large parts of Asia. The colder air of Central Asia is prevented from reaching Southern Asia, which causes humid tropical climates to extend further north than elsewhere. At the same time, they force the moist Southwest Monsoons to rise causing heavy precipitation on their southern slopes. The Hindu Kush-Karakoram-Himalayan system is also the home to extensive snowfields and glaciers. This has coined the term "Third Pole" because they store more frozen water than anywhere else in the world except for the Arctic and Antarctic polar caps. This has huge socioeconomic and cultural significance as if forms the base for the drinking water, food production and livelihoods for almost a quarter of the world's population living in river basins that run off these mountains. (MHS)

Right: the Himalayas are the result of the collision between the Indian and Eurasian Tectonic Plates over the past 10 million years, which is very recent in geological terms! The Himalayas continue to rise by around 5 mm per year. (USGS)

Surface water bodies



The map shows the principal surface water features of Asia (rivers, lakes and wetlands).

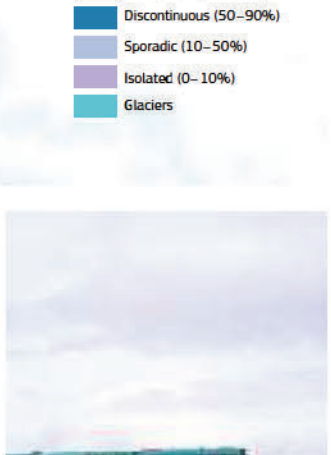
Although a large part of Asia has a dry climate, humid and sub-humid regions possess enough water resources to supply twenty rivers longer than 2 000 km while the 10 largest lakes have a combined surface area greater than 470 000 km².

Many rivers originate in the glaciers of the Hindu Kush, Karakorum, Himalayas and Tibetan Plateau. At 6 300 km long, the longest river in Asia is the Yangtze, which flows from the Tibetan Plateau to the East China Sea (it is also the third longest in the world after the Amazon and the Nile). Other notable rivers include the Yellow, Mekong, Lena, Irtysh, Brahmaputra, Ob, Indus and Yenisey (all longer than 3 000 km). Although much shorter, the Tigres-Euphrates system and the Ganges are globally recognised for their cultural associations while the Ural River marks the boundary of Asia and Europe. In arid areas, such as Western Asia, rivers tend to be ephemeral, where water only flows after rainfall.

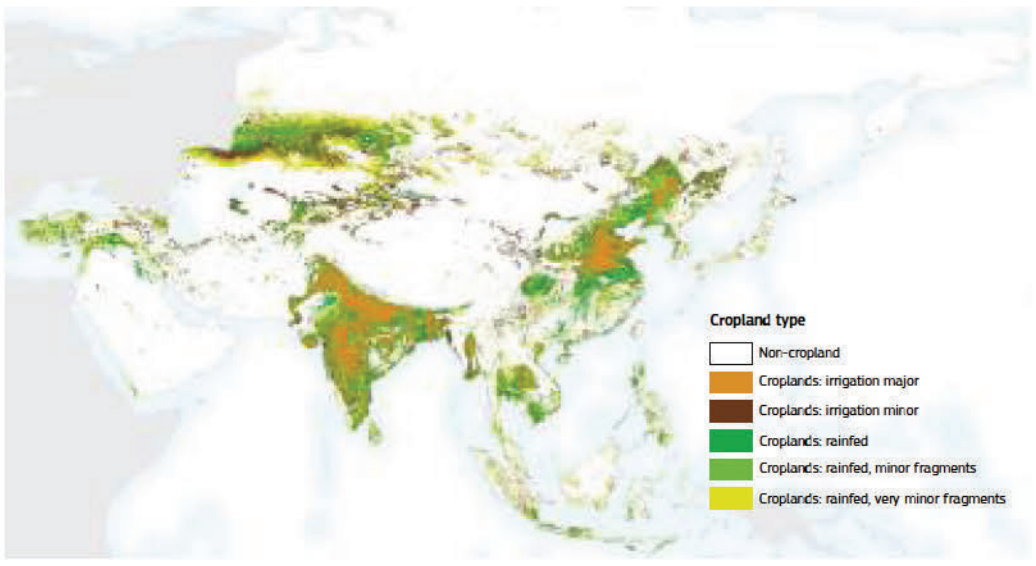
The Caspian Sea is the largest lake in the world, and contains around one-third of the planets freshwater! Like the Aral Sea and Lake Uvs in Mongolia, it is the remains of a much larger water body. Lake Baikal is both the oldest and deepest freshwater body on Earth.

Many drainage basins, especially in Central Asia have no outflow to the sea. This results in salt lakes and salt-affected soils (e.g, the Dead Sea, Lake Balkhash, Lake Van). In regions with volcanic activity, many lakes have formed in the craters of extinct volcanoes.

The vast West Siberian Wetlands, along with the marshes of the Tigris and Euphrates Rivers and the mangroves and forest peats of southern and southeast Asia, are some of the most important wetlands in the world. (FAO) [72]



Croplands



The areas on this map shows the extent of different types of crop cultivation patterns across Asia as mapped by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS) for the Global Food Security-support Analysis Data (GFSAD) initiative. The map shows the dominant crop at a resolution of 1 km, nominally for the year 2010 based on data collected by the Thematic Mapper sensor on board the Landsat series of satellites.

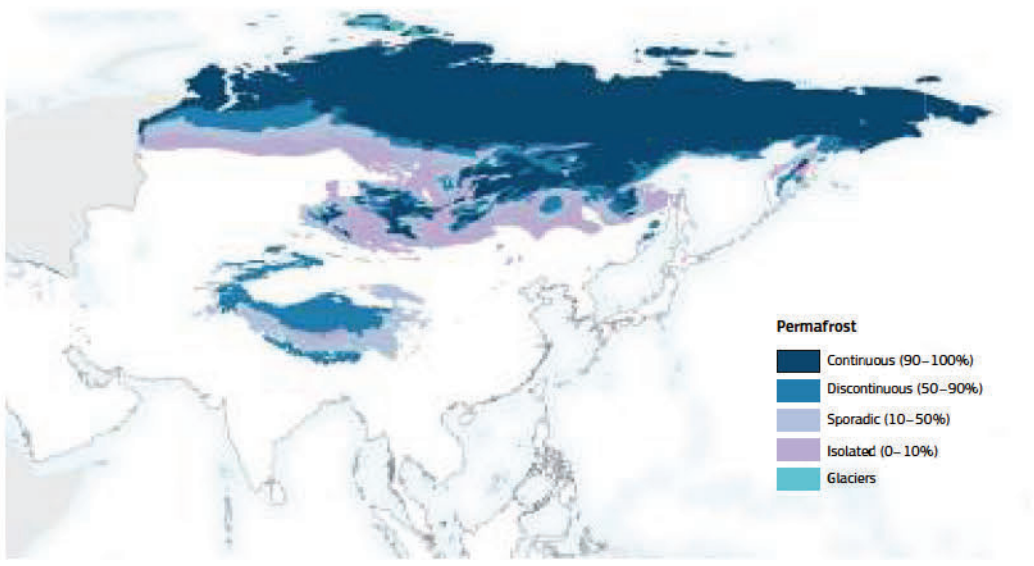
The map shows the location of the five major global cropland types (i.e. wheat, rice, corn, barley and soybeans), which in turn occupy about 60% of all global cropland areas. In addition, each crop is divided into irrigated or rainfed conditions.

Such a map is important in the context of soil-forming factors as it highlights areas where there has been significant modification of the soil in order to support food production. Through agriculture, fertile soils and the presence of water have provided humans with the ability to produce food, feed, fuel and fibres for our overall well being. However, in addition to a change in natural vegetation patterns, the cultivation of the soil generally involves a high level of disturbance through ploughing and harvesting and alters the natural cycling of nutrients in soil. Intensive cultivation and harvesting of crops can effectively mine soil nutrients, including carbon. In some conditions, additional efforts, such as irrigation or drainage to remove excess water, are needed to support the cultivation of crops. These activities modify the soil characteristics and lead to differences with respect to 'natural' conditions.

In recent years, there has been an increasing awareness in sustainable soil management practices that protect the environment, mitigate the effects of climate change and ensure human health (see pages 200-201). (FAO/JRC) [71]



Permafrost



The map shows the extent of soil that has been permanently frozen (i.e. below 0 °C) for more than two years. It is commonly referred to as permafrost. This forms where the mean annual soil temperature is lower than the freezing point of water. Where not covered by ice, permafrost can be overlain by a layer of unfrozen soil or gravel. Where conditions permit, the uppermost part of the permafrost can thaw during warmer summer months before freezing again in the winter. This zone is known as the 'Active Layer' and can vary in thickness according to the climate, vegetation and soil characteristics. Permafrost can extend to a depth of several hundred metres, although many consider very deep permafrost to be relicts from the last Ice Age.

The extent of permafrost is defined according to its areal extent. Where mean annual soil surface temperature remains below −5 °C, then the permafrost does not thaw. This is referred to as Continuous Permafrost, where between 90-100% of the area is affected. Where the mean annual soil temperature is only slightly below 0 °C, permafrost will form only in sheltered spots with a northerly aspect, which means that between 50-90% of the land area is affected. This is referred to as Discontinuous Permafrost. Where less than 50% of land is affected, this is referred to as Sporadic Permafrost.

Most of the area affected by continuous permafrost is found in Siberia, generally above 55 °N latitude. Due to the higher elevation, this area extends southwards into Mongolia. Discontinuous and sporadic permafrost extends further southwards in Siberia and Mongolia, where it can be found almost adjacent to the Gobi Desert. Discontinuous and sporadic permafrost can also be found on the Tibetan Plateau and on the high ground of the Hindu Kush, Karakorum and Himalayas.

Permafrost is an important soil-forming processes as the constant freezing and thawing produced distorted horizons, sorted soils and a variety of patterned grounds. (Map: FAO/JRC; Image: HC) [73]

Asia – the political view


See Soil Atlas of The Northern Circumpolar Region
See Soil Atlas of Europe
See Soil Atlas of Africa
RUSSIAN FEDERATION
KAZAKHSTAN
MONGOLIA
CHINA
INDIA
INDONESIA
MALAYSIA
JAPAN
PHILIPPINES
TÜRKIYE
IRAQ
SAUDI ARABIA
IRAN
PAKISTAN
AFGHANISTAN
OMAN
YEMEN
SRI LANKA
MALDIVES
THAILAND
VIET NAM
MYANMAR (BURMA)
BANGLADESH
NEPAL
BHUTAN
DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
REPUBLIC OF KOREA
TIMOR-LESTE
BRUNEI DARUSSALAM
SINGAPORE
CAMBODIA
LAO PEOPLE'S DEMOCRATIC REPUBLIC
UNITED ARAB EMIRATES
SYRIAN ARAB REPUBLIC
LEBANON
JORDAN
KUWAIT
QATAR
BAHRAIN
CYPRUS
GEORGIA
ARMENIA
AZERBAIJAN
TURKMENISTAN
UZBEKISTAN
KYRGYZSTAN
TAJIKISTAN
ISLAMIC REPUBLIC OF IRAN
OCCUPIED PALESTINIAN TERRITORY
ASTANA
ULAANBAATAR
BEIJING
PYONGYANG
SEOUL
TŌKYŌ
Moscow
Saint Petersburg
Novosibirsk
Yekaterinburg
Omsk
Krasnoyarsk
Irkutsk
Vladivostok
Khabarovsk
Yakutsk
Magadan
Petropavlovsk-Kamchatskiy
Sapporo
Hakodate
Osaka
Nagoya
Shanghai
Taipei
Hong Kong
Guangzhou
Shenzhen
Chongqing
Tianjin
Shenyang
Harbin
Qingdao
Dalian
Wuhan
Nanjing
Xi'an
Chengdu
Kunming
Urumqi
Lhasa
Delhi
Mumbai
Chennai
Kolkata
Karachi
Lahore
Dhaka
Yangon (Rangoon)
Bangkok (Krung Thep)
Hanoi
Ho Chi Minh City (Saigon)
Kuala Lumpur
Singapore
Jakarta
Surabaya
Bandung
Medan
Palembang
Makassar
Manado
Manila
Quezon City
Davao
Tehran
Baku
Yerevan
Tbilisi
Istanbul
Ankara
Izmir
Damascus
Beirut
Amman
Baghdad
Basra
Riyadh
Jeddah
Sana'a
Muscat
Abu Dhabi
Dubai
Doha
Manama
Kabul
Islamabad
Peshawar
Faisalabad
Multan
Jaipur
Agra
Lucknow
Varanasi
Patna
Kanpur
Ahmedabad
Surat
Pune
Hyderabad
Bengaluru
Kochi
Colombo
Thiruvananthapuram
Madurai
Coimbatore
Visakhapatnam
Kolkata
Chittagong
Mandalay
Yangon
Hai Phong
Da Nang
Nha Trang
Phnom Penh
Kota Kinabalu
Kuala Terengganu
Banda Aceh
Pontianak
Samarinda
Balikpapan
Banjarmasin
Bandar Lampung
Cilacap
Malang
Denpasar
Jayapura
Sorong
Ternate
Ambon
Kushiro
Niigata
Kobe
Fukuoka
Hiroshima
Kagoshima
Miyazaki
Nagasaki
Busan
Incheon
Daejeon
Gwangju
Ulsan
Jeju-do
Changchun
Jilin
Shenyang
Dalian
Qiqihar
Daqing
Harbin
Mudanjiang
Vladivostok
Khabarovsk
Komsomol'sk-na-Amure
Yuzhno-Sakhalinsk
Petropavlovsk-Kamchatskiy
Yakutsk
Magadan
Anadyr'
Provideniya
Pevek
Chokurdakh
Norilsk
Dikson
Khatanga
Tiksi
Ust'-Olenek
Zhigansk
Olenek
Yessey
Ust'-Port
Nordvik
Severo-Kuril'sk
Nevel'sk
Sakhalin
Kamchatka
Okha
Ayan
Nerjungri
Neryungri
Udachnyy
Zyryanka
Markovo
Srednekolymsk
Verkhoyansk
Oymyakon
Batagay
Tiksi
Ust'-Kut
Bratsk
Ust'-Ilimsk
Nizhneudinsk
Tulun
Angarsk
Ulan-Ude
Chita
Borzya
Nerchinsk
Mogocha
Tynda
Shimanovsk
Svobodnyy
Blagoveshchensk
Zeya
Skovorodino
Norsk
Chumikan
Okha
Sakhalin
Kamchatka
Petropavlovsk-Kamchatskiy
Yelizovo
Vilyuchinsk
Palana
Ognon
Sangar
Verkhoyansk
Oymyakon
Batagay
Tiksi
Zhigansk
Olenek
Yessey
Ust'-Port
Nordvik
Dikson
Khatanga
Severo-Kuril'sk
Nevel'sk
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Okha
Ayan
Nerjungri
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Anadyr'
Provideniya
Pevek
Chokurdakh
Norilsk
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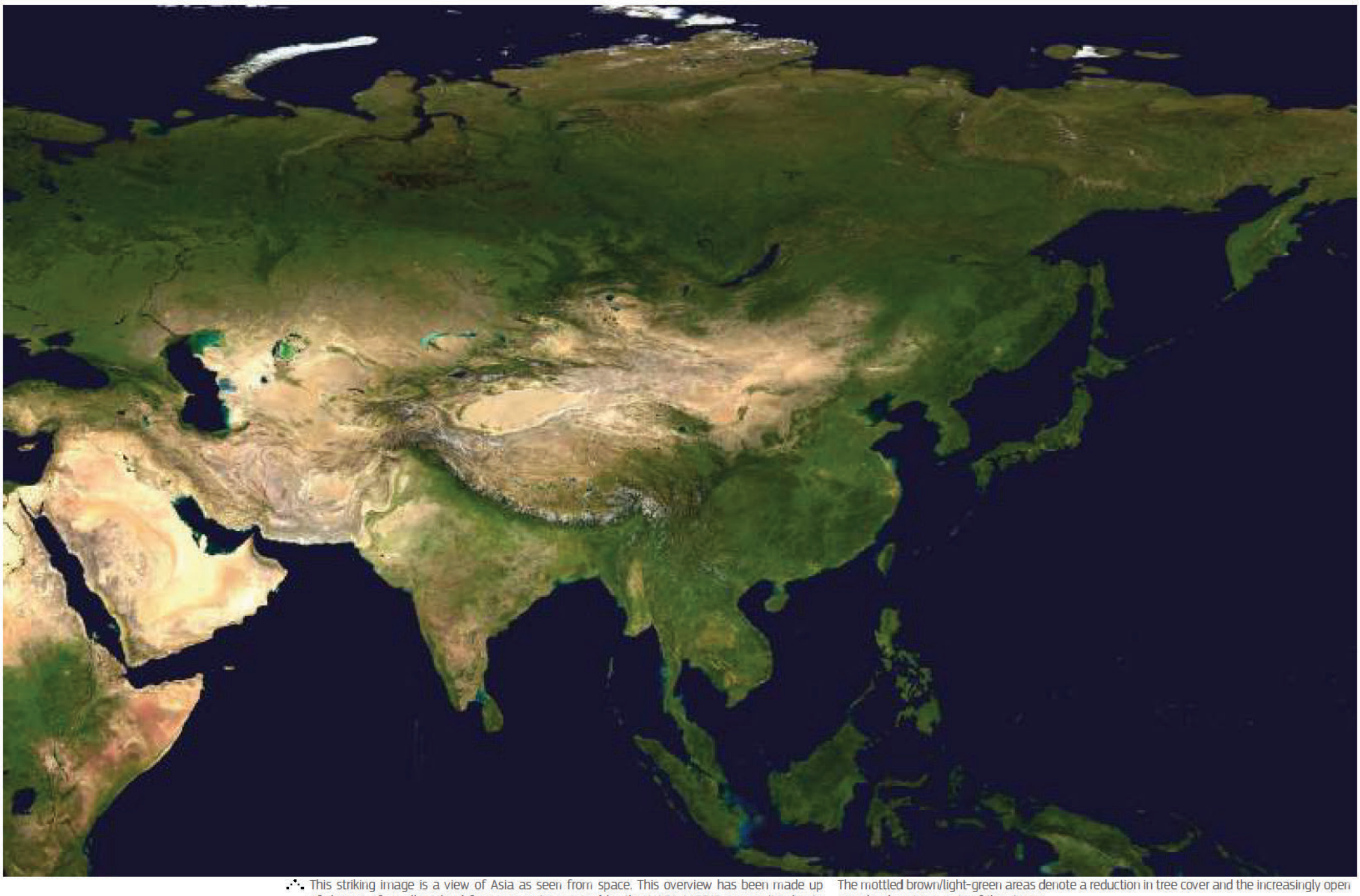
Zhigansk
Olenek
Yessey
Ust'-Port
Nordvik

Asia – the real view?



This striking image is a view of Asia as seen from space. This overview has been made up of dozens of smaller, cloud-free segments acquired by the NASA MODIS sensor (Moderate Resolution Imaging Spectroradiometer) from June to September 2001. The MODIS sensor is carried on-board a satellite that orbits the Earth every 1-2 days at an altitude of 705 km and is an example of remotely sensed data, which, through computer enhancement, can be viewed as an image. In this case, the image is displayed in near true colour which means that it appears almost as if viewed by a person in space.

Green tones correspond to vegetated areas: the tropical rainforests of Southeast Asia and the boreal forests of Siberia are very evident, as are the intensively cultivated soils of the Indus River floodplain.

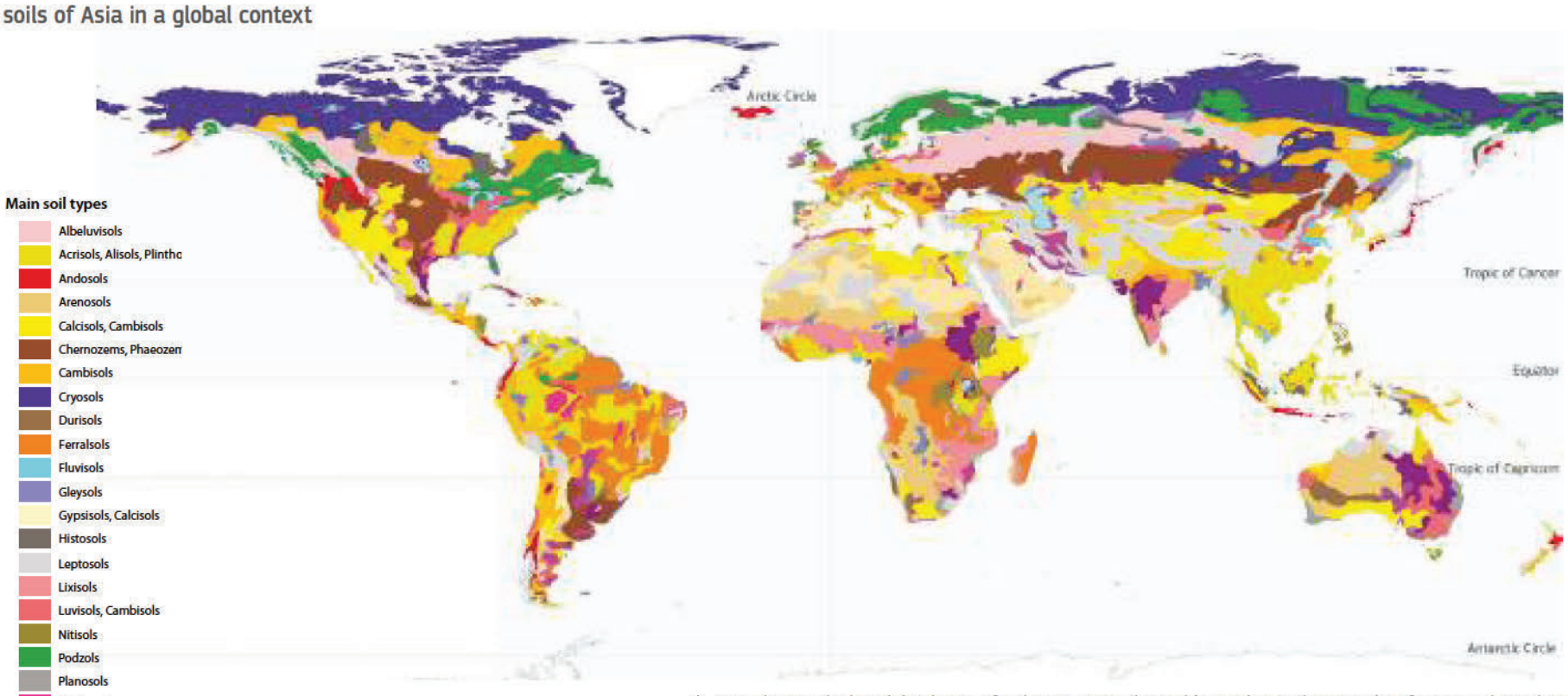
The mottled brown/light-green areas denote a reduction in tree cover and the increasingly open grassland environments of the steppe.

In arid, regions, white and bright yellow colours correspond to sand seas and unvegetated surfaces where the underlying geology is evident. The distinctive oval feature in the centre of the image is the Tarim Basin in Northwest China, which contains the Taklamakan Desert and is bounded by the Tibetan Plateau to the south.

The blue features are water bodies (e.g. the Caspian Sea is clearly visible), with lighter tones in Central Asia reflecting shallower water depths. The path of major rivers running through Siberia to the Arctic Ocean are clearly visible. At this scale, urban areas are difficult to visualise.

The details in the ocean are derived from the General Bathymetric Chart of the Oceans. (NASA)

The soils of Asia in a global context



Map showing the broad distribution of soil types across the world according to the WRB Classification and Correlation system (see pages 55-67). The different colours indicate variations in the chemical, physical, and biological characteristics of soils which, in turn, are a reflection of the principle soil-forming factors described on the preceding pages. The map clearly shows that Asia has a unique pattern of soils that is not replicated on the other continents. Organic-rich Histosols and permafrost-affected Cryosols cover the northern latitudes (and higher elevations for the latter), which in turn give way southwards to the Podzols of the boreal forests and the grassland soils of the steppe region. Weakly developed (Arenosols, Cambisols, Regosols) and saline (Solonchaks, Solonetz) soils of Western and Central Asia reflect the generally arid conditions across these regions. Dark, clay-rich Vertisols are a major feature of central and southern India while a complex arrangement of Acrisols, Ferralsols, Alisols and Luvisols reflect parent materials and weathering patterns under equatorial climatic conditions. Histosols are also extensive in the wetlands of southeast Asia. Leptosols, and to an extent Cambisols, denote the major mountain chains of Asia, while Fluvisols denote soils formed in parent materials deposited by water. (FAO/JRC) [74]

Soil-forming processes

Principle processes

The specific characteristics of an individual soil are determined by a range of soil-forming processes that operate during its lifetime. These biological, chemical and physical actions add, move, transform, remove and destroy material within the soil. It is important to recognise that these processes can change over time in response to the soil-forming factors described in the preceding pages. Soils can exhibit several distinct and different phases of formation.

Weathering

The majority of soils contain varying amounts of stones and minerals that are derived from solid rock or sediments by a process known as weathering. Weathering results in the physical destruction of the rock structure which in turn facilitates chemical changes to the constituent minerals. The material produced by weathering is known as regolith and can vary from a few millimetres to several metres thick. There is often a sharp boundary between the bottom of the regolith and the bedrock. This narrow zone is known as the weathering front and is the focus of active weathering of the parent material. Weathering also continues within the soil body.

In principle, there are two main types of weathering: physical and chemical. Some people consider biological weathering but, in reality, this can be considered as a manifestation of physical and chemical actions (see below).

Physical Weathering

Physical weathering results in the disintegration of rocks without major changes to their chemical composition. Being poor conductors, only the outer few centimetres of rocks heat up while deeper parts remain cool. Minerals in rocks expand at different rates when heated and in preferred directions according to their crystal structure. The repeated cycle of heating and cooling, characteristic of desert climates, causes stress between mineral grains. These eventually develop into cracks that weakens the rock surface, which eventually falls away.

A similar process occurs in cold climates that are typical of high latitudes or altitudes. When water freezes, its volume increases by 10%, causing tremendous pressures if it occurs in confined spaces such as crevices in rocks. Recent research suggests that the expansion of ice crystals also generates huge pressures on unfrozen water in rock pores, which in turn, causes the rock to fracture.

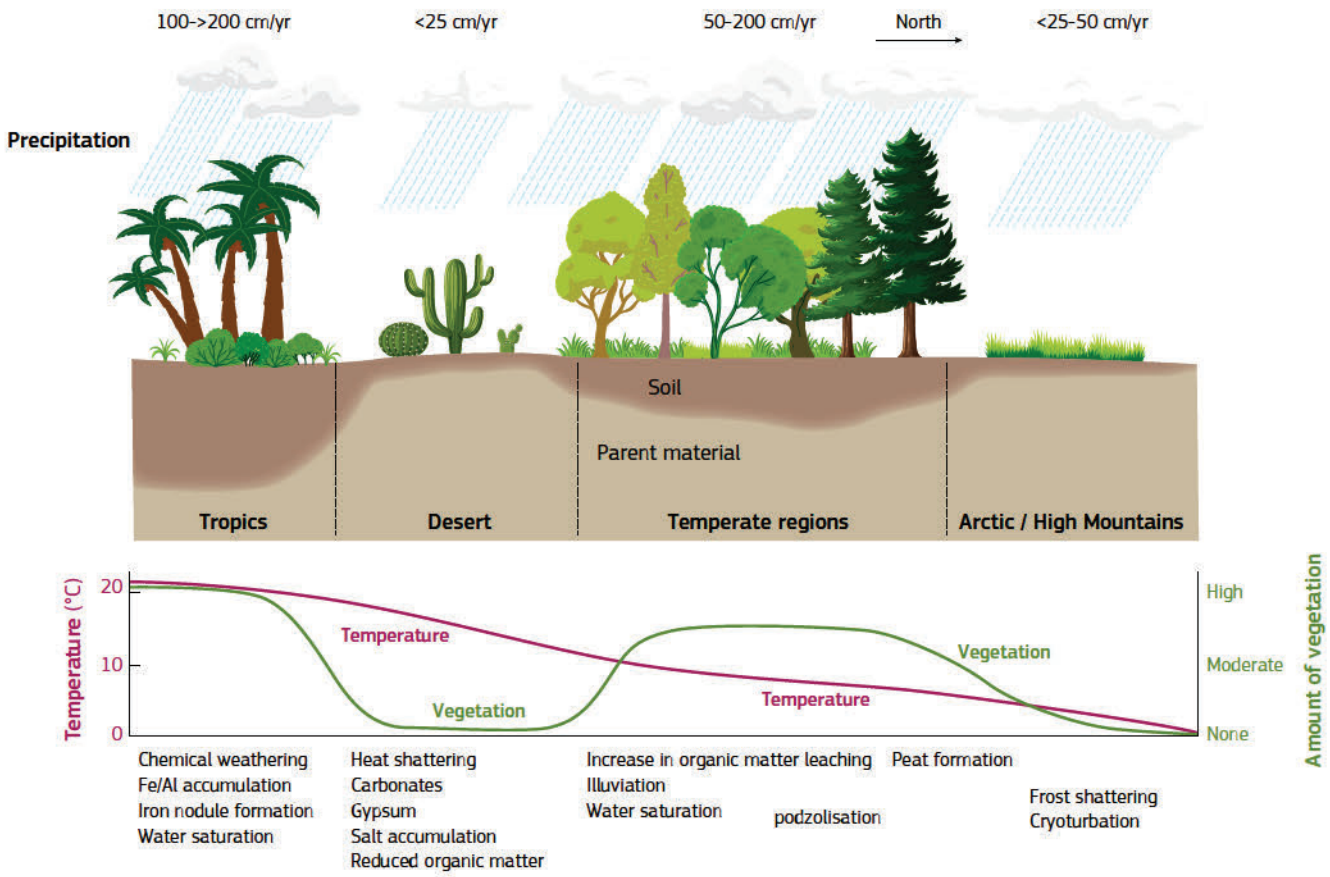


A clear example of physical weathering of shale. Physical weathering produces a layer of angular loose material known as talus or scree that covers the underlying solid rock. The photograph shows the breakdown of the bedrock along vertical joints and horizontal bedding planes. (AJ)

Minerals vs Nutrients

Minerals are naturally occurring solid substances with a characteristic chemical composition and crystal structure. They are formed through geochemical or biological processes. Rocks are composed of one or more minerals. For example, calcium carbonate is the main constituent of limestone while granite is made up of mica, quartz and feldspar.

Nutrients are chemical elements required by organisms to live and grow. Nutrients can be produced by an organism or taken from its environment. Plants absorb nutrients that are released from weathered minerals in the soil. They are a critical part of the food chain.



The above diagram shows the main soil-forming processes along a hypothetical transect running from the equator (on the left) to the Arctic (on the right). As indicated by the dark colour representing soil thickness, weathering processes are strongly linked to climate, which in turn drive the availability of organic matter in soils. Where precipitation exceeds evapotranspiration, soils can become waterlogged or materials tend to move deeper into the soil profile due to leaching or the loss of clays by percolating rainwater. In drier, warmer climates, lime, gypsum and salts tend to rise through the soil through evaporation and capillary action. In hot and cold deserts, physical weathering dominates while in the hot humid tropics, chemical and biological processes tend to influence soil characteristics. Some soil-forming processes depend on the specific properties of the parent material (e.g. shrinking/swelling clays) or their location in the landscape (e.g. acid sulphate), which means that they are not restricted to a specific climatic setting. (LJ after THE)

Chemical Weathering

Chemical weathering is a gradual and constant process that is caused by the reaction between water (often in the form of an acid) and minerals within the parent material. These reactions lead to changes in the molecular structure of rocks and the creation of new or secondary minerals. Chemical weathering is much stronger if temperatures and humidity levels are both high.

Rainfall is the key factor in chemical weathering. Atmospheric gases or compounds produced by root respiration and the decay of organic matter, dissolve in rainwater to produce acids. Some minerals, due to their natural solubility (e.g. salts, gypsum) or inherent instability relative to surface conditions (e.g. primary silicate minerals such as feldspar, mica, augite, hornblende and olivine), will slowly dissolve on contact with these acids to form secondary products. These range from clay minerals (e.g. kaolinite, illite, vermiculite and smectite), iron, aluminium (hydr)oxides, and carbonates to nutrients such as calcium and potassium.

One of the most well-known solution weathering processes is de-calcification, which occurs on parent materials that are rich in calcium carbonate (e.g. limestone and chalk). Rain combines with carbon dioxide in the atmosphere (or an organic acid in plant litter) to form a weak carbonic acid that reacts with calcium carbonate in the limestone to form calcium bicarbonate, which is then removed by water. This process can be even stronger if gases such as sulphur dioxide and nitrogen oxides are present in the atmosphere. These oxides react with the rainwater to produce stronger acids with a pH as low as 3.

Water molecules can break up into positively charged hydronium (H_3O^+) and negatively charged hydroxyl (OH^-) particles (see Glossary for ion and cation). These small and mobile particles can actually penetrate the crystal lattice of silicate and carbonate minerals. Those with positive charge upset the balanced state of the mineral in question causing various cations to be released into the soil. This process is known as hydrolysis and is one of the underlying factors of soil fertility (see page 20).

Another chemical process involves the simultaneous loss (referred to as oxidation) and gain (referred to as reduction) of electrons in substances. These exchanges are referred to as redox reactions. As materials become oxidised, the unbalanced charge will degrade a material's structural composition.



The destruction of bedrock through both physical and chemical weathering is clearly visible in this photograph. The red rock on the right is a dolerite dyke that has intruded into granite (visible to the left). Physical weathering processes have caused blocks of granite to break away while the dolerite breaks down more easily to produce the distinctive red coloured finer material that is accumulating at the foot of the slope. It is very evident that the dolerite is weathering more rapidly than the granite as it is receding into the cliff face. It should be noted that approximately 15 cm of soil has developed above the dolorite while bare rock is still visible on the surface above the granite. (EM)

Biological weathering

Biological weathering is caused by the activities of living organisms, both flora and fauna. Biological weathering has both physical and chemical aspects.

Examples of physical biological weathering include the loosening of rock by roots growing into cracks, surface breakdown from the roots of lichens and burrowing creatures such as termites that mix or churn the soil.

Chemical biological weathering can be caused by bacterial activity or by strong organic acids being released from plant roots or litter. A recent study demonstrated a 3-4 fold increase in weathering rate under lichen-covered surfaces compared to recently exposed bare rock surfaces. Biological weathering factors in Asia are highly significant.

Soils and the accumulation of soil organic matter

The accumulation and decay of organic matter are critical soil-forming processes. Soil organic matter is derived from the remains and exudes of living organisms (predominantly plants) in various stages of decomposition (see below).

Most fresh plant remains contain 60–90% water. The remainder is made up of various organic compounds such as sugars, starches, proteins, carbohydrates, lignins, waxes, resins and organic acids. These substances are primarily composed of carbon, oxygen and hydrogen, which occur with much smaller amounts of nutrients and micronutrients that are essential for plant growth (e.g. nitrogen, potassium, magnesium, zinc).

Decomposition

Decomposition is a biological process by which organic substances (both plant and animals) are broken down after death into simpler organic or inorganic matter. Decomposition can occur due to a number of different processes, which can occur simultaneously. Insects and other soil invertebrates can eat the soft tissues or break up large pieces. The process can be augmented by fungal and microbial colonisation. Some components, such as lignin, posses a very complex chemical structure and therefore may need longer to break down. In general, the following substances are listed according to their rate of decomposition, with the most rapid first: sugars-starches-simple proteins; proteins; hemicelluloses; cellulose, lignins and fats. Substances that are resistant to microbial action are generally referred to as humus (see adjacent text).

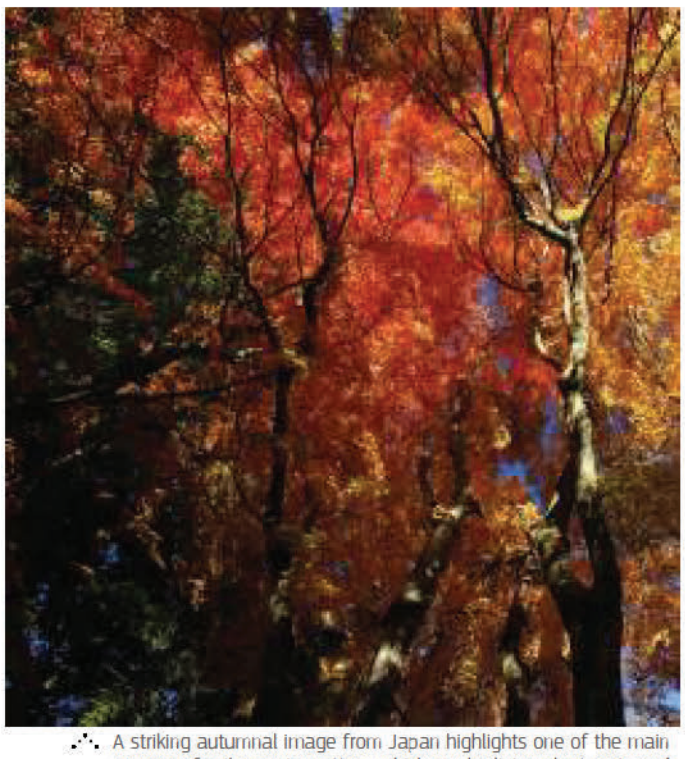


The rich, dark colour of this soil is due to its high levels of organic matter, which is well mixed within the soil, often due to the actions of soil dwelling organisms such as earthworms. (CU)

Climatic factors such as temperature, humidity and soil characteristics, can affect decomposition rates. For example, the breakdown of organic matter is much more rapid in areas such as Southeast Asia where the climate is hot and humid compared to cold tundra or high mountain chains. Very wet (peatlands where there is a lack of oxygen) or very dry (deserts) conditions can slow decomposition. Decomposition rates are also lower in acidic soils and in soils with high levels of clay minerals where organic matter can be strongly bound to soil particles and thus protected from microbial activity. Decomposition is always accompanied by the release of carbon dioxide. Any disturbance of the soil, such as digging or ploughing, increases the amount of oxygen in the soil, which is accompanied by an increase in microbial activity and higher decomposition rates.

Organic matter is utilised by a variety of soil microorganisms such as bacteria, fungi and earthworms, as both a source of energy (to function) and materials for building their bodies. During this process, water, carbon dioxide and the various organic compounds listed above are converted by a process known as mineralisation into inorganic compounds such as ammonium (NH_4^+), phosphate ($H_2PO_4^-$) and sulphate (SO_4^{2-}). This process, together with the release of CO_2 from the soil, is vital for the growth of plants. Some of these compounds are immobilised through being incorporated into the bodies of soil organisms and are only available after the death of the organism.

The annual return of plant and animal residues to the soil varies with the climate, the type of vegetation and how the land is used. Tropical rainforests return about 15 tonnes of litter per hectare each year compared to around 8 tonnes for temperate grasslands. This rate fall to 2 tonnes for agricultural soils and only 0.1 tonnes for mountain forests. Root decay contributes a further 30–50% of the amount produced from leaf fall.



A striking autumnal image from Japan highlights one of the main sources of soil organic matter - which can be living plant roots and animals, their decomposing remains, and microorganisms and their excretions. (ST)

Humus

The decomposition of organic matter leads to the synthesis of new materials, collectively known as humus – a stable, dark brown or black, amorphous material which is less susceptible to decomposition. Humus essentially consists of carbon, oxygen, hydrogen and nitrogen, with organic carbon accounting for 40–60% by weight. It is found predominantly in the organic-enriched mineral horizons at the soil surface.

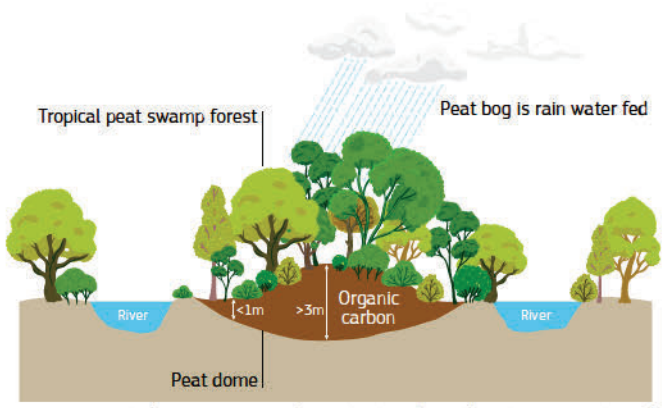
The amount and bio-chemical properties of humus governs several soil functions. Humus-rich layers contain considerable nutrient stocks, which are mineralised upon decomposition so that they can be used by plants. The chemical composition of humus reflects the plants providing the litter, the characteristics of the soil (especially mineralogy and texture) and climate.

Peat formation

Peat is a dark, unconsolidated, organic-rich material that slowly develops when the decay of plant material is repressed in anaerobic conditions (a lack of oxygen due to waterlogged conditions found in bogs, fens, moors, mires or swamps) or by low temperatures. Three main types of peat material are recognised: sapric (very decomposed, hardly any recognisable plant fibres), hemic (moderately decomposed) and fibric (slightly decomposed).

In Asia, peat deposits are most extensive in the northern tundra regions where they occur in a variety of forms, ranging from blanket and raised mires (rain-fed), fens (groundwater-fed), palsa bogs (mounds with a frozen core, separated by wet depressions).

There are significant peat deposits in the humid topics of Southeast Asia (and Japan). In these areas, peat occurs either as fens in basins and river floodplains or in forested swamps (both rain- and groundwater-fed). The country with the greatest extent of peatland in the tropics is Indonesia, covering an area of 200 000 km².



Peat domes are very characteristic of southeast Asia. Continued flooding leads to the creation of higher river banks that result in the development of shallow basins between rivers. Under high rainfall, any litter on the floor of these poorly-drained basins will be periodically submerged, only partially decompose, which leads to the accumulation of peat. As the forests develop, the input of organic matter increases causing the peat to become thicker. A higher water table at the centre creates differential decomposition rates leads to the formation of a distinct dome shaped surface. (after WI)

Organic matter as a soil-forming process

Weathered parent material or recently deposited soil material provide an excellent rooting medium for plants and seeds. Generally, such media are composed of a relatively loose matrix of mineral material. This means that newly forming roots, especially from germinating seeds, can develop in a freely-draining, nutrient-rich matrix that also permits the movement of oxygen.

As plants die, their residues fall on the soil surface. As these decompose, they are mixed with mineral and rock fragments by soil-dwelling organisms and water. In parallel, plant roots can also decay under the surface, thus extending the amount of organic matter deeper into the soil. Over time, and as the amount of organic matter increases, the first hint of layering appears as the upper part of the soil becomes slightly darker in colour that deeper layers. This is the start of the surface horizon.

Acids released from decaying organic matter accelerate the breakdown of minerals, thus releasing soluble nutrients and secondary minerals, such as clay minerals and iron or aluminium oxides. The concentrations of these substances may increase in the surface layer. However, in humid conditions, percolating rainwater may move them downwards so that they accumulate at a lower depth when the movement of water is slowed or blocked. This action contributes to further horizon and soil profile development, often where upper parts are depleted of nutrients and clays while lower layers are enriched.

As these physical and chemical changes take place, they support an evolving community of surface vegetation and soil dwelling organisms, which in turn, affect soil-forming processes.



Young soils tend to be identified through the lack of horizon development within the soil profile or by only exhibiting a thin surface or upper layer, often reflecting the recent accumulation of organic matter. Horizons with notable accumulations or depletions of iron or aluminium oxides and clays are absent or only beginning to become evident. In this profile from Kazakhstan, the darker topsoil (to a depth of around 25 cm) reflects the accumulation of organic matter, largely from the roots of grasses. The subsoil still shows a close similarity to the parent material. (SKV)

Organic v Mineral

Very often, people talk about mineral or organic soils. In these instances, they are referring to the nature of the material that makes up the soil. In this atlas, organic soils have

- either a layer of organic material that starts at the surface that is at least 10 cm thick and is in contact with ice, bedrock or rock fragments;
- or a 40 cm thick layer of organic material within 40 cm of the surface (a thicker layer is required if the organic material is moss).

Organic materials should contain at least 20% organic carbon or be saturated by water for at least 30 consecutive days in most years.

If these criteria are not met, the soil is referred to as mineral. However, mineral soils can possess organic-rich surface horizon.

Soils conditioned by cold climates

As shown in the preceding section on soil-forming factors, it is clear than many parts of Asia are characterised by low temperature, either throughout the year or only notably in winter.

The most striking characteristics of soils in these regions are low soil temperatures often with a pronounced change in temperature with depth, the presence of ice in winter, and a perennially frozen portion of the subsoil (known as permafrost) that is often subjected to freeze/thaw cycles. In many areas, the temperature of the topsoil can drop to an astonishing -30°C during the winter while not exceeding 10°C during the summer. These harsh thermal conditions reduce biological activity, rates of chemical processes and weathering.

During the warmer summer months, the surface and upper part of the soil can thaw, allowing water to exist in a liquid form and plants to grow during the summer warming. As temperatures fall in the autumn, the soil will begin to freeze again. The portion of the soil that thaws and freezes is known as the active layer'.

This annual temperature gradient (unfrozen to perennially frozen provides the mechanism for water to move in the soil, for ground ice to build up and for cryogenic processes to operate. Although soil temperatures are directly related to air temperature, factors such as vegetation cover, soil moisture content, texture, thickness of snow cover and underlying permafrost have a modifying effect.

Permafrost affected soils can be found in regions with a **polar climate** (e.g. northern Russian Federation, the Himalayas) where no month displays an average temperature above 0°C. Vegetation is absent and the dominant soil processes is frost shattering. Lower latitudes and altitudes give rise to an **arctic climate** where at least one month has an average temperature above 0°C but not exceeding 10°C. Here, there is enough heat to produce an active layer. This gives rise to tundra landscapes, with lichen and moss covered rocks, mixed with extensive shrubs and grasses. Trees do not grow due to the presence of permafrost. The arctic climate in mountainous regions is sometimes referred to as **alpine** (temperatures are similar, but steeper slopes give rise to better drainage, which means that there is not enough water in the soil for permafrost to form).

Areas with a **subarctic climate** are characterised by long, cold winters and short, cool summers (e.g. southwest China, northern Mongolia). In winter, average temperatures are below 0°C for 5-7 consecutive months but can drop below -30°C (summer temperatures can sometimes exceed 10°C). Only hardy plant types can survive these conditions. Trees are limited to conifers, which give rise to taiga or boreal forests.

Most cold climates have low levels of precipitation (<400mm annually), often falling as snow in the warmer months, giving rise to a **cold semi-arid climate**. Due to the low levels of evapotranspiration, the water-logged terrain of subarctic climates is sufficient to support low levels of vegetation.

Frost heave

When the ground freezes, soil material is displaced as a result of a process known as 'frost heave'.

One of the most common mechanisms that drives frost heave is the migration of water from warm to cold areas because ice molecules have a lower energy state than liquid water. Since the system tends towards a lower energy level, the free water flows towards the developing segregated ice forms (ice lenses, ice crystals and vein ice). Because these ice forms develop parallel to the freezing front and continuously increase in size, the result is an upward movement of the ground (frost heave). This process depends on temperature, the availability of water, and the texture of the soil.

If the soil is underlain by a layer of permafrost (or other impermeable barrier such as hard bedrock) and at the same time, bounded by a lateral obstruction such as ice wedges, tremendous cryostatic pressure can build up when the soil freezes. This pressure leads to dramatic structural changes in the soil and may result in the upward or downward movement of rock fragments within the profile. This movement may cause a bulging (differential heave) of the surface or even the expulsion of material from the soil. Frost-heave causes fine particles to be separated from coarse fragments and stone (frost sorting). In addition, stones in the soil become orientated in a uniform direction.

Cryogenic processes

As previously described, one of main differences concerning soil-forming processes in cold climates is that water occurs mainly in the form of ice and freeze/thaw cycles, leading to a dominance of frost-related or cryogenic processes (the prefix Cryo comes from the Greek word *krúos*, meaning ice). Cryogenic processes produce cryoturbated horizons, frost heave, thermal cracking, ice segregation and patterned ground microrelief. During the cooling part of the cycle, moisture is removed from the unfrozen soil material between the two fronts (known as frost desiccation). This drying is responsible for the development of blocky structures that are typical of many fine-textured frozen soils. Readers are directed to the Soil Atlas of the Northern Circumpolar Region for more detailed information about soil-forming process in cold climates [75]. It should be noted that other soil-forming process, such as gley, peat formation, and salinisation, can also occur in cold climates.

Ice in soil

Below 0°C almost all moisture in the soil occurs as ice. In permafrost regions ground ice influences the landscape and vegetation patterns. The build up of ice is one of the key processes operating in permafrost-affected soils and can considerably change the characteristics of the soil.

Soil freezing starts from the surface and moves to deeper layers as the soil cools. This moving boundary between frozen and unfrozen soil is known as the freezing front. In permafrost affected soil, a freezing front can also develop at the bottom of the active layer, which can move towards the surface. Water in the soil is attracted towards these freezing fronts, supporting the growth of ice crystals. Soil profiles can often exhibit a distinctive upper and lower horizon of ice accumulation. The middle part of the profile, containing little or no ice, is known as the zone of dehydration.

Perennially-frozen soil contains diverse forms of ice. The first frosts of the autumn can initiate the growth of ice crystals that eventually bind soil particles together to create a hard and impermeable structure. Within increasing frosts, needle-like crystals develop perpendicular to the soil surface towards the colder parts of the soil. Ice needles loosen the surface of the soil and lead to the sorting of mineral material. Rock fragments (up to 15kg) can be lifted simply by the growth of ice needles. Horizontal ice crystals, known as vein ice, are often found adjacent to the freezing front and can result in the development of platy structures in soil.

In very wet conditions, the zone of freezing can be in contact with unfrozen water. As a result, ice lenses become very thick and can lift the surface layers of the soil. By this mechanism, peat mounds, peat plateaus and palsa bogs in the wetlands of the subarctic zone with discontinuous permafrost are developed.



Cryogenic sorting is the separation of coarse soil materials from fine materials, which takes place at both the macro- and micro-scale. The macro-scale can be seen in the above photograph which shows a sorted, patterned ground of coarse domes in the tundra. At the micro-scale, it produces rounded and banded micro-fabrics (see cryoturbation photo below). (SW)



Ice wedges in the fine sediments of the treeless tundra of the Lena Delta in the Russian Federation form regular polygons with small ponds. A common phenomenon in cold soils is frost cracking. When the soil contracts under rapid cooling, parallel vertical cracks develop at points of weakness in the soil body. The resulting cracks are typically several centimetres wide. During the thaw, the cracks become filled in with water, which in turn, freezes the following winter. The ice in the crack expands forcing the soil apart. Over time, the ice will grow laterally and an ice wedge will develop. Ice wedges can vary in size from 10cm-3m at the top, tapering to a point at depths of 1-10m. In areas where the permafrost has disappeared due to climate change, the cavities resulting from melted ice wedges become filled with sediment. The sediment preserves the shape of the original ice wedge and is called ice wedge casts. (PP)



Cryoturbation mixes the soil matrix and results in irregular or broken soil horizons, involutions, organic intrusions, organic matter occurrences in the subsoil, oriented rock fragments, silt-enriched layers, silt caps and oriented micro-fabrics. This photograph illustrates several features of cryoturbation (also known as frost churning). These include irregular and broken soil horizons and involutions. Over time, cryoturbation can move organic matter from the surface in to the subsoil. This process can have strong implications for climate change. (BH/AM)

Common processes in humid conditions

Many parts of Asia are characterised by a climate that provides a precipitation surplus during some parts of the year (i.e. when rainfall is greater than evaporation rates). This surplus fills up the spaces or voids in the soil, which might have been emptied during the dry season, and then percolates down through the soil body to accumulate as groundwater. In doing so, the movement of water drives three important soil-forming processes:

1. Leaching

When water passes through the soil, it dissolves soluble salts (such as chlorides, nitrates, sulphates and carbonates) and flushes them, together with organic and chemical solutes, into the deeper parts of the soil. In the drier climates, these salts can be re-precipitated, for example, as a calcium carbonate-rich horizon in the subsoil. In more humid regions, significant amounts of materials can be completely removed from the soil by leaching.

This loss of mineral and organic solutes due to percolation is known as leaching. The rate and extent of leaching depends on two factors:

- the mobility of an element, which in turn is based on its solubility in water and the effect of pH on that solubility – chlorides and sulphates are very mobile while titanium is insoluble even at a pH of 2.5;
- the rate of water percolation, which in turn depends on climate, soil texture and structure, porosity and the slope of the ground – in dry regions, even the most mobile compounds (e.g. sodium chloride) tend to stay in the topsoil and eventually give rise to saline soils.

As humidity levels increase, losses of salts, organic compounds and silica in the topsoil increase and the soil is regarded as being leached.

Leaching is a major controller of soil fertility. As long as calcium carbonate is present, the pH of the soil will be above 7 and the soil will often be whitish or light coloured. When the calcium carbonate is dissolved and leached away, the pH will drop and calcium, magnesium and sodium will be released from the surfaces of clay minerals and humus to be replaced by hydrogen and aluminium. Unless there is a change in the soil-forming factors or there is human intervention, the pH of soil will fall below 7 and under such conditions the soil is referred to as acid.

Highly acidic soils are not very suitable for the cultivation of food crops. Such soils will require the addition of calcium carbonate (a practice known as liming) in order to raise the pH to a more acceptable level for plant production. A reduction of pH below 5.5 can cause a release of aluminium cations in the soil solution, which is toxic for some plants, crops and nearby water bodies.



A leached soil profile from Siberia. In this soil, material has been leached from uppermost 15 cm of the topsoil which is represented by the grey layer. (EM).

In some instances, immobile elements can be leached when they are combined with organic compounds (e.g. organic and amino acids) derived from the humification of litter or from soil microorganisms. This process, known as cheluvation, is an important mechanism for increasing nutrient availability to plants. Chelates are very important in micronutrient management.

2. The movement of clay particles

A common soil-forming process is the movement or translocation of clay particles from one soil horizon to another. This involves the mechanical transfer (illuviation) of clay particles from the upper part of the soil by percolating water and their re-deposition deeper in the soil on the surfaces of soil particles or in soil pores and cavities.

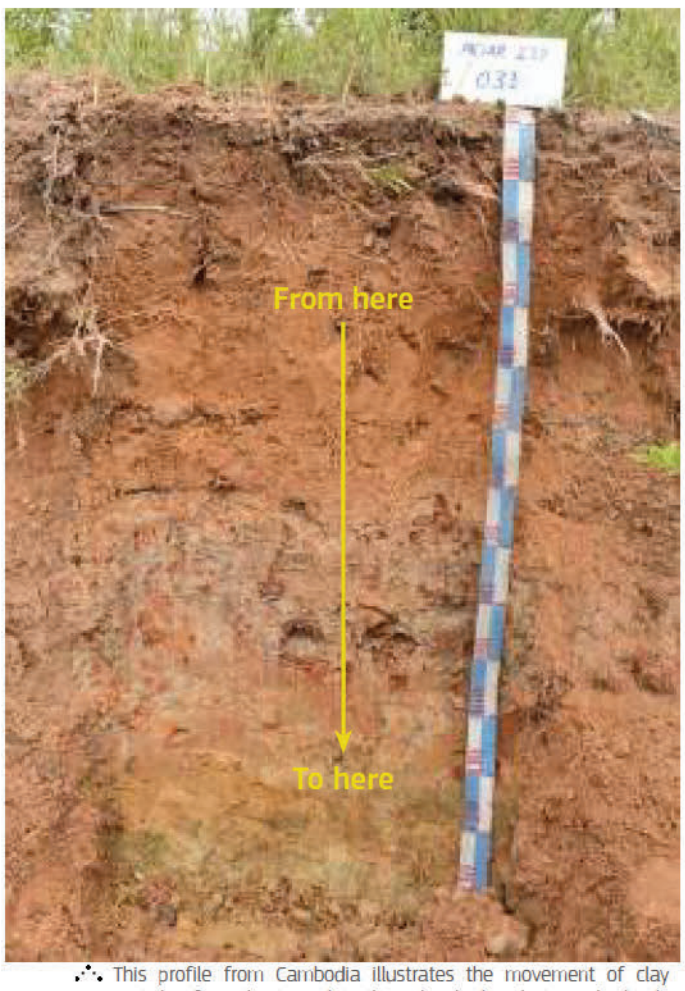
This process is dependent on the soil texture, structure and chemistry. If a continuous and coarse pore system exists in the soil, percolating water can then transport the clay particles downwards. Such conditions will develop as the soil shrinks and cracks during dry seasons. The clay will accumulate where the cracks end and water movement almost ceases or where the water penetrates into the dry aggregates and the clay particles are filtered at the ped surfaces forming clay layers or skins called cutans or argillans.

Another process that can lead to low clay content in the topsoil is raindrop erosion where splashes move the finer particles down the slope leaving behind silt and sand. This process is believed to be widespread and appears to be enhanced by shifting cultivation practices on sloping terrain.

3. Clay destruction

A significant soil process is the destruction of clay. The leaching of base cations leads to the build up of hydrogen ions on clay minerals and organic matter. This state is unstable and leads to the eventual disintegration of the crystalline structure of the clay, releasing aluminium and silica in the process.

As a result, the soil exhibits less clay and a lower pH in the topsoil and subsoil immediately below the topsoil than in the main part of the subsoil. Similar clay distribution can be found in soils where the clay in the topsoil has been redistributed rather than being destroyed (see below).



This profile from Cambodia illustrates the movement of clay particles from the topsoil to the subsoil. The photograph clearly shows an upper grey layer (0-20 cm) which is a ploughed horizon where the soil has been mixed by cultivation. Directly underneath is a light-toned layer (between 20-60 cm) resulting from the destruction and removal of brown and red coloured clay particles. Below 60 cm, dark blocks indicate the accumulation of clay particles from above. This process is known as illuviation. (ACIAR)

Podzolisation

A specific combination of humid climate, quartz-rich, coarse-grained parent material and particular vegetation characteristics, gives rise to a characteristic soil-forming process known as podzolisation.

Soluble organic substances released during the decomposition of plant litter can bind with iron and aluminium oxides in the soil, which given suitable chemical conditions, can be leached from the topsoil. Percolating water redeposits these elements deeper into the soil, leaving behind a zone of bleached, immobile sand grains. Over time, the redeposited mix of organic matter, iron and aluminium can form a hardened horizon, which acts as a barrier to the passage of organic matter and roots. Organic matter then accumulates on this obstruction, forming a dark, humus-rich sub-surface horizon. Precipitating iron can give a uniform orange-red colouration to this horizon. The end product of this process is a soil type known as a Podzol, which is characterised by the presence of this subsurface deposition horizon (known as a spodic horizon).

Podzols are highly characteristic of the temperate and boreal regions of Siberia. They are also recorded in wet, tropical regions, in southeast Asia. Tropical Podzols occur in two distinct situations: a) thick deposits of quartz sands in the lowlands that are free draining; b) a cool temperature regime that prevails at high elevations in areas that have often been influenced by volcanic ash. These tropical Podzols are typical of mountain slopes that produce orogenic rains (e.g. Japan, Indonesia).



This profile from the northern Tiga of Siberia clearly illustrates the various elements of a Podzol. It shows the typical sequence of organic-rich surface horizon on top of a leached grey-white layer. In turn, this overlays a dark iron-rich horizon upon which organic matter has redeposited. (IS/GK/ASV)

Precipitation v Evaporation

Precipitation is the scientific term that describes any form of water that falls out of the sky under gravity as a result of the condensation of water vapour in the atmosphere. Precipitation includes drizzling (droplets less than 0.5 mm in diameter), rain, sleet (a mix of rain and melted snow), snow (frozen crystalline water), ice pellets and hail (balls or irregular lumps of ice). Freezing rain is the name given to droplets of liquid that are supercooled as they pass through a layer of freezing air in the atmosphere and then freeze only upon impact with the ground.

Precipitation occurs when a portion of the atmosphere becomes saturated with water vapour (reaching 100% relative humidity), so that the water condenses and falls (in chemistry, the term precipitation is used for the formation of a solid from a solution through condensation). Fog and mist are not considered as precipitation as the water vapour does not condense sufficiently to fall.

In certain conditions, precipitation may fall from a cloud but evaporates or vaporises (sublimes) before it reaches the surface. This is termed virga and more characteristic of hot and dry climates.

Asia is the holder of some notable precipitation records! Cherrapunji, situated on the southern slopes of the Eastern Himalaya in India, is the wettest place on Earth, with an average annual rainfall of 11 430 mm. In 1986, Gopalganj District in Bangladesh recorded the world's heaviest hailstone, weighing in at 1.02 kg - the storm also killed nearly 100 people.

In contrast, evaporation occurs when liquid water is converted to gas molecules (vapour) as a result of heating. This vapour can then rise up and form clouds.

Soils processes under a wet tropical climate

A significant part of southern and eastern Asia possesses a humid tropical climate where constantly high temperatures (average annual temperature is around 26°C), copious daily rainfall (over 2000mm annually) and high humidity, occur throughout the year. In addition, parts of tropical Asia are characterised by old, geologically stable, shield areas that have been deeply weathered. Under such conditions, chemical weathering, leaching and translocation combine to produce a number of distinctive soils.

In summary, many of the soils of the humid tropics are old, characteristically red or yellow in colour, and strongly leached. They are deep, finely textured, contain only traces of weatherable minerals, have low-activity clays (see adjacent box), less than 5% recognisable rock structure and gradual soil boundaries.

The most typical divisions are based on:

• soils with a ferralic horizon

In deeply weathered sediments, a combination of high soil temperature and intense percolation, dissolve and remove all weatherable primary minerals from the soil body. Only less soluble compounds, such as coarse quartz grains, iron and aluminium oxides, together with the clay mineral kaolinite, remain behind. This process eventually leads to the formation of a ferralic horizon.

High concentrations of the iron oxide haematite give a distinctive red colouration to the soil while in more temperate conditions, the mineral goethite (also an iron oxide) tends to dominate giving soils a more yellow colour. The formation of these soils requires a humid climate, low soil pH, geologically stable land surfaces and basic parent material containing abundant levels of iron and aluminium in the form of easily weatherable minerals but little silica.

Clay content and texture are relatively constant with depth due to the mixing of the soil by biological activity (primarily termites). Soils matching these characteristics are referred to as Ferralsols (see page 61).

While such soils can support luxuriant natural vegetation (e.g. rainforest), their cultivation for crops is problematic. Plant nutrients (e.g. Ca, Mg, K, P) are generally lacking. The low pH, coupled with a high levels of iron and aluminium oxides causes phosphorus fertiliser to bind to the soil and become unavailable to plants.

Dense natural vegetation can flourish on these soils due to a self-sustaining nutrient cycle. If this cycle is broken (e.g. as a result of deforestation or through the export of agricultural products to urban areas), the soil quickly loses its fertility and is prone to degradation processes such as erosion. Traditional agricultural practices of temporary forest clearance and shifting cultivation recognise this cycle.



Typical Ferralsol from the Philippines, displaying a characteristic deep, homogeneous, red profile lacking any distinct horizon features. (BSWM)



Plinthite is visible below a depth of 50cm in this profile from Sri Lanka. (UV)

• soils with a nitic horizon

A derivation of the ferralisation process can lead to the development of soils containing a characteristic 'nutty', polyhedric, blocky structure with shiny ped faces. Typically, the soil body is deep, developed in fine textured weathering products of intermediate to basic parent material that contains high levels of kaolinite and iron (hence the characteristic red colour). In some respects, these soils could be seen as young examples of the ferralisation process. Following the intensive hydrolysis of minerals, together with leaching of silica and base cations, alternating micro-swelling and shrinking processes produce well-defined structural elements with strong, shiny pressure faces.

The soil body can become highly mixed through the action of soil fauna, which results in a characteristic crumbly or subangular blocky soil structure and diffuse soil horizon boundaries. The spatial distribution of this process is highly dependent on subtle variations in the landscape and parent material. Soils matching these characteristics are known as Nitisols (see page 64).



A clear example of the typical nut-shaped soil structure from a nitic horizon in China. The dark red colour is indicative of a significant amount of clay and active iron. Such soils are associated with the weathering of basic rocks such as basalts. (EM)

Low and high activity clays

Layered silicate clays found in soil are distinguished on their capacity to retain and supply nutrients such as calcium, magnesium, potassium and ammonium. High activity clays have a cation exchange capacity (CEC) =>24cmol(+)/kg clay due to their large surface area. Generally, soils with large amounts of high activity clays are not highly weathered and have a high CEC under all pH levels.

In contrast, low activity clays are more highly weathered. Due to their reduced surface area, low activity clays have a lower capacity to retain and supply nutrients (CEC<24cmol(+)/kg clay) and, depending upon the pH of the soil, supply phosphate, sulphate and nitrate, rather than base cations.

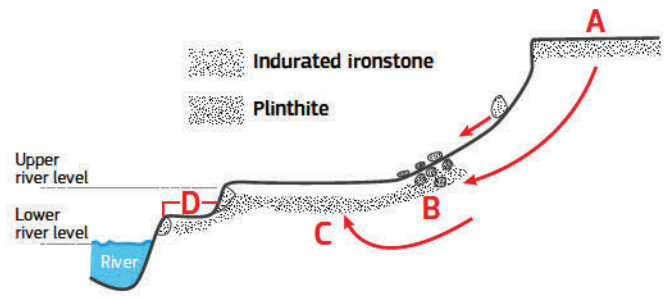


Figure illustrating the four distinct landscape positions where plinthite and ironstone occur. (LJ) **[after 76]**

A: indurated ironstone (massive iron pan or gravel) capping an old erosion surface. Ironstone caps form a shield against erosion. The result is an inversion of the original relief where parts that initially were the lowest of the landscape become the highest.

B: plinthite and ironstone (gravel and boulders) in a colluvial footslope (subject to iron-rich water)

C: plinthite in soils of a low level plain (river terrace) with periods of high groundwater

D: along the banks of rivers where plinthite becomes exposed and hardens to ironstone

• soils with a plinthic (or petroplinthic) horizon

Where the land is level or gently sloping and subjected to fluctuating groundwater levels in iron-rich parent material, a substance known as plinthite can develop (from the Greek *plinthos*, meaning brick). Plinthite, also known in the past as laterite (see box), is a subsurface accumulation of iron(hydr) oxides, kaolinitic clay and quartz. Plinthite is generally formed by the segregation of iron in soil material that has been saturated with water during the year. The iron has probably been transported by soil water from higher ground as ferrous iron under anaerobic conditions. Alternatively, iron concentrations may increase due to the removal of silica and base cations through the leaching of dissolved weathering products. The resulting ferrous iron is precipitated as soft, clayey, red or dark-red ferric iron concretions. Soils matching these characteristics are referred to as Plinthosols (see page 65).

When enough iron has been precipitated and the soil starts to dry out, the soft clay begins to harden irreversibly. This is often initiated by removal of the vegetation as this triggers erosion of the surface soil and exposure of plinthite to the open air. Hardened plinthite occurs in concretionary (skeletic) form or as a continuous layer (petroplinthite), also referred to as ironstone. Soils with petroplinthite are especially abundant in the transition zone from rain forest to savannah, especially in areas that were once much wetter.

In other cases the plinthite concretions may not be sufficiently concentrated to form a continuous layer but harden irreversibly as pisolites in a dense layer of nodules. Such layers can sometimes be found close to the surface due to the removal of the soil between the pisolites by termites for building their nests.

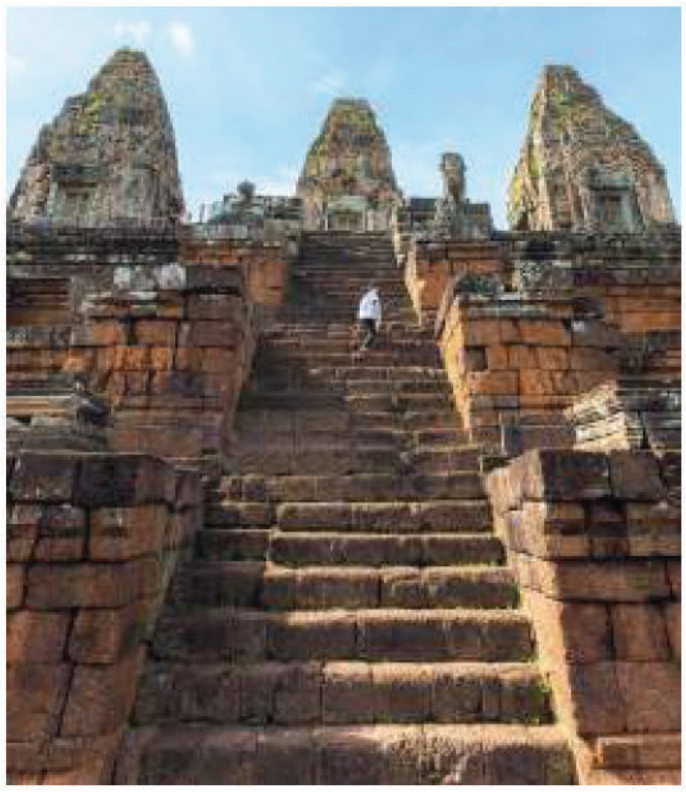
Exposed plinthite may ultimately lead to an inversion of the original relief as it functions as a protective cap against erosion of the underlying soil. Over time, the uncapped soil is removed, leaving the capped soil as the highest parts of the landscape.

Laterite

The term laterite as been credited to Francis Buchanan-Hamilton, a British scientist living in India at the beginning of the 19th century. He used it to describe a red-mottled clay that was dug out of the ground in India. While moist, the clay could be shaped easily into bricks that hardened irreversibly as they dried (the term *later* is from the Latin for brick). Laterite blocks were used throughout tropical Asia for buildings and road surfaces.

The word laterite was subsequently used to describe any highly weathered, red subsoils, predominantly under tropical forests, that were rich in iron and/or aluminium oxides, quartz and kaolinite but almost devoid of base cations and primary silicates.

Today, the use of the term laterite is discouraged, with preference being given to stricter definitions such as plinthite and petroplinthite.



The ancient city of Angkor in Cambodia was built between the 9th-15th centuries. Many of its buildings and walls were constructed from hardened plinthite blocks. (DD)

• **soils with an argic horizon**

The climatic conditions in the humid tropics can give rise to a subsurface horizon with a higher clay content than the overlying soil. Such situations can arise as the result of illuviation (see page 47), the destruction of clay in the overlying horizon, the selective erosion of clay, sedimentation or biological activities. Most of the siliceous minerals produced by the original weathering process are subsequently dissolved and leached out of the soil. Depending on the composition of the parent material, clays in the argic horizon can be weathered to liberate large volumes of soluble aluminium. Three common soil types occur in the humid tropics displaying clay-rich subsurface horizons.

- strongly acidic soils that develop on the weathering products of metamorphic rocks containing high-activity clay minerals such as vermiculite or smectite are referred to as Alisols (see page 58). These soils are most common in old land surfaces with a hilly or undulating topography under humid tropical or monsoon climates. The weathering of the clay minerals in the argic horizon gives rise to high levels of aluminium in the subsoil which hinders biological activity.
- strongly acidic soils that develop on the weathering products of acidic parent material (which give rise to an accumulation of low activity clays) in old land surfaces with a hilly or undulating topography under humid tropical climates are referred to as Acrisols (see page 57). Acrisols generally exhibit a strong yellow to red coloured argic horizon overlain by a much lighter (whitish to yellow) bleached horizon.
- where the climate has a pronounced dry season and the soils on old erosional or depositional surfaces are enriched in base cations through different processes (e.g. aeolian dust, biological activity, etc.), the resulting soils are known as Lixisols (see page 63).



An Acrisol profile from China with weakly defined horizons. The distinctive red-brown colour underlines the presence of pedogenic iron oxides. As for Alisols and Lixisols, they display a clay-rich subsoil with a low pH. Commonly found under natural woodlands or grasslands, the low fertility and high levels of aluminium pose limitations to agricultural use. With fertilisation, tea, rubber tree, oil palm, coffee and sugar cane can be grown. (IUSS)



Lixisols reflect the washing of low activity clays from the upper part of the soil to a subsurface accumulation horizon. Unlike Acrisols and Alisols, they have a high pH, often reflecting parent materials containing wind blown materials. Lixisols are strongly weathered and tend to occur in the drier parts of the tropics and subtropics. They are extensive in the eastern regions of India, Sri Lanka and southeast Asia. Most researchers consider Lixisols to be products of wetter climatic conditions in the past. Lixisols on slopes are highly prone to erosion. (IUSS)



Alisols have an acidic clay-accumulation horizon, which has a high cation exchange capacity. Compared to Lixisols, Acrisols and Ferralsols, Alisols have much higher-activity clays and are likely to be found on geologically active regions. The low pH means that aluminium and manganese toxicity can be an issue when they are cultivated. (PS)

The red soils of Mediterranean Asia

"*Terra rossa*", from the Italian for red earth, is a clay-rich soil with a strong red colour and structure, that has developed on limestone or dolomite, in areas with Mediterranean-type climates. Despite their high clay content, their well defined structure means that they are well drained. They are generally referred to as Chromic Luvisols (see page 63).

Recent research has suggested that these soils formed during the last glacial period (12000-25000 years ago) from sediments transported by wind from the Sahara Desert.

Others, who note their strong affinity to areas with limestone bedrock, suggest that they are the insoluble residue of the underlying limestone Iron oxides in the residual layer produces the characteristic red colour. In this case, these soils are very old relict soils, reflecting a range of soil-forming processes.

Volcanic soils

Volcanic eruptions produce a range of materials, often containing high proportions of volcanic glass. They include ash (a mixture of rock, mineral, and glass particles), tuff (a relatively soft, porous rock that is usually formed by the compaction and cementation of volcanic ash), pumice, (rock produced from lava with a very high content of water and gases), cinders (loose pyroclastic fragments) and lava (molten rock emerging as a liquid onto Earth's surface, for example, basalt).

This range of parent materials gives rise to soils with distinctive characteristics. The weathering of primary minerals and volcanic glass leads to the formation of non-crystalline (amorphous) secondary aluminium- and silica-rich minerals such as allophane and imogolite (under high rainfall) or halloysite (where rainfall is lower). Weathering liberates aluminium (Al^{3+}) ions, which become tied up with humus in stable Al-organic compounds as the aluminium protects the organic material against bio-degradation. Any free ferric iron (Fe^{3+}) usually precipitates as ferrihydrite (a form of iron oxide).

Such poorly crystalline materials have a large surface area and consequently can absorb large amounts of water.

Volcanic soils are usually light and fluffy and are easily cultivated. When not highly weathered, volcanic soils are typically very fertile. However, due to their high anion exchange capacity, such soils have a low ability to retain and supply nutrients thus requiring very large additions of phosphorus.



Mount Mayon is an active stratovolcano in the Philippines. The upper slopes are made of ash while several lava flows are visible lower down and on the footslopes. Eleven soil types have been recorded. (D)

Acid sulphate soils

In waterlogged, organic-rich, saline sediments, bacteria decomposing organic matter under anaerobic conditions, reduce dissolved sulphate ions (from sea water - normally absent in freshwater) to sulphide and iron III oxides to iron II. The stable end product of these reactions is pyrite, a mineral composed of iron and sulphur (FeS_2). Dense coastal vegetation, such as mangroves, ensures that there is a constant supply of organic matter for the bacteria to feed on. Tides bring in fresh sediments and dissolved sulphate while removing soluble. Under such conditions, significant levels of pyrite can accumulate.

Left undisturbed, these soils do not present any risk. However, when they are exposed to air through drainage or tectonic uplift, oxygen can enter, which reacts with the pyrite, together with bacteria, to form sulphuric acid. The liberated iron crystallises as the mineral goethite. The sulphuric acid lowers the pH of the soil below 4, which releases aluminium present in clay minerals in toxic amounts.

The release of acid and metals has several serious consequences. If they enter watercourses, plants, animals and fish are killed while metal and concrete structures can be corroded and weakened. Contact with the soil irritates skin and eyes while drinking acidic water will make animals ill.

Normally, such soils are not a problem if the potential acidity, represented by pyrite, is neutralised by the presence of calcium carbonate (by at least a ration of 3:1). Unfortunately, shallow seawater or brackish environments in the humid tropics contain almost no carbonates.



An acid sulphate soil from a low-lying delta in Kerala, India. The yellowish colour denotes the presence of pyrite. The dark colour of the soil reflects their high organic matter content. pH levels are around 5.0 (ICAR-NBSS&LUP)

Soils conditioned by a dry tropical/ sub-tropical climate

Where precipitation is lower than evapotranspiration, high temperatures cause groundwater to rise to the surface. In these conditions, several soil types exhibit substantial secondary accumulations of salts, lime, gypsum or silica.

• soils with accumulations of salt

A soil is regarded as saline if the salt concentration is around 2 500 parts per million. Soils affected by soluble salts or by their ions occupy a significant part of Asia, especially in Western and Central Asia (but also locally elsewhere).

Soluble salts can be released through the weathering of rocks or because the parent material contains high levels of salt (e.g. old marine sediments or evaporation deposits). However, the majority of salt-affected soils develop where saline groundwater rises to the surface and dissolved salts accumulate in the soil through the evaporation of the groundwater. Salts can also be carried into depressions in the landscape by saline surface water flowing from higher ground. In dry lands, salinity can occur even when the water table is two or three metres from the surface of the soil.

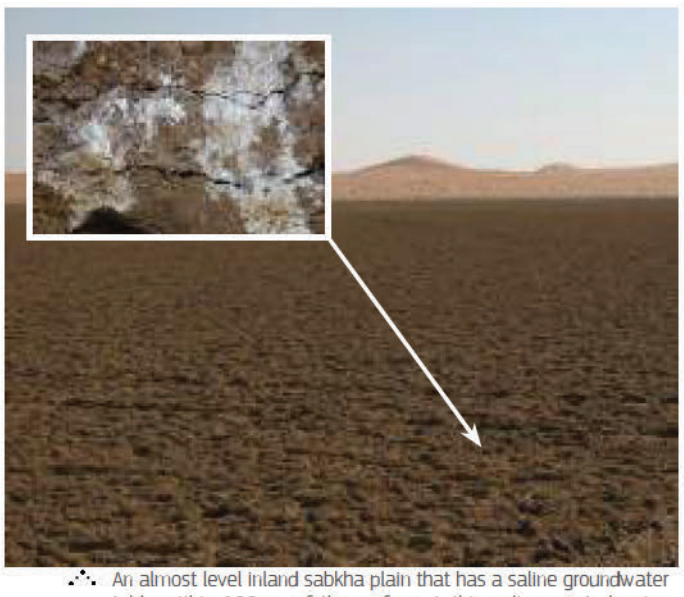
The main ions responsible for salinisation are Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^-. Depending on the chemical composition, the reaction between the soil and salts may differ. Salts containing sodium (Na) cause organic compounds to become mobile and are eventually leached out of the topsoil, resulting in the development of a bleached horizon. The pH of such soil types is typically above 9.

Almost all water (even natural rainfall) contains some dissolved salts. Where soils are irrigated, salts can accumulate if there is not enough seasonal rain, which means that they must be artificially leached out of the root zone by applying additional water. Salination can also be increased due to poor drainage or through the use of saline water for irrigating.

Saline soils also occur in ephemeral or closed basin lakebeds, also referred to as salt pans or salt flats. In Western Asia, they are referred to as sabkhas.



A close-up of the boundary between the topsoil and subsoil of a sodium-rich subsoil from Kazakhstan. The characteristic columnar structure with rounded tops and the organic coatings on the structural elements are clearly visible. (AK)



An almost level inland sabkha plain that has a saline groundwater table within 100 cm of the surface. A thin saline crust showing polygonal or rectangular cracking is evident with a distinctive gilgai microrelief similar (see swelling clays on adjacent page). (main image - BA; inset - AK)

• soils with accumulations of calcium carbonate

One of the most widespread soil-forming processes in dry climates involves the movement of calcium carbonate ($CaCO_3$) from surface horizons to an accumulation layer at some depth (a process referred to as secondary accumulation). On wetting (such as after rainfall), lime dissolves allowing Ca^{2+} and HCO^{3-} ions to move downwards with the percolating soil water. When the water eventually evaporates, calcium carbonate precipitates where the percolation stopped (calcium carbonate can also percolate if the concentration in solution becomes high enough). Calcite precipitation is not evenly distributed over the soil matrix. Root channels and wormholes act as channels along which the solution can flow allowing the calcite to precipitate on the channel walls. When narrow root channels become filled with calcite, the resulting cast-like shape of the root is known as pseudomycelium. Other characteristic forms of calcium carbonate accumulation are soft or hard lime nodules (calcrete), platy or continuous layers of calcrete and calcite 'beards' known as pendants below pebbles. In eroding land, lime concretions may occur right at the surface of the soil.



Soil development and conservation along an excavationt through a limestone plateau in northern Jordan. Soil depth seems closely connected with karst features. (LB)



A profile of a calcium-rich soil from Lebanon. The white material is calcium carbonate (also known as lime). Much of the free lime in the topsoil has been leached out giving it a darker appearance. (TD)

• soils with accumulations of gypsum

As **gypsum** ($CaSO_4.2H_2O$) is dissolved from gypsiferous parent materials, it is moved through the soil by water and precipitated in an accumulation layer when the water is removed. Where soil moisture moves predominantly upward (i.e. where a net evaporation surplus exists for an extended period each year), a gypsum-rich horizon occurs within the soil body.

Gypsum is also leached from the surface soil in wet winter seasons and re-accumulates deeper in the soil as a loose, powdery substance. Over time, gypsum crystals may cluster together as compact layers or surface crusts that can become tens of centimetres thick. Gypsum can precipitate in former root channels (gypsum pseudomycelium), in voids, as coarse crystalline gypsum sand or in strongly cemented horizons (petrogypsic).

In places, it forms massive crystalline structures known as desert roses.



A Petric Gypsisol in northwestern Kuwait. The surface has well developed angular to subangular blocky structure followed by sandy layer to 70 cm depth where a Petrogypsic horizon was identified. These soils are unsuitable for crop production due to the occurrence of hard pan n the topsoil. The soil can subside after gypsum dissolution. (SAS)

• soils with accumulations of silica

In many arid regions (although not exclusively), soils known as **Durisols** contain very hard layers of silica-enriched materials in the subsoil. These materials range from silica-cemented sand and gravel to a nebulous matrix enriched with small silica particles.

The conditions under which such features develop are uncertain as nearly all occurrences are "fossil" as such soils do not seem to be forming extensively at present. Theories include the precipitation from silica-rich groundwater in arid/semi-arid climates or by intense weathering in a warm, humid climate.

Durisols are not extensive in Asia. There are reports of limited distribution in Western Asia (e.g. Mediterranean region, Kuwait). Durisols are generally associated with moderately deep, well-drained alluvial or colluvial materials on level or slightly sloping plains and terraces in arid or semi-arid conditions.

A precise indication of their extnet is currently not available. They commonly occur with the soils described on this page.

Using these soils

Soils with lower levels of gypsum, calcium carbonate and silica in the upper 30 cm soil layer can support some extensive grazing and some drought-tolerant crops when carefully irrigated or shallow hardpans are broken up.

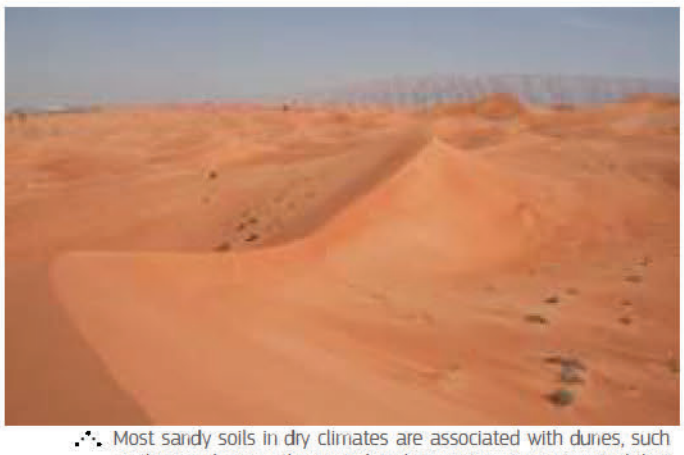
Hard duripan material is used for road construction.

• **soils in sandy materials**

Soils that have developed in coarse material (> 0.063 mm) have poor cohesion and structure, coupled with low water retention capacity and organic matter levels. These factors affect soil formation. Large parts of Asia, especially in arid regions are characterised by blown sand (predominantly quartz but other materials, such as gypsum, can dominate). Along desert margins, climatic fluctuations mean that dunes have been fixed by vegetation. In some cases, their aeolian nature is still obvious but in other situations, soil-forming processes can give rise to quite different soils. Sandy soils can be found in all climates.

Additionally, soils can develop in the coarse sediments that occur as a result of intense and long-term weathering of sandstones and granite, as well as beach or river deposits.

High stocking densities of grazing animals on sandy soils can lead to overgrazing and a reduction in the vegetation cover. Such situations can leave sandy soils vulnerable to wind erosion and, in more arid conditions, more vulnerable to the onset of desertification. The situation can be reversed through effective rangeland restoration practices.



Most sandy soils in dry climates are associated with dunes, such as this sand sea in the United Arab Emirates. It is estimated that around 10% of the Earth's surface is covered by sandy soils. (BA)



Stratified layers in a sandy soil in southern Jordan. Such soils often display a thin A-horizon with surface crusts or the beginnings of a crumbly structure, overlaying a massive C-horizon. (LB)

What is a salt?

Most people think of salt as the product that they add to food or the substance that makes seawater salty. In most cases, this is the salt sodium chloride (NaCl).

However, salt is the substance formed by the reaction of an acid with a base where the hydrogen of the acid is replaced by a metal ion (some other reactions can also create salts). Hence, sodium hydroxide and hydrochloric acid react to create a salt, sodium chloride, and water. Examples of other salts include copper sulphate, lead nitrate, magnesium chloride and magnesium sulphate.

If solutions of salts are allowed to evaporate, then the salt is precipitated as crystals. Salts can be clear and transparent or highly coloured and opaque. The solubility of salts depends on their chemistry and the nature of the solvent.

Saline and alkaline soils can seriously affect the growth of plants causing water stress, ion toxicity or the inability to absorb nutrients.

Soils conditioned by water

When it rains, water percolates through the soil and, in many cases, this water drains away. However, if the texture of the soil or the presence of an impermeable barrier prevents water from escaping, pores and cavities become full of water (this is known as groundwater). In some soils, groundwater exists at relatively shallow depths (< 2 m), reflecting a slowly permeable substrate, depressions in the landscape or marshy areas near to the coast.

A shallow groundwater table strongly decreases the movement of gases in the soil because oxygen and carbon dioxide diffusion in waterlogged pores is very slow compared to air-filled pores. If organic matter is present in the waterlogged soil, the metabolic activity of the microorganisms will create an oxygen deficit and a state known as 'reduction' develops. In these conditions, ferric iron is converted to the more soluble, and therefore mobile, ferrous iron. While ferric oxides are responsible for giving subsoils their characteristic yellowish- or reddish-brown colours, ferrous oxides give the soil a distinctive greyish or bluish colour. However, in some of the larger pores where some oxygen may remain, mottles of rust-coloured material indicate the redeposition of ferric oxides. In soil science, two basic types of waterlogged soils are recognised, surface water and groundwater gley.



A well developed surface water gley in Japan. After rainfall, water is held for a period above an impervious clay-rich horizon (a state known as stagnant). In periods with a precipitation surplus stagnant water can appear on the surface but will disappear when the soil dries out. This soil is characterised by the presence of grey ped surfaces and root channels while the interior of the peds are enriched by ferric iron. (YM)





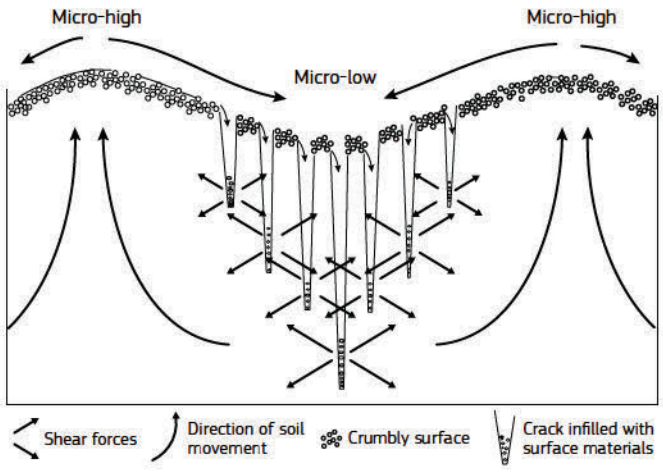
Soils that develop in river or marine sediments display evidence of stratification (layering), reflecting deposition in water and periodic flooding, which brings in additional sediments, organic matter and nutrients. Such soils tend to occur on alluvial plains, alluvial fans (**above: Taklamakan Desert in China – NASA**), valleys and tidal marshes, including mangroves (**below: from Sumatra, Indonesia – MEC**).

Soils conditioned by the presence of swelling clays

In areas with distinct dry and wet seasons and where the parent material contains large quantities of swelling clay minerals known as smectites, soils are characterised by the presence of deep cracks in dry periods which close in the wet season. The closure of the cracks is driven by the expansion of the smectite minerals as they absorb water. Such soils are also defined by the presence of characteristic structural aggregates (spheroids).

Shrinkage of the clay on drying leads to the formation of cracks. In addition, the surface breaks up into granules or crumbs which can fall into the cracks. When the soil is re-wetted, part of the space that the soil requires for its increased volume is now occupied by the granular material in the cracks which results in the build up of shear stress within the soil material. Continued pressures through the uptake of more water eventually cause the soil masses to shear and slide against each other.

The shear planes are known as slickensides and display polished surfaces that are grooved in the direction of shear. Intersecting shear planes produce wedge-shaped angular blocky peds that tend to increase with depth (probably reflecting the moisture gradient). This internal movement of soil, coupled with the deposition of surface crumbs in deep cracks, means that the subsurface soil is pushed towards the surface and mixed. This process is known as churning or pedoturbation. This constant mixing of the soil material results in an extremely deep A horizon. Such soils tend to develop either at the foot of slopes or on plains as a result of the weathering of basalt or redeposition of smectite-rich lacustrine sediments.



A simplified view of the processes operating in soils with swelling clays. During dry periods, the clays shrink causing cracks to open in the soil surface. Over time, crumbs from the surface fall into the cracks. On wetting, clays in the soil body expand causing the cracks close. However, the newly buried surface material causes internal stresses which leads to a mixing of the soil body. This churning often creates a distinctive micro-relief known as gilgai, where the land surface becomes irregular with alternating mounds (puffs) and depressions (hollows). (MF)



Characteristic surface cracking in a Vertisol in the Dhamar Basin of Yemen. Cracks open when the soil is dry and close when wet. (MHAM)

Soil classification



A Ferralsol on sloping land in northwest Viet Nam. Note the distictitive colour and lack of clear horizons. Ferralsols are acidic, very porous and airy because of a good soil structure. (VMQ)



A deep, unconsolidated sandy soil from the Lao People's Democratic Republic. Such soils are known as Arenosols and often associated with the movement and deposition of grains of a sandy texture by water or wind. The holes are burrows. (AC)



This dark red Acrisol is from the hilly plateau of Shan State in Myanmar. This soil is a silty clay loam with homogeneous fine textured profile. The pH of the soil is about 5.6 with very high levels of iron and alluminum. Phosphorus fixation restricts agriculture, which means sunflower and garlic are the main crops. (AKT)



Plinthosols are iron-rich soils characterised by the presence of dark red concretions made up of iron mixed with clay, quartz and other minerals. Generally, these concretions, known as plinthite, form when the soil is saturated with iron-rich water for some time during the year. Plinthite hardens irreversibly to an ironstone hardpan or to irregular soil aggregates on exposure to air. (PT)

Naming and grouping soils together

From the previous pages of this Atlas, one can understand how soils can develop different characteristics in different geographical areas. Apart from glaciers, water and urban areas, soil covers the Earth's surface as a continuum (even bare rock surfaces can have soil material at microscopic level). The gradual changes of soil characteristics across the landscape make the comparison of different soil types difficult. In addition, soil lacks the hierarchical order of many biological systems (e.g. orders, families, genera or singular: genus). To overcome this problem pedologists (scientists who study soil) have developed various rules to characterise, identify, label and group soil bodies. This important task is known as soil classification.

Classification is the procedure by which soil is arranged into groups, categories or, as the word implies, classes, relevant to a specific purpose. The process involves the formation of classes on the basis of common properties. Classification helps us deal with complexity. There are too many objects to consider individually. If we can find some common properties or behaviour between them, we can make meaningful classes to help us organise our knowledge and simplify our decision making.

Early soil classifications were based on individual characteristics such as texture (e.g. loam, clay or sand) or parent material (e.g. alluvial soil, gravelly soil, etc.). In the late 1880s, the Russian geologist Dokuchaev, now regarded as the father of soil science, suggested a more scientific approach based on the combination of soil characteristics linked to their formation. This became known as the genetic principle and is the basis for most national soil classification. This principle allows features resulting from soil-forming processes to be distinguished from those whose origin is geological.

Different approaches to soil classification

During the twentieth century many new soil classification systems were developed around the world as a result of a growing interest in soil conservation and alternative land uses from agriculture. These systems focused on various basic and applied aspects which could be grouped into two categories: natural and technical.

Natural classifications group soil types by some intrinsic properties, behaviour, or origin without reference to any particular use. Examples include:

- Group by ecologically important characteristics such as soils of savannah or tropical rainforest. Such groups are geographically-compact but can have diverse properties;
- Group by origin where a common development, depending on the interpretation of soil-forming factors and soil genesis, is presumed. This type of classification is called genetic.

Technical classifications group soil types by properties or functions that relate to a proposed purpose. Examples include:

- Hydrological: groups soil types according to water regimes such as drainage classes;
- Agricultural suitability: groups soil types according to their ability to support specific crops or agricultural activities;
- Land use capability: groups soil types according to their land management capacities;
- Fertility: groups soil types according to the availability of essential nutrients;
- Engineering: groups soil types according to their bearing strength and behaviour under different moisture conditions.

Soil science does not have a single, universally used, classification system (see text on current trends below). Therefore, many countries have developed their own specific approaches to classifying soils based on national concepts or practical needs, often using local names for soil types based on the identification of typical examples. This approach complicates the comparison of soils between different parts of the world as names often do not translate well between taxonomic systems. The FAO Legend for the Soil Map of the World was an attempt to address the need for a globally accepted soil classification system. While several countries have used the FAO Legend for national mapping purposes, many difficulties were encountered.

Current trends in classification

A number of soil classification systems have developed that use quantitative criteria involving field assessed soil characteristics and/or laboratory analysis to identify and refine hierarchical classes. Such approaches have been used in many countries to revise national classification schemes. The availability of quantitative soil parameters eases the comparison of national classification systems because specific characteristics can be examined rather than broad concepts. The revision of the United States Department of Agriculture's (USDA) Soil Taxonomy classification scheme [77] and the development of the World Reference Base for Soil Resources (pages 55-67) from the FAO Legend of the Soil Map of the World were important responses to this more analytical approach.

The World Reference Base

In the 1970s and '80s, FAO and the United Nations Educational, Scientific and Cultural Organization (UNESCO) prepared a legend for the 1:5 million soil map of the world, broadly based on the main soil-forming factors. This map was used by many UN sponsored projects and, over time, many countries modified and adopted the legend to fit their particular needs [78]. Consequently, many of the soil units used in the FAO system are known in many countries and have similar meanings.

The World Reference Base for Soil Resources (WRB) was developed under the auspices of the International Union of Soil Science, by building on the foundations of the FAO Legend, to create a common basis for correlating the soil resources of different countries [79]. Objective criteria derived from both field inspections and laboratory analysis are used to systematically classify a soil into a Reference Group with specific characteristics denoted through the use of prefixes and suffixes (see page 55).

The WRB is not meant to replace national soil classification systems but rather designed to serve as a common language through which national soil classification systems can be compared and correlated.

In 1998, the 16th Congress of the International Union of Soil Science in Montpellier, France, adopted the WRB as the official terminology to name and classify soils - the system used in this Atlas.

A new edition of the WRB was launched in 2022 [80].

Towards a Universal Soil Classification System?

Most national soil classification systems were developed for a specific purpose, often quite different from the questions being posed today. Soils suitable for agricultural purposes, especially cultivation, usually received more attention in the past. In addition, national conditions often gave rise to particular perspectives and where the broad or global view of soils was normally not considered. This often led to massive confusion and disagreements between soil scientists. However, the current broader view of soil functions and understanding the role of soil in global environmental processes require a better understanding and description of all soils (in particular, anthropogenic soil, cold soils, soils of the tropical regions). In addition, most classification schemes were elaborated before the recent boom of observation technologies, data storage and computer processing capability.

At a meeting in Gödöllő (Hungary) in 2009 to celebrate the 100th anniversary of the 1st International Conference of Agrogeology (widely regarded as the first ever international soil science conference), participants called on the International Union of Soil Sciences (IUSS) to address the problem of our lack of a common language within the soil science community, particularly in relation to the taxonomy of soils.

Consequently, during the 2010 World Congress of Soil Sciences in Brisbane, Australia, the IUSS Council unanimously accepted the "Godollo Resolution" and established a Working Group to coordinate investigations and development of common standards, methods and terminology in soil observations and investigations towards a new universal soil classification system. In this context, the term 'universal' implies that a system is commonly accepted and commonly applicable.









Despite some common attributes, these pictures show the variability of soils. The upper pair of images shows two soils with dark brown topsoils, suggesting elevated organic matter content. However, the one on the left has developed in a calcareous silt that has been deposited by wind while the one on the right has formed in quartz sand. Differences in pH will place these soils in different soil groups.

The lower pair of images also show soils with the same colour, in this case a strong red, which could superficially indicate similar characteristics. However, it is clear that the lower left soil is very shallow and overlies hard rock, while the soil on the lower left is much deeper and shows evidence of saturation by groundwater. In this case, the depth of the soil would be an important criteria to consider in their classification. (MK, EM, TD, AC)

Development of soil classification in Asia

"Asia is one of the cradles of agriculture in the world, and here people paid attention to soils since the origin of land management. Folk classifications are widespread among the people in Asia" [81], and these classifications were integrated in the formalised soil knowledge in many countries. The first soil classification was documented in China more than 2 500 YBP in an ancient book Yugong [82].

Current scientific soil classifications originated from the Russian Federation, where in 1883, Vasilii Dokuchaev and his followers first used pedogenetic principles for soil classification and assessment [83]. Konstantin Glinka, who headed soil and geobotanical field research in the Resettlement Department, further used the same principles for classifying and mapping soils in the Asiatic part of the Russian Empire. The terminology of this classification was based mainly on the traditional Russian and Ukrainian soil names such as chernozem, podzol, gley etc. The tradition was followed by soil survey in the Soviet Union, though no uniform system existed until the 1960s, and soil terminology slightly varied between the maps, even in the State Soil Map of the USSR (1:1 000 000). A complete detailed system of classification was prepared in 1967 for the Ministry of Agriculture by E. I. Ivanova and N. N. Rozov of the Dokuchaev Soil Science Institute. It was published in five separate volumes, each one corresponding to a certain bioclimatic zone. It was considered that a soil surveyor would work within a specific zone, and should consult mainly a corresponding volume. Later on, the Dokuchaev Institute reworked the classification, and edited the final version of the Soviet classification [84].

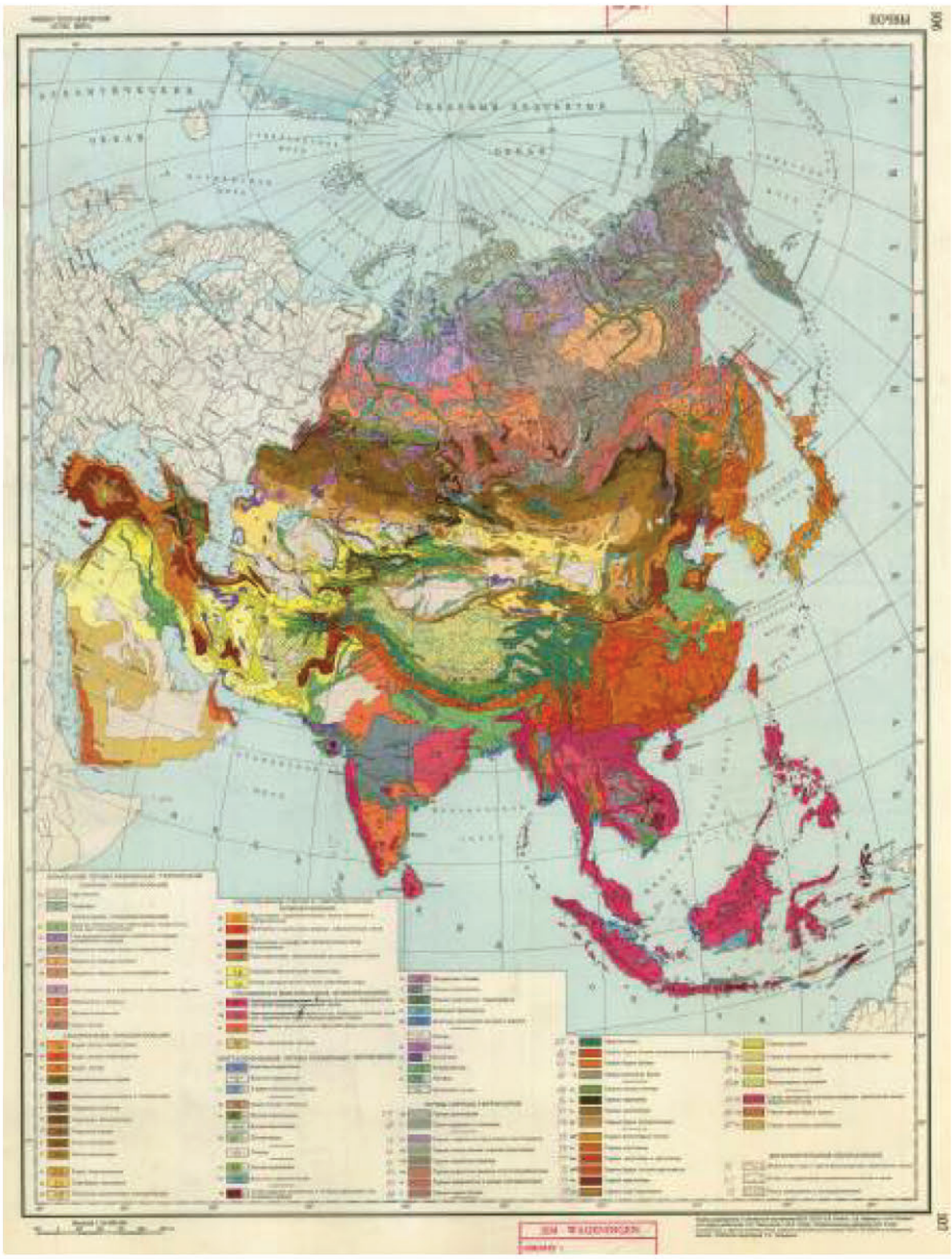
After the fall of the Soviet Union, most countries in Central Asia and South Caucasus used technical manuals based on the Soviet classification. Only few independent states of the post-Soviet Asian territory published their own classifications, e.g. Azerbaijan and Russia. Others did not publish any official documents on their national classifications. In the period of independence in Azerbaijan, a new version of soil classification was published [85]. It was based mainly on the same map legend developed in the USSR, but included more detailed division of taxa and a system of diagnostics and was successfully used for large-scale soil mapping. Later, an updated soil classification was proposed for Azerbaijan [86].

In the Russian Federation, the situation is somewhat chaotic. The 1977 classification and diagnostics of soils of USSR is still used in some soil surveys. However, a big part of the scientific community uses a new version, which significantly differ from the older classification (Arnold, 2001; Shishov et al, 2004). Also, the Ministry of Agriculture officially recognises the Unified State Register of Soil Resources of Russia (Soil Institute named after V. V. Dokuchaev) based on the legend of the Soil Map of Russia at a scale of 1:2 500 000. The Register is not a soil classification sensu stricto, because it lacks clear diagnostics. The variety of classification schemes cause problems in harmonisation of maps.

China is another big country that uses its proper soil classification. The early variant of scientific soil classification was proposed by James Thorp in 1939, and systematic work on the development of soil classification started in the 1950s [87]. Chinese pedology was strongly influenced by the Soviet soil science school at that time and the classification resembled that of the soils of the USSR. Until recently the genetic soil classification of China served as a basis for soil survey and research in the country. In the 1980s leading pedologists of China understood that the classification system should be updated according to newer pedogenetic and classification concepts. New Chinese soil taxonomy [88] integrated old genetic approach and contemporary quantitative diagnostics of soils. Though in Chinese traditional terminology was used according to the rules of Mandarin language, the English translation included artificial names in the style of the US Soil Taxonomy [77].

Mongolia used soil classification that resembles older versions of the Soviet soil classification and is currently developing a new system [89].

Japan also has a long history of soil classification. The first agrogeological classification of soils of Japan was published as early as in late 19th century [90], and in the 1920s, the American system of soil series was introduced to Japan. In the 1980s a working group to develop a uniform soil classification of Japan was created, and soon the 1st Approximation was used as a legend for a soil map of Japan at a scale of 1:1 000 000. It is still used for soil survey in the country with little updates [91].



The first ever soil map of Asia, at a scale of 1:25 million, was developed in 1964 by the Soil Institute of the USSR's Ministry of Agriculture by V.A. Kovdoy, E.V. Lobova and N.N Rozov as part of the Physical-Geographical Atlas of the World. While soil names may have changed and boundaries refined, the basic information portrayed by the map is still very reliable. The original map is stored in the library of ISRIC. A high resolution version of the map can be downloaded from the EUDASM archive (see page 173). (ISRIC/JRC)

In South-East Asia, soil classifications until the second part of the 20th century by soil scientists from overseas: Dutch, French, British, and Russian [92]. Practically all these countries still use the US Soil Taxonomy [77], except for Viet Nam [93] and Indonesia [94], which have developed their own system of soil classification. Many other countries may have their classifications for soil surveys published as technical documents in national languages, which are not accessible in libraries or online.

The United States Soil Taxonomy [77] is one of the most widely used classification systems used in Asia. To a great extent it has been accepted in 1980s and 1990s due to the enthusiastic efforts of Richard Arnold and Hari Eswaran from USDA Soil Survey, who provided extensive technical assistance to soil mapping in the region. Some countries combine the use of traditional classifications for general public and USDA Soil Taxonomy for professional soil inventory, like India.

In the Near East, practically all countries use USDA Soil Taxonomy both in scientific research, and in practical soil survey.

The use of the World Reference Base is limited in Asia. Currently, many countries include WRB names in the correlation matrices to facilitate understanding the national systems of soil classification.

Indigenous soil classification concepts

Local perceptions about the potentials and limitations of soils give rise to indigenous soil classification systems, often reflecting factors that govern agricultural productivity (e.g colour, texture).

A study from Lao PDR showed that a number of ethnic groups used soil colour as the main criteria for soil classification. However, within the same ethnic group, some villages used the soil's water holding capabilities as the main factor. In contrast, other groups classified soil types in relation to their rock content.

In India, native soil classification was made on the basis of fertility, climate, and the land revenue system. This knowledge was passed on from generation to generation through pastoral songs, maxims, and proverbs that guided farmers. The first soil map of India recognised four major groups of soils (Indo-Gangetic alluvial soils, black or regur soils, red soils, and laterite and lateritic soils).

Soils in Chia were classified into nine groups such as pale rang, black fen, red chi-fen, mud tu ni, blue li, yellow rang, white fen, lu, and zhi according to their colours as well as some terms related to soil texture.

Farmers in northern part of the Syrian Arab Republic identify red soils (Turba hamra) for olive cultivation, cultivation on black soils (Turba soda) require irrigation and white soils (Turba byda) that are easy to cultivate but dry quickly after rain and become very smooth and easily erodable when wet.

The World Reference Base for Soil Resources (WRB)

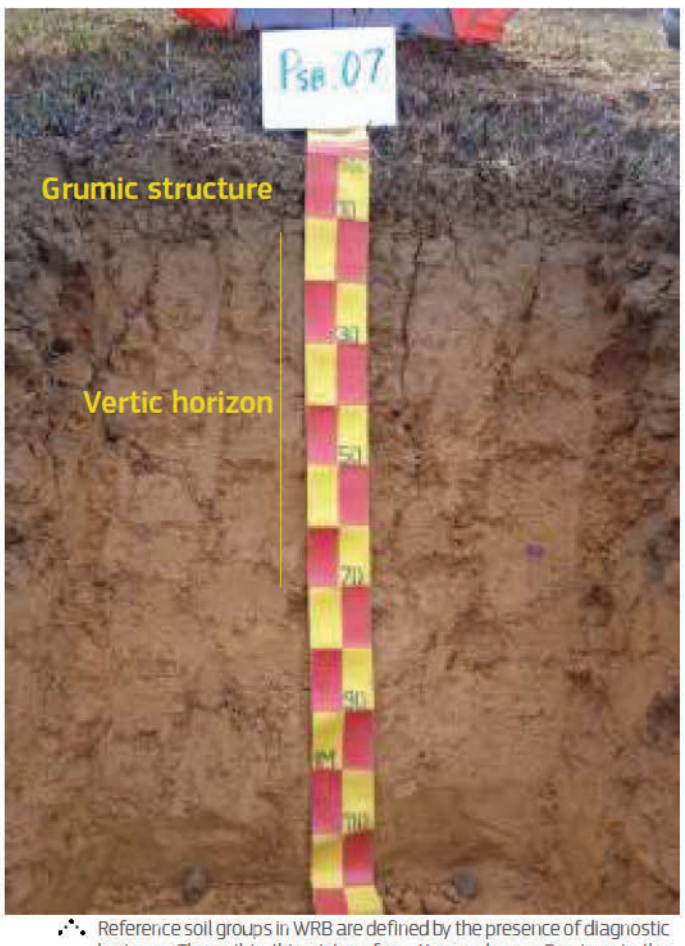
The World Reference Base for Soil Resources

The WRB places all types of soil within thirty-two major soil groups with a series of uniquely defined qualifiers for specific soil characteristics (see legend on page 70-71).

For describing and defining different types of soil, the WRB exploits the following nomenclature:

- soil characteristics comprising single observable or measured parameters;
- soil properties, a combination of characteristics indicating soil-forming processes;
- soil horizons, representing three-dimensional bodies characterised by one or more soil properties.

Soil horizons and properties are used to describe and define soil classes on the basis of 'diagnostic' criteria. This means reaching a certain degree of expression, as determined visually, by prominence, measurability, importance and relevance for soil formation, soil use and quantitative criteria. To be diagnostic, soil horizons also require a minimum thickness.



Reference soil groups in WRB are defined by the presence of diagnostic horizons. The soil in this picture from Xaysomboune Province in the Lao People's Democratic Republic, displays a deep clay-rich horizon (>30% clay content) with pronounced cracks separated by wedge-shaped polished or shiny surfaces, known as slikensides, that meet at sharp angles clearly evident between 10-70 cm depth. These cracks open and close periodically according to moisture conditions. These are the characteristics of a vertic horizon. Above the vertic horizon, the soil displays a 10 cm deep grumic surface layer with a well defined structure. These characteristics indicate a Vertisol. (LDALM)

The WRB Reference Soil Groups

The thirty-two WRB Reference Soil Groups (RSG) are allocated on the basis of dominant identifiers which are usually the factors or processes that most clearly condition the formation of the soil. The sequence of the groups is according to the following principles:

Firstly, **organic soil**, known as **Histosols**, consisting of partially decomposed biomass, is defined to separate it from mineral soil.

The second major distinction is to recognise **human activity** as a soil-forming factor: **Anthrosols** are the result of long-term agricultural use, while **Technosols** are dominated by human-made materials (artefacts), which can be even toxic.

Next are soil types with a **severe limitation to rooting**: **Cryosols** combine all mineral soil types that are affected by permanently frozen subsurface layers. **Leptosols** are mainly found in mountainous or desert areas and comprise shallow soils over hard rock or extremely stony layers.

Then comes a group of RSG that are or have been **strongly influenced by water**: **Vertisols** are churning, heavy clay soils with a high proportion of swelling clays. Deep and wide cracks form from the surface downward when they dry out and close when wet. **Fluvisols** occur in river valleys and comprise soil in recent alluvial, lacustrine or marine deposits and display a stratification of sediments. **Solonchaks** have a high concentration of soluble salts at some time in the year and are largely confined to arid and semi-arid climate zones or coastal regions. **Solonetz** are strongly alkaline soils (pH > 8.5) and have a dense, strongly structured, clayey subsurface horizon that has a high proportion of adsorbed sodium and/or magnesium ions. **Gleysols** are strongly influenced by oxidation-reduction processes caused by periodic saturation with groundwater. The resulting gleyic properties appear as reddish brownish colours on the outer side of structural elements and along pores versus a grey, blue or green colours inside the aggregates.

The following group contains soils where **iron (Fe) and/or aluminium (Al)** chemistry plays a major role in their formation: **Andosols** are soils developed in volcanic ejecta. They are characterised by a unique aluminium-silica chemistry as a result of rapid weathering of the volcanic minerals. **Podzols** have a typical ash-grey upper subsurface horizon, bleached by the loss of organic matter and iron oxides, on top of a dark accumulation horizon of humus and Fe compounds. **Plinthosols** include plinthite, an iron-rich, humus-poor mixture of kaolinitic clay, quartz and other constituents that hardens irreversibly on exposure to repeated wetting and drying, **Nitisols** are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon having shiny, flat-edged or nut-shaped polyhedric structural elements. **Ferralsols** are the classical deeply weathered, red or yellow soils of the humid tropics. They have diffuse horizon boundaries, and low nutrient holding capacity.

Next comes a group of soil types with **perched water**: **Planosols** have a light-coloured, coarse-textured surface horizon that shows signs of periodic water stagnation and abruptly overlies a dense, slowly permeable subsoil with significantly more clay than the surface horizon. Found on flat lands, they are typically seasonally waterlogged. **Stagnosols** display a characteristic oxidation-reduction mottling pattern due to processes caused by periodically stagnating surface water.

The next grouping comprises soils that occur predominantly in **dry grassland regions** (e.g. savannahs) that have well developed humus-rich topsoils and a high base saturation: **Chernozems** have a thick, dark, humus-rich surface horizon. **Kastanozems**, found in drier conditions, also display a humus-rich surface horizon but it is thinner and not as dark when compared to Chernozems. They generally have prominent accumulation of calcium carbonate in the subsurface. Due to more humid conditions, **Phaeozems** are more intensively leached so that the dark, humus-rich surface horizon contains less bases.

The next group comprises soil from **drier regions** with accumulation of gypsum (**Gypsisols**), silica (**Durisols**) or calcium carbonate (**Calcisols**).

Then comes a group with a **clay-rich (argic) subsoil horizon**: **Albeluvisols** (referred to as Retisols in WRB 2022) have tongues of topsoil extending into the subsoil. The other members of the group reflect a) low base status, with high-activity clays (**Alisols**) or low-activity clay (**Acrisols**) or b) high base status, with high-activity clay (**Luvisols**) or low-activity clay (**Lixisols**).

The last group contains relatively very homogenous sands and young soils that have **limited or poor profile development**: **Umbrisols** have deep, dark surface horizons and low base or even acidic subsurface horizons and parent material. **Arenosols** are undifferentiated soils in sandy deposits such as wind-blown sands of deserts. **Cambisols** have a subsurface horizon that only shows some initial development such as a change in colour and/or soil structure. **Regosols** comprise undifferentiated fine and medium textured soils.

How to identify a soil according to the WRB?

Let's take a closer look at this soil profile from the Lao People's Democratic Republic.



An Acrisol profile from the Lao People's Democratic Republic showing characteristic horizons. (AC)

Reference soil groups in the WRB are defined by the presence of diagnostic horizons, properties and materials. The soil in the picture has developed in mineral parent material with a silty texture, under the influence of periodic waterlogging. Four main horizons are visible.

A dark coloured surface horizon (0-20 cm) has moderately high accumulation of organic matter and low base saturation. This satisfies the criteria for a diagnostic umbric horizon. Below the umbric horizon (20-65 cm), the light yellowish subsurface horizon is not bleached enough to satisfy the colour requirements of an albic horizon. In the deeper subsurface (below 65 cm), there is an increase in clay content, satisfying the criteria of the argic diagnostic horizon. Cation exchange capacity analysis in the laboratory confirms that the clays are low activity.

Evidence of reducing conditions (a diagnostic property) and stagnic colour patterns (diagnostic property) can be recognised beneath the umbric horizon, which become more prominent in the deeper horizons (>70 cm) with the bleached greyish strikes and oxidised reddish matrix colours in the surrounding material.

Because of the presence of the argic horizon and its low activity clay and low base saturation, the soil belongs to the Acrisols group.

Prefix qualifiers	Suffix qualifiers
Vetic	Anthric
Lamellic	Albic
Cutanic	Fragic
Technic	Sombric
Leptic	Manganiferric
Fractiplinthic	Ferric
Petroplinthic	Abruptic
Pisoplinthic	Ruptic
Plinthic	Alumic
Gleyic	Humic
Vitric	**Hyperdystric**
Andic	Epieutric
Nitic	Oxyaquic
Stagnic	Greyic
Umbric	Profondic
Haplic	Hyperochric
	Skeletic
	Arenic
	Siltic
	Clayic
	Rhodic
	Chromic
	Novic

Following the convention followed by the WRB, the full name for the soil shown in the photograph would be **Umbric Stagnic Acrisol (Hypedystric, Siltic)**.

Major soil types of Asia



The ancient rice terraces of Banaue in the Philippines are often cited as the "8th Wonder of the World". It is though that this organic paddy farming system was first established over 2000 years ago. The continued existence and viability of the terraces is a manifestation of strong culture-nature connections, unique engineering system, innovation and determined spirit of the Ifugao population to maximise use of the mountainous lands for food production. Lying between 800 and 1500m above sea level, constant maintenance is required to prevent the gradual erosion and collapse of the terraces. (FAO/LG)



Land adjacnet to volcanoes, as seen in this landscape in Indonesia, can be excellent locations for farming. Materials released during volcanic erruptions are rich in elements such as magnesium and potassium. When volcanic materials (e.g. ash, lava) weather, these elements are released, resulting in extremely fertile soils. Volcanic soils, also known as Andosols are usually light, which means that they are easily tilled and can hold a lot of water. However, they also bind phosphorus to soil particles, which means that it is not availabe to plants. People living near to volcanoes are also at risk of volcanic blasts, earthquakes, floods, landslides, and wildfires. (MF)

Reader's Tip!

The following pages aim to help readers understand the most important characteristics of the major types of soil that can be found in Asia, as defined by the World Reference Base (WRB). In this section, the soils are presented alphabetically according to the names of the WRB Reference Soil Groups.

Specifically, in each block:

- The colour used in the box surrounding the soil name is the same as the legend on pages 70-71, as well as for the various maps shown on pages 74-161.
- In this way, when you see a specific colour on the map (e.g. red), you can locate the same colour in this section to discover the basic characteristics of the soil in question (i.e. red corresponds to Andosols).
- There is an explanation of the origin of the name, together with a simple description of the soil.
- The reader is shown a typical vertical exposure (profile) that illustrates the soil's key characteristics.
- There is a photograph of a landscape, land cover or land use that is generally associated with that soil.
- There is a map that displays their broad distribution pattern across Asia.
- Please note that a particular soil is not limited to the areas shown on the map. At the small scale of these maps, it is not possible to show small occurrences.
- In a few cases, the extent of soil types with a more restricted or patchy occurrence across the continent cannot be displayed on the map due to the small scale of the overview map.
- There is a section highlighting the Strengths, Weaknesses, Opportunities and Threats of each soil. These terms are an indication of the benefits or ecosystem services that the soil brings (often reflected in how the soil is being used), issues that may cause problems (e.g. low water holding capacity), how land management may overcome these problems, and finally, the main degradational pressures facing them.



Terracing in China to facilitate the cultivation of crops on a sloping valley floor. In many parts of the tropics and subtropics, Gleysols are widely planted with rice as the impeded drainage supports the creation of paddy fields. (EM)



Peppers (Capsicum spp) are widley used to flavour our diets. Pepper plants need friable, well-drained, sandy loam soil with pH of 6.5-7.5 for optimum production. Salt content in the soil should be low. Such conditions are found in China and Indonesia. (EM)

Acrisols

Strongly acid soils with a clay-enriched subsoil and low nutrient-holding capacity (from Latin *acer*, acid).

Acrisols are acidic soils (i.e. pH <7), dominated by low charge minerals such as kaolinte, with a subsoil horizon that shows an accumulation clay (often with an corresponding lighter coloured horizon above from where clay has been removed). They are quite common in Asia and are mainly found in the wetter parts of the tropics and subtropics. They are normally associated with acidic bedrock (e.g. granite) and are deficient in nutrients, thus requiring substantial applications of fertiliser to produce satisfactory crop yields. Soil Taxonomy classifies most of these soils as Ultisols.



Above: A deep red Acrisol from China with a thin, dark-coloured, surface layer that is enriched with humus. The clay-rich subsoil is slightly darker than the overlying layer, which has been depleted of clay. (EM)

Below: A rubber plantation in China that is managed to produce gum. These trees require an acidic soil that drains freely. (EM)

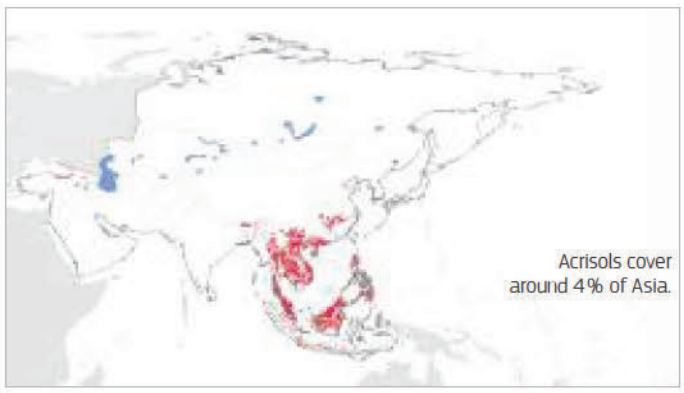


Strengths: Usually under natural vegetation but can support some agriculture if managed appropriately.

Weaknesses: Can become very hard in climates with a pronounced dry season Acrisols; land preparation for the next rainy season is tough, especially by hand.

Opportunities: Productive if fertiliser is applied in small, regular doses that are applied close to the plants as Acrisols do not have the capacity to hold large amounts of nutrients. Good for acid-tolerant crops such as pineapple or tea.

Threats: Acrisols are notorious for their susceptibility to erosion and capping once left bare or by frequent loosening of the topsoil to permit rain to percolate. As their productivity is low, they are best left under natural vegetation.



Albeluvisols

Soils with tongues of bleached material into a clay-enriched subsoil (from Latin *albus*, white and *eluere*, to wash out)

Albeluvisols have a thin, dark surface horizon over a bleached horizon (albic) that extends as narrow tongues into a lower clay-rich horizon (where clay from the topsoil has accumulated). These soils are formed in glacial till, lacustrine or fluvial materials or aeolian deposits such as loess. They occur on flat to undulating plains under coniferous forest or mixed forest in boreal and temperate climates with cold winters and short cool summers. Soil Taxonomy classifies most of these soils as Glossaqualfs, Glossocryalfs and Glossudalfs.



Above: Albeluvisol from the Middle Taiga of Siberia under a mixed birch-spruce forest. The profile clearly shows a bleached upper horizon with tonguing. The tonguing has a horizontal component similar to ice wedges which makes some suggest that their formation is indicative of a very cold, periglacial environment. (LSV).

Below: Albeluvisols occur on flat or undulating plains under coniferous forest or mixed forest in boreal climates. (PD)



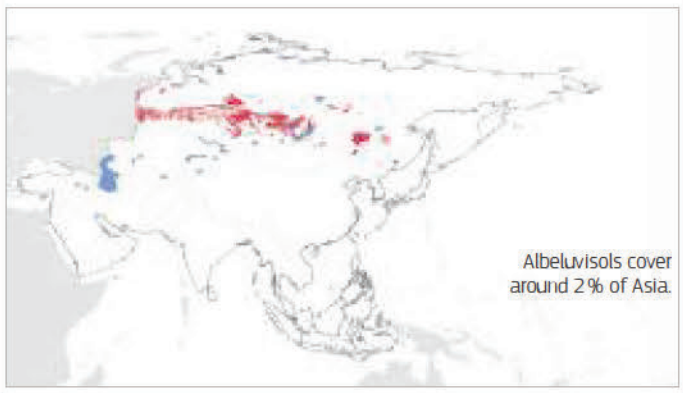
Strengths: Best left under natural forest. Small areas can support pasture or hay production. High clay content and movement of clay particles has high carbon sequestration potential under natural conditions.

Weaknesses: Limited agricultural potential due to their acidity, low nutrient levels, drainage problems together with short and cold growing season.

Opportunities: Careful tillage, liming and fertiliser applications can support some winter cereal cultivation. Carbon sequestration.

Threats: Climate change, in particular a warming of the boreal region, may affect the natural forest cover. Cultivation can destroy evidence of the tonguing, which may lead to their mapping as Luvisols.

***Renamed to Retisols in the 2022 version of WRB.**



Alisols

Very acid soils with a clay-enriched subsoil and high nutrient-holding capacity (from Latin ***alumen***, alum).

Alisols are highly acidic soils (i.e. pH <7) that have a higher clay content in the subsoil than in the topsoil as a result of clay migration. Alisols have a low base saturation at certain depths while high-activity clays (e.g. vermiculite, illite and montmorillonite) are present in the clay-rich horizon. The acidity is caused by high levels of aluminium, which is released by the weathering of minerals. They occur predominantly in humid tropical, humid subtropical and warm temperate regions. Soil Taxonomy classifies most of these soils as Ultisols.



Above: A deep red Alisol from China with no clear horizons. The acid nature of the soil inhibits deep rooting. The strong red colour of the soil is due to the presence of iron oxides. (EM)

Below: Undulating Alisol landscape. Vegetation is semi-natural shrubland with pockets of woodland. The dense vegetation canopy reduces the risk of erosion by water. (EM)

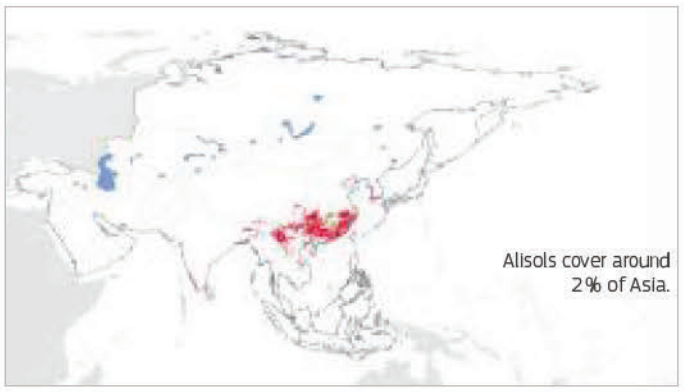


Strengths: Potentially fertile soils once acidity is reduced by liming and the soil is replenished with nutrients, after which a wide range of crops can be successfully grown. Increasingly, Alisols are planted with acid-tolerant estate crops such as tea, rubber or oil-palm. Can be transformed into Luvisols through land management.

Weaknesses: Very acid as a result of the rapid weathering of minerals that release a large amount of aluminium into the soil. Often levels of aluminium are so high that they are toxic to most crops. In subsistence agriculture their productivity is low as recovery from nutrient depletion is slow.

Opportunities: Shallow-rooting crops can be cultivated thus avoiding the acidic subsoil.

Threats: Once left fallow, Alisols are very prone to erosion.



Andosols

Young soils that have developed in volcanic deposits (from Japanese ***an***, black and ***do***, soil).

Andosols develop from materials ejected from volcanoes (e.g. ash, pumice, cinder) that weather to produce specific clay minerals. In more humid climates, many Andosols develop a thick, dark topsoil as a result of the fixing of organic substances by aluminium that is released from the weathering of the clay minerals. Andosols are found along the Pacific Rim of Fire and the margins of continents where tectonic activity is more active.

Soil Taxonomy classifies most of these soils as Andisols.



Above: This profile from Japan shows layers of volcanic ash from two eruptions. Under the black organic-rich horizon, the yellow pumice layer dates from around 13 700 yBP while the red layer is a little earlier (ca.14 000 yBP). (YM)

Below: The picture shows thick ash layers, probably from the volcanic cones in the background. There are many active and extinct volcanoes across Asia. (YM)

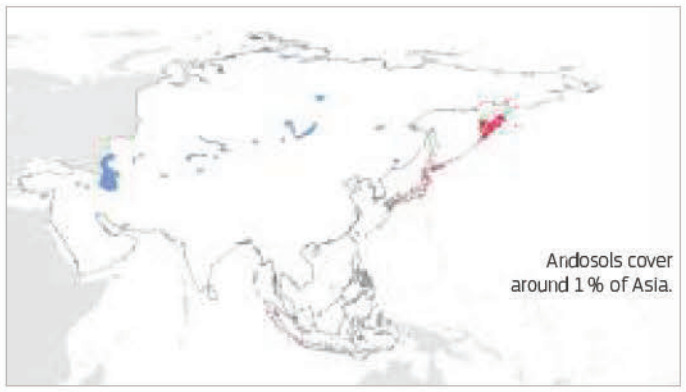


Strengths: Andosols are high in nutrients and easy to cultivate.

Weaknesses: High levels of phosphate fertiliser are needed to affect yields due to fixation by iron compounds in soil. The use of heavy machinery may pose problems because of their low bearing capacity, and being prone to smearing and stickiness.

Opportunities: They can be planted with a wide variety of crops such as sugar cane, tobacco, sweet potato (all tolerant to low phosphate levels), tea, vegetables, wheat and orchard crops.

Threats: Andosols on steep slopes are best kept under forest to prevent erosion. Volcanic eruptions can be dangerous to those living nearby!



Anthrosols

Soil formed or modified by agricultural activity over a long period of time (from Greek ***anthropos***, man).

Anthrosols are formed through human activities such as the addition of organic material, household wastes, lime, charcoal, earth-sods or mineral matter. The added material is usually deeply tilled into the original soil. In most cases, a buried soil can still be found at some depth from the surface. Anthrosols include 'Paddy Soil' where the long-term cultivation of rice causes unique soil characteristics as a result of the repeated lack of oxygen. The characteristics of Anthrosols vary according to the human activity.

Soil Taxonomy classifies most of these soils as Anthreps.



Above: An Anthrosol from China that has developed as a result of rice cultivation. The grey colour of the uppermost 20 cm is due to being flooding for part of the year. Tillage when wet has destroyed all structure. Below this (20-30 cm) lies a compact plough pan that is a barrier to the movement of water through the soil. The boundary with the undisturbed soil is very clear. (EM)

Below: Due to their high organic matter content and good soil structure, Anthrosols are intensively cultivated. An terraced example from Yemen. (MHAM)



Strengths: Favourable physical properties for cultivation (porosity, rootability and moisture availability).

Weaknesses: If not maintained, may have less satisfactory chemical characteristics (acidity, nutrient deficiencies). Sufficient workforce and supply of soil improvement media must be readily available.

Opportunities: Provide cultivation opportunities in unfavourable natural conditions – support local produce and economy.

Threats: Land abandonment, climate change.

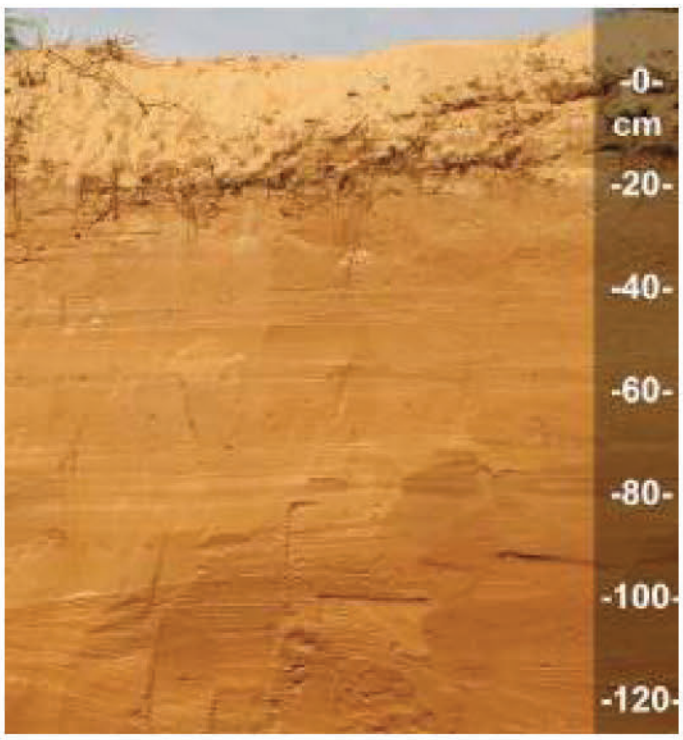


Arenosols

Sandy soil with low water- and nutrient-holding capacity (from Latin, ***arena***, meaning sand).

Arenosols develop as a result of the in situ weathering of quartz-rich parent material or in recently deposited sands (e.g. dunes, beaches). They are among the most extensive soil types in Asia. Soil formation is often limited by a low weathering rate. If vegetation has not developed, they can be prone to wind erosion. Once vegetated, the accumulation of organic matter, clay bands or the formation of humus-aluminium complexes can occur.

Soil Taxonomy classifies most of these soils as Psamments.



Above: Deep Calcaric Arenosol consisting of wind born sands from the United Arab Emirates. Note the lack of stones and depositional layers. (BA)

Below: Arenosols are often found as dunes or sand sheets. This transverse barchanoid dune is part of a sand sea in the UAE that extends to the border with Oman. (BA)

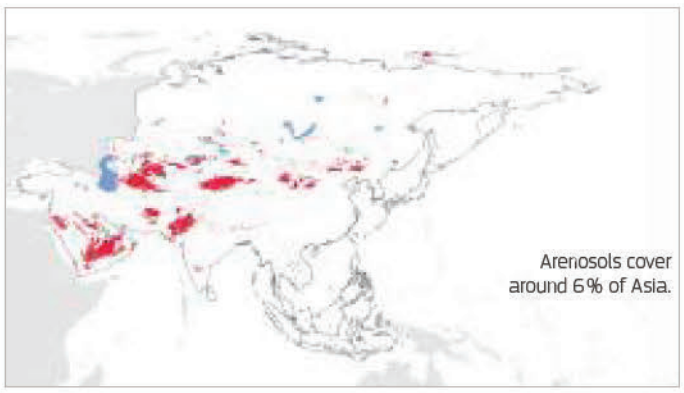


Strengths: Sandy soils are easy to work and therefore much sought after by farmers.

Weaknesses: They only hold a small amount of organic matter, nutrients and water. Crops have to be irrigated frequently to provide the necessary moisture.

Opportunities: As Arenosols occur mainly in the drier parts of the continent, land use is normally limited to extensive (nomadic) grazing. If used for horticulture, additions of organic matter can improve properties.

Threats: Without good soil conservation measures, Arenosols are prone to wind erosion. Wind breaks are essential in conserving the soil, which is easily turned into shifting sands and dunes.



Calcisols

Soil with significant accumulation of calcium carbonate, generally found in dry areas (from Latin ***calcarius***, lime).

Calcisols are common throughout Asia where the climate is dry enough to allow the accumulation of calcium carbonate in the soil. They form through the leaching of carbonates from the upper part of the soil, from carbonate-rich water moving through the soil or by the evaporation of water which leaves dissolved carbonates behind. Precipitated calcium carbonate can fill pores in the soil, which acts as a cementing agent to form a solid hard pan (calcrete) that is impenetrable to plant roots.

Soil Taxonomy classifies most of these soils as Calcids.



Above: A Calcisol from the United Arab Emirates where thick layers of alluvial clay in an alluvial fan have been cemented by calcium carbonate. Annual precipitation is less than 80 mm. (PZ)

Below: Low intensity grazing is one of the few options on dry Calcisols. (PZ)

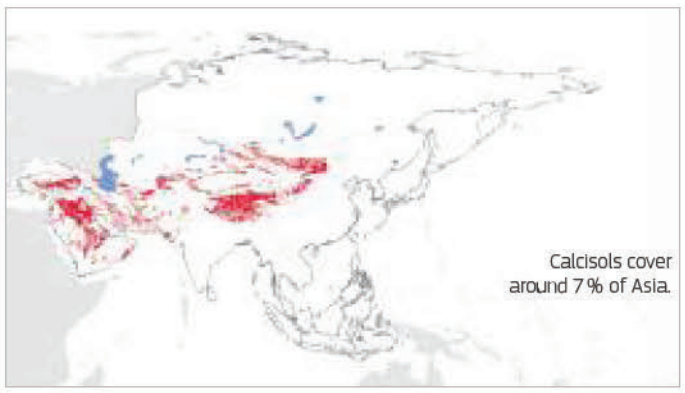


Strengths: Cultivation can often be successful with irrigation.

Weaknesses: High pH unsuitable for many crops. Fertilisation with nitrogen, phosphorus and trace elements like iron and zinc may be necessary as these are only available naturally in small amounts.

Opportunities: Extensive areas are used for grazing and the production of irrigated crops (e.g. winter wheat, melons and cotton).

Threats: Overgrazing and lack of vegetation makes them prone to wind and water erosion. Crusts can develop easily.



Cambisols

Soil that is only moderately developed on account of limited age (from Latin ***cambiare***, to change).

These are young soils. Generally lacking distinct horizons, Cambisols exhibit only slight evidence of soil-forming processes usually through variations in colour, the formation of structure or presence of clay minerals. They are extensive throughout Asia and can have varied characteristics depending on the nature of the parent material, climate and terrain.

Soil Taxonomy classifies most of these soils as Inceptisols.



Above: A Cambisol under long-term rice cultivation, Tamil Nadu, India. (ICAR-NBSS&LUP, Nagpur)

Below: A farmer standing in his rice field in Thiruvarur (Tamil Nadu) India. The soil for this field is shown above. Note the productive nature of this soil. (ICAR-NBSS&LUP, Nagpur)

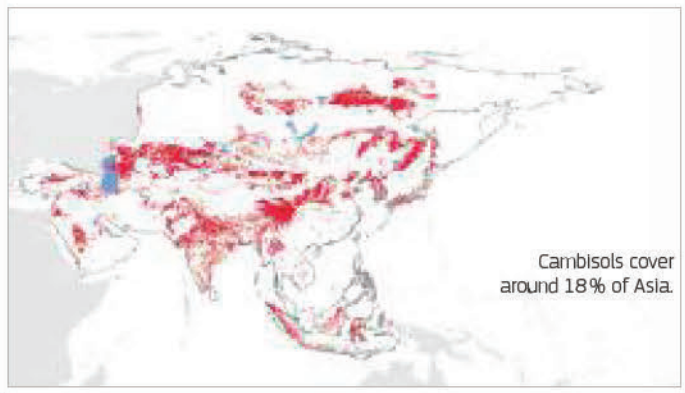


Strengths: Cambisols are among the better agricultural soils in Asia as they are less depleted of nutrients than other tropical soils and have a sufficiently high nutrient-holding capacity to retain fertilisers.

Weaknesses: Strongly weathered Cambisols contain limited amounts of nutrients.

Opportunities: Depending on their depth, their water-holding capacity can be high.

Threats: In hilly or mountainous areas, where Cambisols are most frequent, care should be taken to prevent erosion when the surface is bare. In such conditions, these soils are best be kept under forest or perennial crops such as tea.



Chernozems

Soil with a deep, dark topsoil that is rich in organic matter (from Russian ***chern*** black, and ***zemlja***, earth).

Chernozems have a very dark-brown or blackish surface horizon with a significant accumulation of organic matter and a neutral pH. Secondary calcium carbonate deposits occur within 50 cm of the lower limit of the humus-rich horizon. They show high biological activity and are typically found in the long-grassland areas in humid-temperate climates (e.g. steppe). Chernozems are among the most productive soil types in the world.

Soil Taxonomy classifies these soils as Mollisols.



Above: The darker topsoil (0-30 cm) of this Chernozem from Kazakhstan contains significant amounts of organic matter. The lighter material in the subsoil is calcareous loess. Chernozems are one of the major grassland soil types of the steppe zone. (SKV)

Below: Chernozems are dominant in the grassland steppe regions of Asia. In grassland ecosystems, most organic carbon inputs occur through the development of extensive root networks. (MK)

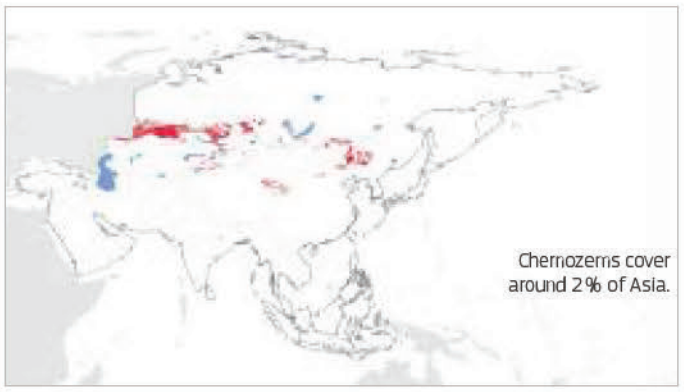


Strengths: Very fertile soils. High carbon content.

Weaknesses: Preservation of a favourable soil structure needed through timely cultivation and careful irrigation at low watering rates. Application of phosphorous fertilisers is required for high yields.

Opportunities: High agricultural potential.

Threats: Prone to wind erosion if allowed to dry out and water erosion on slopes following tillage.



Cryosols

Soil of cold regions with permafrost and/or cryoturbation (from Greek ***kraios***, cold or ice).

Cryosols develop in cold regions where permanently frozen subsoil (permafrost) is found. In this type of soil, water occurs primarily in the form of ice and cryogenic processes such as freeze-thawing cycles, cryoturbation (warping), frost heave, cryogenic sorting, cracking and ice segregation are the dominant soil-forming processes. Cryosols often exhibit distorted horizons and/or patterned ground.

Soil Taxonomy classifies most of these soils as Gelisols.



Above: A Cryosol from the Russian Federation. In this example, the thawed active layer with roots is sitting on top of the still frozen subsoil. The topsoil is so heavily mixed due to cryoturbation that no horizons are evident. (LSV)

Below: Thawing permafrost in Siberia - meltwater channels cause gullies to form in the ice. The surrounding green areas are actually conifer trees. (PZ)

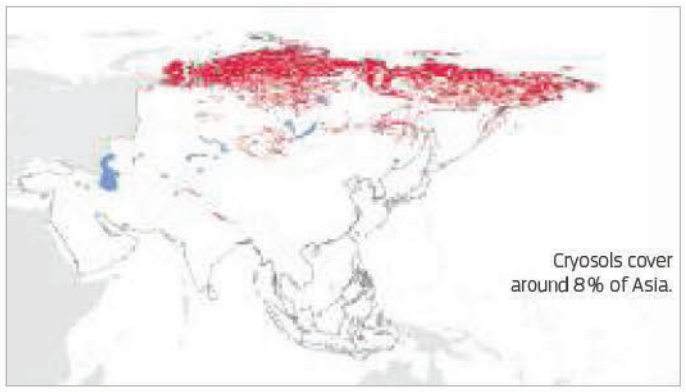


Strengths: Carbon sink – permafrost and cryoturbation lock frozen organic matter in the soil.

Weaknesses: Frozen ground limits vegetation development. Collapse and subsidence due to thawing (thermokarst).

Opportunities: High ecological and environmental value. Many extinct animal remains have been preserved within the permafrost (e.g. mammoths).

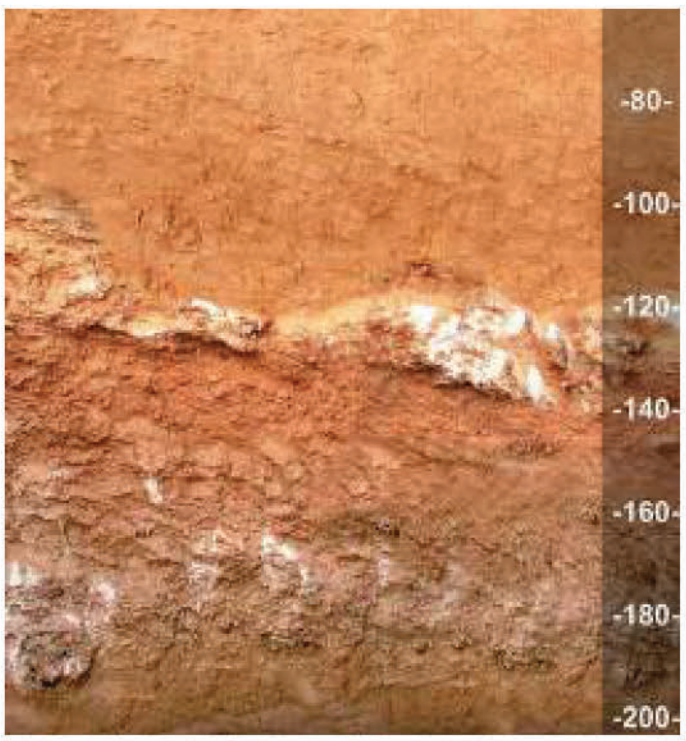
Threats: Warming climate will lead to thawing and increased release of greenhouse gases from soil.



Durisols

Soils with accumulation of silica (from Latin ***durus***, meaning hard).

Durisols display hardened (secondary) accumulations of silica (SiO_2). They generally develop in alluvial and colluvial deposits in level and slightly sloping plains and in arid and semi-arid regions. Durisols develop over long periods during which the soil reaction is so alkaline (pH >8) that silicon becomes mobile. The dissolved silicon precipitates as an amorphous opal, nodules (durinodes) and eventually, hard layers known as duripans develop. Eventually, such hard pans may turn into silcrete. Soil Taxonomy classifies most of these soils as Durids.



Above: Durisols are confined to dry regions where they occur in association with Gypsiols and Calcisols. This profile shows a soils with Calcisols underlain by a hard gypsum layer. (BA)

Below: Durisols develop in level and slightly sloping plains and in arid and semi-arid regions. (pxhere)



Strengths: The hard cap can protect landscapes from erosion.

Weaknesses: Their use is fairly restricted once a pan has developed.

Opportunities: Only after breaking up the pan, and with irrigation they can be successfully be planted with crops.

Threats: Crust development can hamper cultivation.



Ferralsols

Strongly weathered soils with low nutrient-holding capacity (from Latin ***ferrum***, iron and ***alumen***, alum).

Ferralsols are mostly associated with high rainfall areas and very old (Tertiary) land surfaces. They are so strongly leached that they have lost nearly all of their weatherable minerals. As a result, they are dominated by stable products such as aluminium oxides, iron oxides and kaolinite, which give Ferralsols their strong red and yellow colours. Levels of calcium and magnesium are very low. The binding of particles by iron oxides gives an apparent sandy or silty feeling (known as pseudosand).
Soil Taxonomy classifies most of these soils as Oxisols.



Above: A Ferralsol from China. Noticeable is the characteristic red colour due to iron and aluminium oxides, the lack of layering in the profile as a result of biological mixing and the low organic matter content of the topsoil. (EM)

Below: In very acid soils, such as on this Arenic Ferralsol in the Lao People's Democratic Republic, plants such as pineapple (*Ananas comosus*) are a good choice as an intercrop with cashew (*Anacardium occidentale*). (AC)

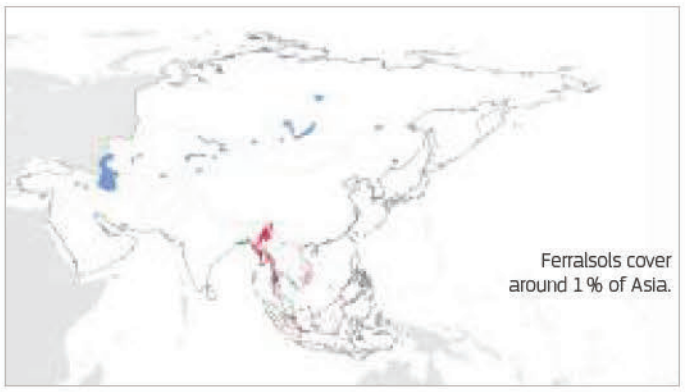


Strengths: Usually under natural vegetation but can support some agriculture if managed appropriately.

Weaknesses: Require careful management. As nutrient levels and retention are low, soil amendments must be given in small portions. Very highly weathered examples do not hold nutrients any more. The loose aggregate structure leads to low water retention.

Opportunities: Despite low pH and high aluminium saturation, actual amounts of exchangeable aluminium are low and can easily be corrected by liming. However, the high iron content results in the fixation phosphorus from fertilisers.

Threats: Maintaining soil fertility and the prevention of soil erosion are important management requirements.



Fluvisols

Young soil in floodplains, lakes, deltas or tidal deposits (from Latin ***fluvius***, river).

Fluvisols occur in all periodically flooded areas such as flood plains, river fans, valleys, tidal marshes and mangroves. They show a layering of sediments as a result of deposition by water. Their characteristics and fertility depend on the nature and sequence of the sediments, together with the interval between flood events.
Soil Taxonomy classifies most of these soils as Fluvents.



Above: Distinctive horizontal strata of a Fluvisol in the bank of a dry river channel north of Sana'a, Yemen. Fast moving water gives rise to gravelly or sandy soils. Lower velocities or standing water give rise to fine-textured soils, often mixed with significant amounts of organic debris. (MHAM)

Below: Fluvisols can be found on floodplains adjacent to rivers. Nutrients deposited during floods make these soils highy fertile, which menas that they are often intensively cultivated. (AC)

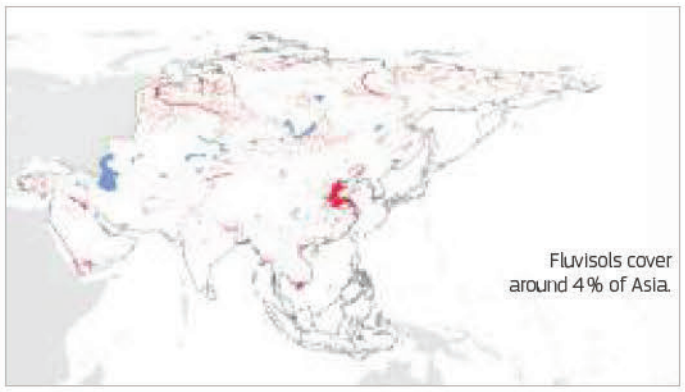


Strengths: Fluvisols, except for the very acid variants, are fertile because of the regular supply of nutrients and proximity of irrigation water in dry conditions. Riverine Fluvisols are highly suitable for wetland rice because of the close proximity to fresh water and level terrain.

Weaknesses: Flood control or drainage may be needed due to proximity of rivers. Low-lying backswamps, if not suitable for wetland rice, are best left under natural vegetation; these areas may be used for extensive grazing when they are accessible.

Opportunities: High agricultural potential.

Threats: Flooding and waterlogging. Prone to urbanisation and sealing. At risk of soil pollution due to intensive use and flooding.



Gleysols

Soils saturated by groundwater for long periods (from Russian ***gley***, 'mucky mass').

Gleysols occur in low-lying areas or depressions where the groundwater comes close to the surface and the soil is waterlogged for long periods of time (saturated with water). Gleysols display characteristic reddish, brownish or yellowish colours in the upper part of the soil where oxygen is present, in combination with greyish/bluish colours deeper in the soil where oxygen is absent (this state is referred to as reduced).

Soil Taxonomy classifies most of these soils as aquic suborders.



Above: Completely reduced Gleysol from a river delta in the Lao People's Democratic Republic. Because of their wetness Gleysols show little soil development apart from the accumulation of organic matter in the surface layer and rust mottling. (AC)

Below: Typical Gleysol landscape in the Lao People's Democratic Republic. The impeded drainage is well suited for rice cultivation. Gleysols are often found with wetland vegetation (e.g. grass, reeds, sedges). (PT)

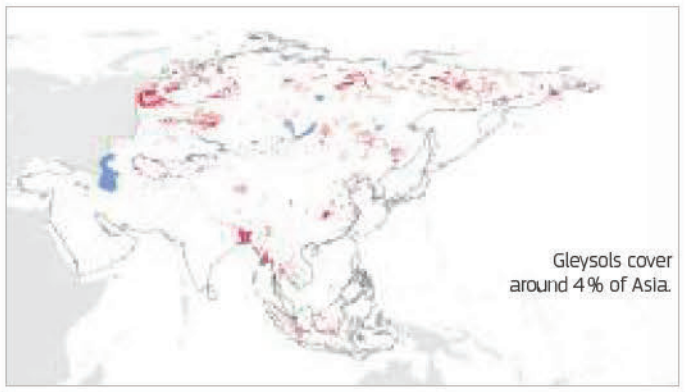


Strengths: Gleysols normally occur in level terrain. The proximity to groundwater makes them very suitable for growing wetland rice.

Weaknesses: Care is needed if large amounts of iron are present as this can lead to bronzing of the leaves and yield reduction. Most crops need to be drained and water levels in the soil need to be controlled.

Opportunities: Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture.

Threats: Waterlogging, lack of air for roots, compaction.

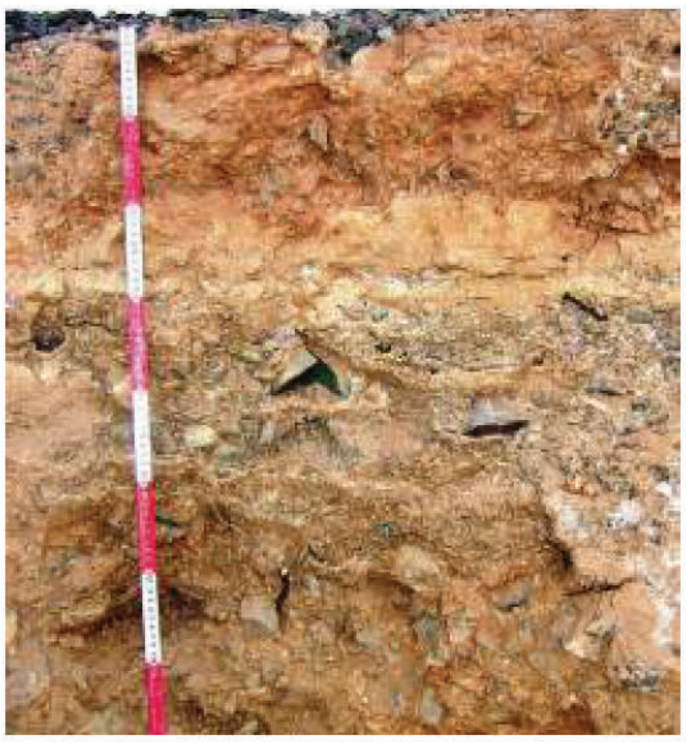


Gypsisols

Soil with significant accumulation of gypsum, generally found in dry areas (from Greek *gypsos*, gypsum).

Gypsisols are soils with substantial redeposition of gypsum ($CaSO_4.2H_2O$). They are found in the driest parts of the arid climate zone. Many Gypsisols occur in depressions and reflect former lake beds that have dried up through evaporation. The processes for gypsum precipitation are similar to Calcisols (see page 59). Gypsum that forms a solid hard pan is referred to as gypcrete. They often reflect past climates.

Soil Taxonomy classifies most of these soils as Gypsids.



Above: A Gypsisol profile from Mongolia. A harder (more indurated), petrogypsic horizon is evident between 20-30 cm. (OB)

Below: Gypsisols are found in driest parts of arid zones, often in depressions associated with former inland lakes, such as this sabka in Oman. Natural vegetation is sparse. (JL)

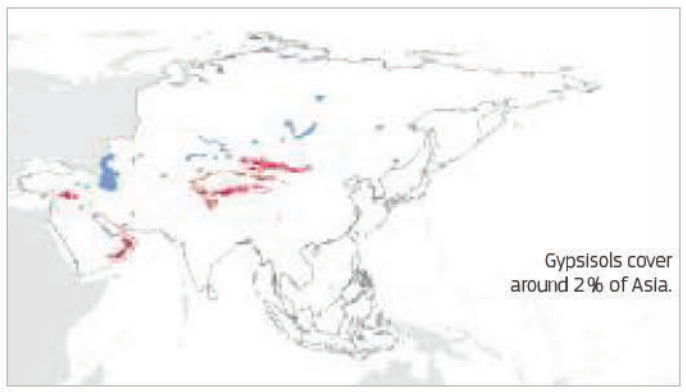


Strengths: Can support limited extensive grazing.

Weaknesses: Gypsisols do not hold much water. Due to the presence of gypsum the soils have a high pH, normally above 8, which affects the supply of plant-available nutrients. The sandy nature, the alkaline character and the lack of water make most Gypsisols unsuitable for cropping. Moreover, when irrigated gypsum dissolves, water will easily seep through the soil and become unavailable to plants.

Opportunities: Limited. Cultivation possible on soils with relatively low gypsum content if irrigated.

Threats: When high amounts of gypsum are present, the soil structure may collapse under irrigation.

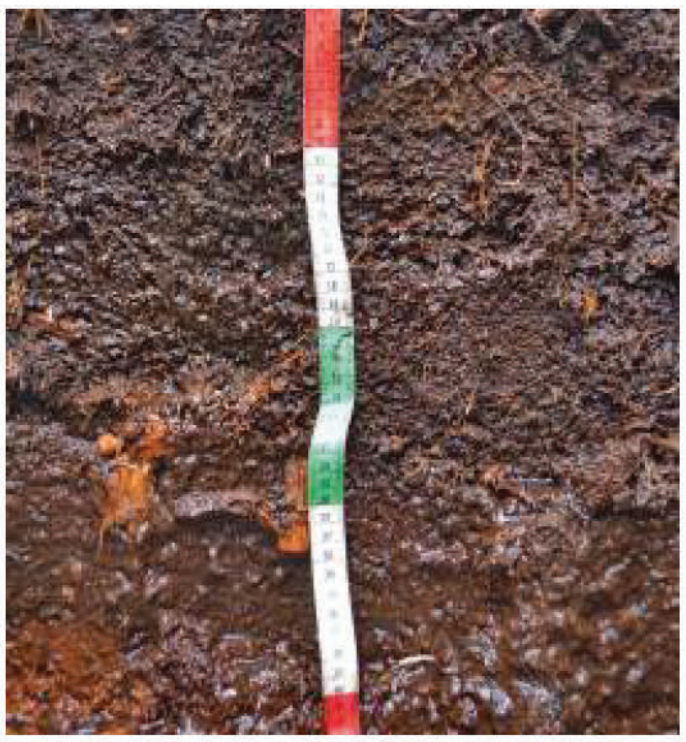


Histosols

Soils with a high levels of organic material, often with visible plant remains (from Greek *histos*, tissue).

Histosols, also known as peat, contain a high amount of organic matter, usually more than 20%, and have a high water content. They occur in areas with low temperature or wetlands, isolated depressions in low-lying areas and in coastal regions where organic debris accumulates.

Soil Taxonomy classifies these soils as Histosols.



Above:A Histosol from the southern taiga region of Siberia. In this example, it is clearly evident that the soil is saturated with water. As decomposing plant remains are still visible, this would infer the Histic qualifier. (INS)

Below: Tropical Histosols form in waterlogged conditions in peat swamp forests such as shown here in Selangor, Malaysia. (TYH)

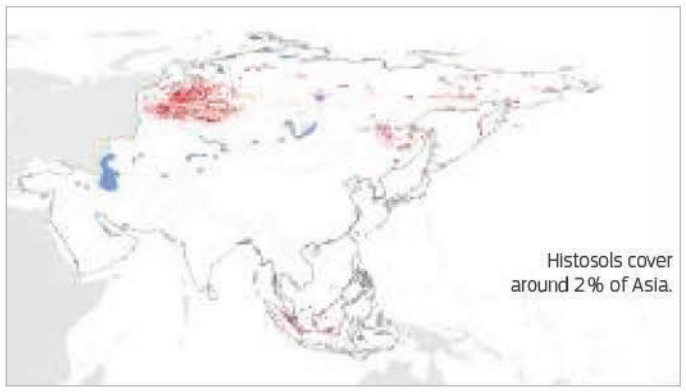


Strengths: Contain more than 20% organic matter and have a high water content. An major component of the terrestrial carbon cycle. An important wildlife habitat.

Weaknesses: Their bulk density is very low, some 0.4 kg dm^{-3} or less. Weight bearing capacity is very low. Nutrient imbalances are high and macronutrients such as calcium or magnesium are often lacking or occur only in very small quantities.

Opportunities: High ecological and environmental value – important store of terrestrial carbon.

Threats When drained, they suffer from a risk of fire, irreversible shrinkage and surface subsidence. Loss of wetland habitat.



Kastanozems

Soil with an organic-rich topsoil and carbonates in the subsoil (from Latin *castanea*, chestnut, Russian *zemlja*, earth).

Kastanozems have a deep, dark coloured surface layer with a significant accumulation of organic matter, a high base saturation (pH) and an accumulation of calcium carbonate in the subsoil. They develop in the drier parts of shrubby grassland habitats where there is still sufficient biomass production to form the organic-rich surface layer and dry enough to facilitate the precipitation of carbonates or gypsum.

Soil Taxonomy classifies most of these soils as Mollisols.



Above: Kastanozem from the Mongolian Steppe, showing a dark, humus-rich surface layer. Secondary calcium carbonate is visible below 60 cm. (OB)

Below: The semi-arid tussocky grasslands of the steppe of Inner Mongolia, China, illustrate the typical landscapes of Kastanozems. (PL)

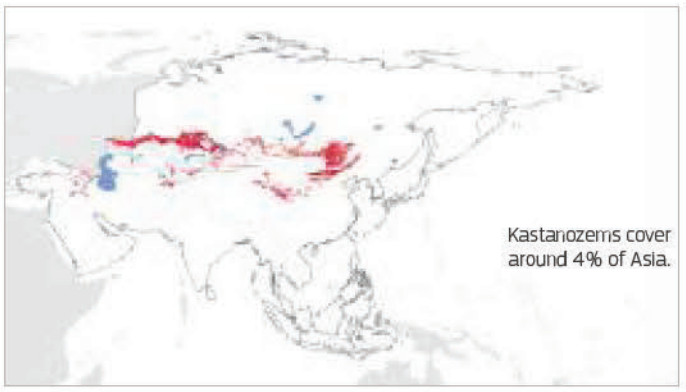


Strengths: Kastanozems are highly fertile soils and therefore much sought after by farmers.

Weaknesses: They may suffer from nutrient imbalances because of the excess of calcium in the subsoil. To make them productive during dry, hot summer seasons, irrigation is necessary.

Opportunities: Kastanozems in the Mediterranean region are planted mainly with winter wheat during the rainy season. .

Threats: When dry and under fallow conditions, the soil is susceptible to wind erosion; when situated on slopes the soil may suffer from water erosion under high-intensity rainfall.

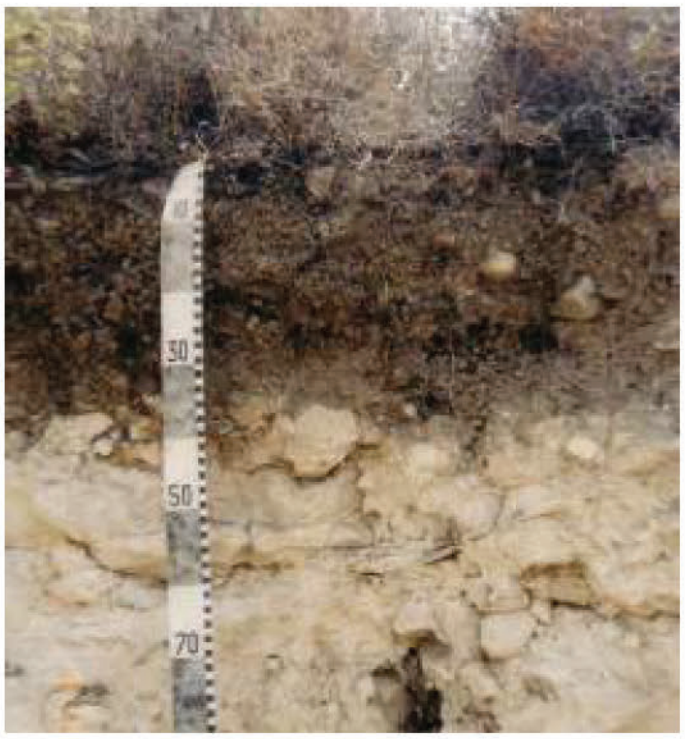


Leptosols

Shallow soil over hard rock or gravelly material (from Greek *leptos*, thin).

Leptosols are shallow soils over hard rock, very gravelly material or highly calcareous deposits. Because of limited pedogenic development, Leptosols have a weak soil structure. Leptosols tend to occur in mountainous and desert regions where bedrock is exposed and the physical disintegration of rocks due to freeze/thaw or heating/cooling cycles are the main soil-forming processes. Bare rock, possibly displaying only microscopic soil formation, are referred to as Nudilithic Leptosols.

Soil Taxonomy classifies most of these soils as Entisols.



Above: Leptosol from Lebanon – a cover of debris some 20 cm thick overlies a dolerite. Soil development is slow. Only limited extensive grazing is possible. (TD)

Below: Irrigated land in a narrow valley in the Pamir highlands where Fluvisols are cultivated for subsistence crops. The Leptosols of the slopes are the source of fine earth transported by water from the melting glaciers covering the higher-lying parts of the mountain valleys. (VC)

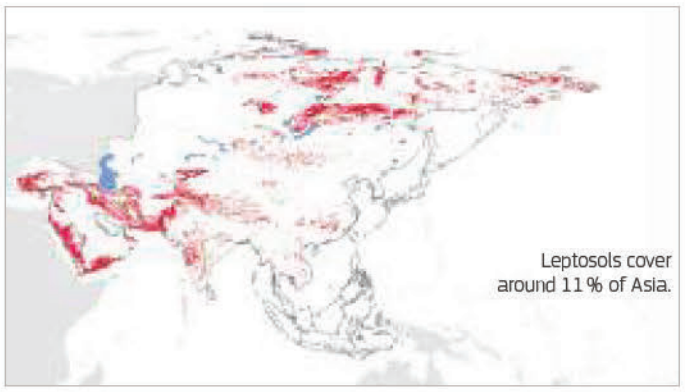


Strengths: They provide a solid foundation for construction.

Weaknesses: Leptosols are unsuitable for growing crops. They have a limited rooting depth, a low water-holding capacity and their nutrient supply is confined to what is available in the shallow top layer.

Opportunities: Farmers can use Leptosols for low-density livestock grazing.

Threats: Can be very prone to erosion.



Lixisols

Slightly acid soils with clay-enriched subsoil and low nutrient levels (from Latin *lixivia*, washed-out substances).

Lixisols are slightly acid soils that show a distinct increase in clay content with depth. The clay is predominantly kaolinite with limited capacity to hold nutrients. Occurring mainly in the dry savannah region with low biomass production, Lixisols do not hold much organic matter and lack a well developed soil structure. Lixisols are prone to the development of crusts, which prevents rain entering the soil. Overland flow can then erode the topsoil which is the most fertile part. Wind erosion may be an issue.

Soil Taxonomy classifies most of these soils as Alfisols.



Above: A characteristically red Lixisol from China. (EM)

Below: A cultivated Lixisol in China. (EM)



Strengths: Can be fairly productive. The low inherent fertility and nutrient-retention capacity dictate a split-application of fertilisers, preferably applied close to the plants. Liming is not required.

Weaknesses: Lixisols do not hold much organic matter as dry savannah regions have low biomass production. High-intensity rainfall will destroy any soil structure present.

Opportunities: Surface mulch during fallow periods helps prevent the development of crusts. Irrigation may be needed to grow crops during the dry season or to overcome dry spells during the rainy season. The use of water traps is recommended to store as much rainwater as possible.

Threats: Prone to erosion and development of surface crusts that can exacerbate erosion.



Luvisols

Slightly acid soils with a clay-enriched subsoil and high nutrient-holding capacity (from Latin *luere*, to wash).

Luvisols have a distinct increase in clay content with depth as a result of clay movement from the upper part of the soil to the lower part. The clay is usually a mixture of kaolinite, illite and montmorillonite, giving the soil a high nutrient-holding capacity. In general, Luvisols have a well-developed soil structure, which contributes to a good water-holding capacity. They are widespread across much of temperate Asia.

Soil Taxonomy classifies most of these soils as Alfisols.



Above: A dark red Luvisol from China. Clay has been moved from the upper part of the soil to deeper horizons. (EM)

Below: Luvisol under primary mixed forest in the hills of Liaoning Province in China.

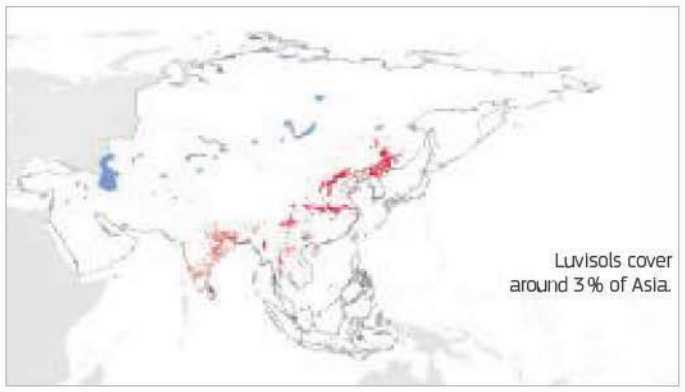


Strengths: Luvisols are productive soils. They have a large mineral nutrient reserve and a good aeration. Rooting depth is normally unlimited unless they overlie continuous hard rock or a petrified layer.

Weaknesses: Due to long and continued cultivation, many Luvisols have lost their topsoil. This can result in low organic matter content while nitrogen-deficiency is quite common.

Opportunities: Productive soils if managed appropriately.

Threats: Prone to erosion on slopes.



Nitisols

Deep red soils with a well developed, nut-shaped structure (from Latin ***nitidus***, shiny).

Nitisols develop mainly from basic iron-rich rocks such as basalt. Their main characteristics are a dark red colour and a well-developed structure that is nutty in appearance with shiny surfaces. The active iron content is high, which enforces strong the bonding of soil particles and the formation of the nut-shaped aggregates. The shiny surfaces are a mixture of clay and iron coatings. Most Nitisols are dominated by kaolinite clay.

Soil Taxonomy classifies most of these soils as Oxisols.



Above: Nitisols are mainly developed in highly weathered products of basic igneous parent rock. This Nitisol from Thailand shows a well-developed structure. Rooting is limited to the upper part of the soil due to strong acidity and high aluminium toxicity in the subsoil. (EM)

Below: As shown by this landscape in China, Nitisols are much sought after because of their high productivity despite a high phosphate-fixing capacity. (EM)



Strengths: Nitisols are suited for a wide range of crops. Deep and well drained. Many Nitisol areas are used to grow coffee.

Weaknesses: Low in nutrients. In annual cropping, fertiliser application is necessary to make these soils productive. Due to the high amount of active iron, Nitisols suffer from phosphate-fixation. Retention rates of 80% or higher are common.

Opportunities: Intensive liming can overcome the aluminium toxicity. Once limitations are addressed, Nitisols can have high agricultural potential.

Threats: Prone to erosion on slopes.



Nitisols cover less than 1% of Asia.

Phaeozems

Slightly acid soils with a thick, dark-coloured surface layer (from the Greek ***phaios***, dusk and Russian, ***zemlja***, earth).

Phaeozems are characterised by a thick, dark-coloured, surface layer that is rich in organic matter and well-supplied with nutrients. Their development requires a reasonable amount of precipitation and a lush vegetation, preferably grasses. This characteristic distinguishes them from Chernozems, which they border where conditions are drier. As a result, carbonates are leached from Phaeozems. In Asia, they are typical steppe and mountain forest soils. Soil Taxonomy classifies most of these soils as Oxisols.

Soil Taxonomy classifies most of these soils as Mollisols.



Above: A Leptic Phaeozem in China. Phaeozems generally form in unconsolidated sediments such as loess. (EM)

Below: Phaeozems are typical of the mountainous medows found in the Caucasus regions. (RM)

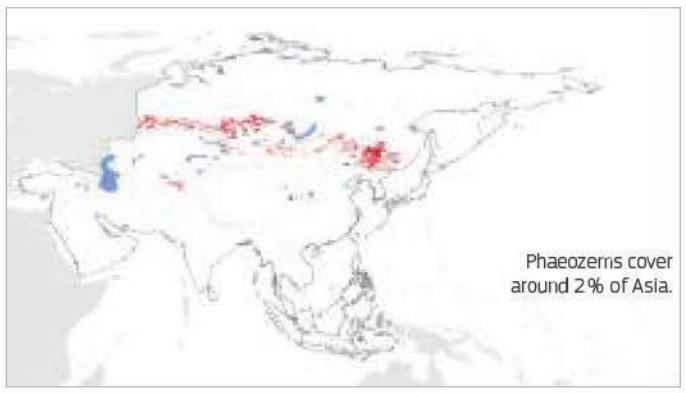


Strengths: Phaeozems are highly productive soils, provided rooting if not inhibited by continuous hard rock.

Weaknesses: Phaeozems may suffer during drought conditions because the water-holding capacity is limited to the surface layer.

Opportunities: Good agricultural potential. Used extensively for cereal and cotton production.

Threats: Drought and prone to wind erosion. Diffuse pollution due to excess use of agrochemicals (i.e. fertilisers, pesticides).



Phaeozems cover around 2% of Asia.

Planosols

Poorly structured surface layer abruptly overlying a slowly permeable layer (from Latin ***planus***, flat).

Their key characteristic is the very slow permeability of the subsoil, which causes water entering the soil to stagnate above this layer. The transition to the slowly permeable layer is very sharp (e.g. clay content doubles). The frequent waterlogging dissolves iron and manganese, which are precipitated as reddish-brown or black concretions on both sides of the abrupt boundary. The removal of iron in the topsoil causes the structure to collapse.

Soil Taxonomy classifies most of these soils as Albaqualfs and Albaquults.



Above: The abrupt textural change at around 30 cm depth is clearly visible in this Planosol from the southern part of the West Siberian Plain. The surface layer is almost structureless and has a thin (5 cm) organic layer. (SOI)

Below: The above profile was located in a micro-depression on almost level ground within a birch glade with a herbaceous understory. (PD PXFUEL)

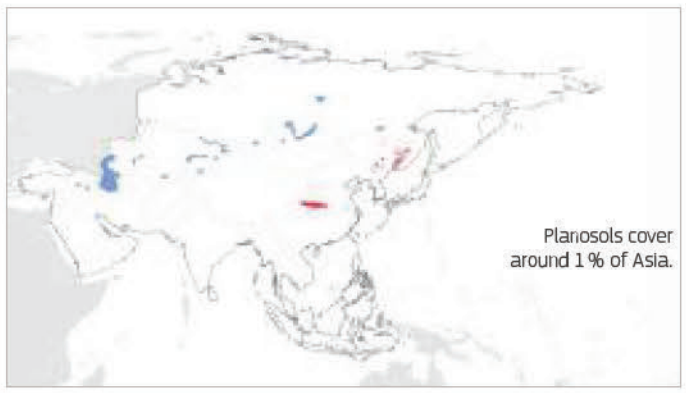


Strengths: Most areas with Planosols are best kept under natural vegetation, usually grassland; some are used for rice cultivation.

Weaknesses: Because these soils are subject to frequent waterlogging in flat terrain, their use is limited. Strongly developed Planosols with a very silty or sandy surface are best left untouched. Low nutrient levels.

Opportunities: Grasslands with supplemental irrigation in the dry season are a good land use in climates with long dry periods and short infrequent wet spells. Can support some cereal or shallow root crops if fertilisers are applied.

Threats: Waterlogging, wind erosion if the soil dries out.



Planosols cover around 1% of Asia.

Plinthosols

Soils with accumulation of iron that hardens irreversibly when exposed to air and sunlight (from Greek *plinthos*, brick).

Plinthosols display an accumulation of iron (and manganese) in the subsoil as large mottles or concretions. This layer develops mostly under the influence of fluctuating groundwater. While buried, the layer (called plinthite) is soft and can be cut by a knife. However, once exposed to air and sunlight, it hardens irreversibly and is often known as ironstone). When brought to the surface by erosion, the hard ironstone layer forms a cap that protects the area from further erosion.

Soil Taxonomy classifies most of these soils with the Plinth- prefix of Ultisols and Oxysols.



Above: A Plinthosol profile from the Lao People's Democratic Republic. The photograph clearly shows the distinctive red-coloured iron-rich nodules that harden irreversibly on drying or exposure to oxygen. The grey horizon below the surface is the resulting of ploughing. (AC)

Below: Petroplintite is widely used throughout southeast Asia as building material. In this photograph from Thailand, it is used for paving. (EM)

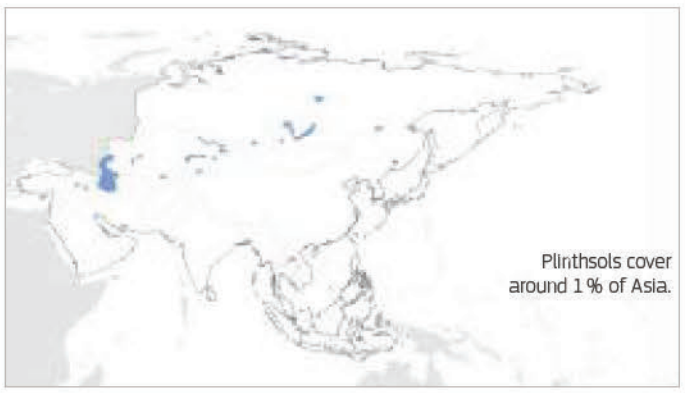


Strengths: When still soft, plinthite can be cut and dried to use as building stone. When it hardens as loose concretions, it can be used for road surfacing or airstrip construction. Can protect land from erosion.

Weaknesses: When cultivating Plinthosols, care must be taken that water levels do not drop below the depth where the iron-rich layer occurs.

Opportunities: Limited for agriculture. Plinthosols are a source of raw material as aggregate or as an ore deposit.

Threats: Plinthosols may also occur on slopes where groundwater comes close to the surface; in this position they must be protected from erosion.



Podzols

Acid soil with a bleached horizon underlain by leached material (from Russian *pod*, under, and *zola*, ash).

Podzols have a distinctive ash-grey horizon that has been bleached by the loss of organic matter and iron oxides. This sits on top of a dark accumulation horizon of redeposited humus and/or reddish iron compounds. Typically occurring in quartz-rich sands in temperate zones with high precipitation, often under coniferous forests.

Soil Taxonomy classifies most of these soils as Spodosols.



Above: A classic Podzol from Thailand showing a contrasting grey leached horizon overlaying a dark reddish-brown iron and humus accumulation horizon. (LDDT)

Below: Podzols are the characteristics soils of the Siberian boreal forests, which lie between the tundra zones to the north and the temperate forests to the south. (PD)

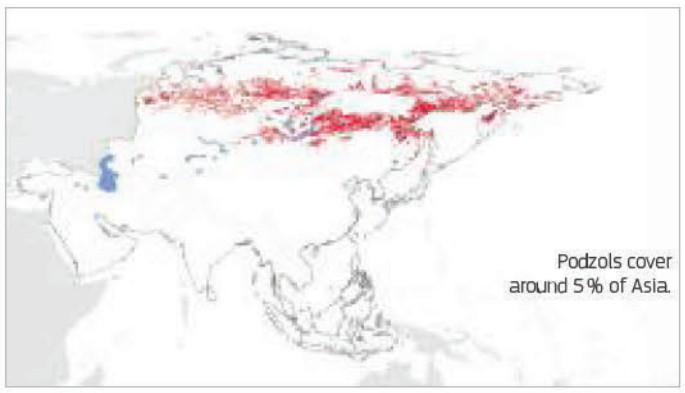


Strengths: Tropical Podzols normally sustain a light forest cover that recovers very slowly after cutting or burning.

Weaknesses: Sandy parent materials means that Podzols have low nutrient status, low level of available moisture and low pH. Shallow rooting zone, phosphate deficiencies and aluminium toxicity make them unattractive soils for arable farming.

Opportunities: Limited. Mature Podzols are generally best used for extensive grazing or left under their natural vegetation.

Threats: Lacking nutrients. Once left bare, vegetation may have great difficulties to re-establish itself.



Regosols

Weakly developed soils in unconsolidated material (from Greek *rhegos*, blanket).

Regosols show only slight signs of soil development. The are the remnant group of WRB, lacking diagnostic horizons that would have keyed them out to another Group. Some accumulation of organic matter producing a somewhat darker topsoil is often the only evidence of soil formation. Limiting factors for development range from low temperatures, prolonged dryness, characteristics of the parent material or erosion. Regosols are extensive in eroding lands such as mountains or deserts.

Soil Taxonomy classifies most of these soils as Entisols.



Above: A moderately developed Regosol from China. Apart from organic matter accumulation in the uppermost part, there is a lack of any significant soil horizon indicating the presence of soil-forming processes. (EM)

Below: Landscape with Regosols in Yemen. Wind has removed fine materials leaving a layer of gravels on the surface. High temperatures and low precipitation give little chance for soil formation. (MHAM)

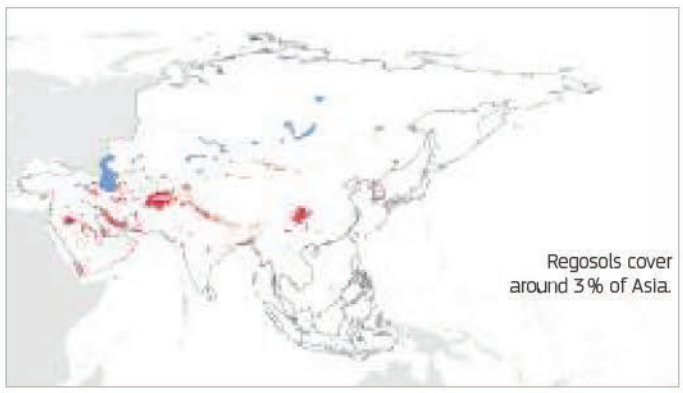


Strengths: Most Regosols are well supplied with nutrients as they occur in actively weathering material.

Weaknesses: Water-holding capacity is often low and water stress of crops is common.

Opportunities: Shrub and tree cultivation where climate allows (irrigation may be required). Some dry farming possibilities. Otherwise, best left under natural vegetation.

Threats: A weakly developed soil formation makes these soils prone to erosion.

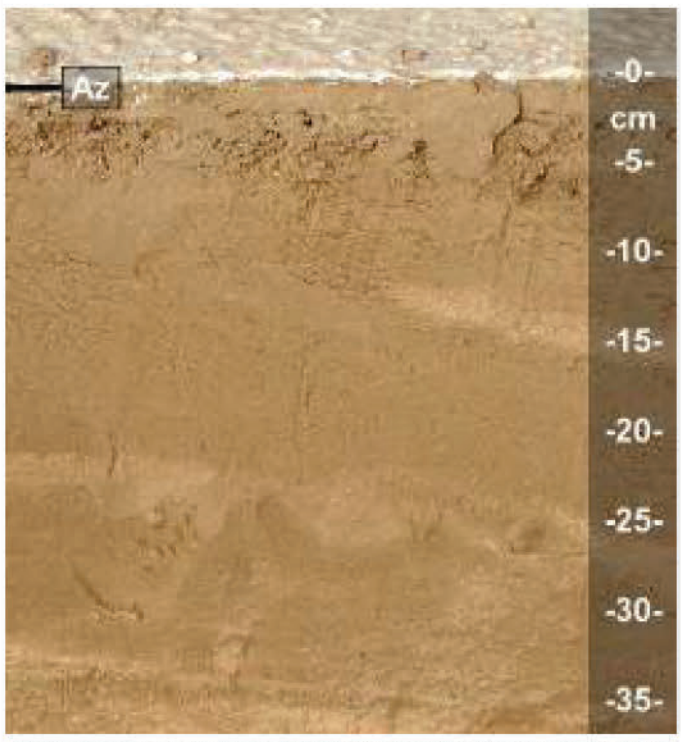


Solonchaks

Soils with accumulation of salt (from Russian ***sol***, salt).

Solonchaks are pale coloured soils containing high concentrations of soluble salts. They are mostly associated with arid regions where saline groundwater comes close to the surface or where evapotranspiration rates are considerably higher than precipitation during a large part of the year. Salts dissolved in the groundwater remain behind after the evaporation of the water and accumulate on or just below the surface.

Soil Taxonomy classifies most of these soils as Salids.



Above: A Solonchak from a salt flat in the United Arab Emirates. The white surface layer is very rich in soluble salt derived from saline groundwater at a depth of 45 cm which comes to the surface by capillary rise. (BA)

Below: Polygonal surface cracking in a salt flat in Türkiye. Recent water has evaporated leaving a distinctive salt crystals on the surface. (MAC)

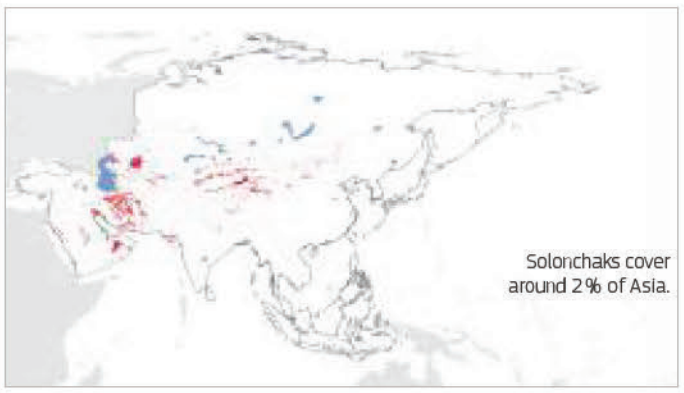


Strengths: Support natural habitats. Little agricultural value apart from extensive grazing.

Weaknesses: As salts are harmful to most crops, these soils are not directly suitable as farmland. When they dry out, the soil becomes very hard making land preparation, especially with hand tools, very difficult.

Opportunities: Cultivation possible only after salts have been flushed from the soil (which then ceases to be a Solonchak). Irrigation must satisfy the needs of the crop and maintain downward water flow to flush excess salts from the root zone. Limitations to plant growth depend on the amount, depth and composition of the salts.

Threats: Salinisation and wind erosion.



Solonetz

Soil with a clay accumulation horizon, rich in sodium (from the Russian, ***sol***, for salt and ***etz***, meaning strongly expressed).

Strongly alkaline soils with a dense, clay-rich subsoil containing a high amount of exchangeable sodium and a distinctive columnar structure. Sodium disperses clay particles and organic matter in the topsoil, which are then washed deeper into the soil. Large pores are filled with clay and structural elements capped with organic coatings. Solonetz are normally associated with flat lands in climates with hot, dry summers or with former coastal deposits that contain a high proportion of salt.

Soil Taxonomy classifies most of these soils as Aridisols.



Above: The profile shows light coloured surface horizon (0-20 cm) overlaying a dense, strongly structured, sodium-rich subsoil horizon (20-80 cm) that exhibits a blocky or columnar top. Note the abrupt transition to the sodium-rich subsoil. (MK)

Below: In this example from Uzbekistan, groundwater with high sodium content moves to the soil surface due to evaporation. Note the characteristic polygons on the surface and the presence of salt-tolerant vegetation, which has collected fine wind-blown sand. (MK)

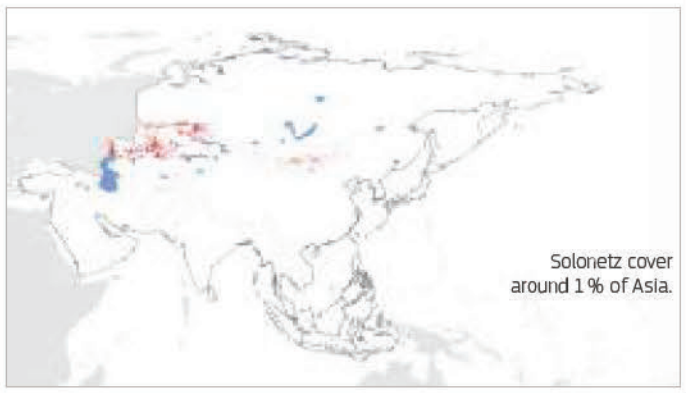


Strengths: Support natural habitats. Can be used for grazing.

Weaknesses: As high pH is harmful to most crops, these soils are not directly suitable for the cultivation of crops. Land preparation becomes difficult when they dry out.

Opportunities: Can be improved if pH lowered or gypsum added.

Threats: Increased alkalinity and wind erosion.



Stagnosols

Soils with periodic water stagnation (from Latin ***stagnare***, to flood).

Stagnosols are soils with a perched water table, often caused by the presence of an impermeable barrier deep in the soil. Perched water tables lead to temporary water logging and the mobilisation of iron and/or manganese. This process gives rise to a characteristic colour pattern; aggregate surfaces are bleached and depleted of iron whereas the centres are enriched showing brown to orange colours. Found on flat or gently sloping ground in humid climates.

Soil Taxonomy classifies most of these soils as the epiaquic members of Inceptisols.



Above: A vertical section in a Stagnosol from the Lao People's Democratic Republic shows the intricate colour patterns that exist in such soil. (AC)

Below: Surface ponding of water and stagnant conditions after rainfall in India due to the presence of a slowly permeable subsoil, is characteristic of Stagnosols. (IWP)

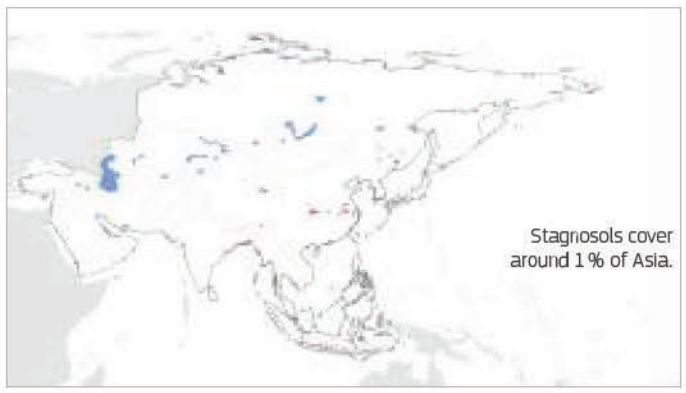


Strengths: Drained Stagnosols can be fertile owing to their moderate degree of leaching.

Weaknesses: Limited because of their oxygen deficiency and saturated status. A dense subsoil.

Opportunities: Can be improved by drainage and deep ploughing.

Threats: Climate change.



Technosols

Soils that are sealed or contain a significant amount of human artefacts (from Greek *technikos*, skilfully made).

Technosols contain large quantities of man-made artefacts (e.g. household garbage or industrial waste), or contain material that has been brought to the surface (e.g. mine dumps or oil spills). They also include soils that have been sealed by an artificial surface (e.g. roads, hard standing areas). They can often contain toxic material. Most Technosols occur in and around urban, industrial or mining areas.

While Technosols are referred to as urban or mine soil, there are no equivalents in Soil Taxonomy.



Above: Technosol containing layers of ash from a coal buring powerstation. The brown horizon is a dense loamy layer that has been added to seal the ash beneath. However, roots have penetrated this barrier. (KAO)

Below: Sealed soils, such as roads and pavements, with underlying unconsolidated materials are considered Technosols. This example come from Timor-Leste. (ILO)

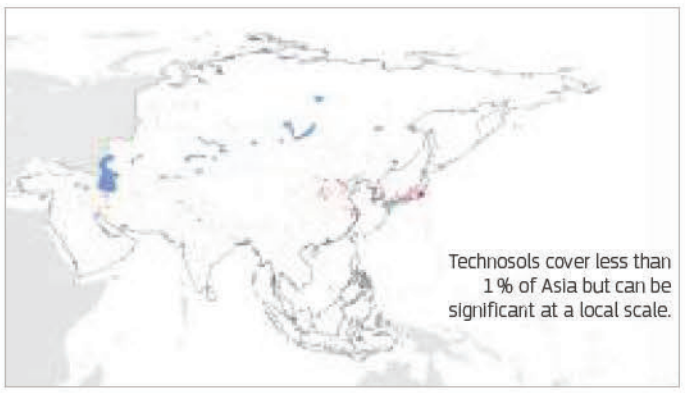


Strengths: Can buffer toxic material and provide foundations for structures.

Weaknesses: Sealed by artificial surfaces and can contain toxic material – loss of most soil functions, often total.

Opportunities: Limited unless greatly restored.

Threats: Loss of most soil functions. Can be contaminated by harmful substances.



Umbrisols

Acidic soil with a dark, organic-rich surface horizon (from Latin *umbra*, shade).

Umbrisols have a deep, dark-coloured surface layer that is rich in organic matter but has a low nutrient content. They are mainly associated with acid parent materials and areas with high rainfall. In Asia they mainly occur in mountains and highland regions and on sandy soils in the tropics in areas with high rainfall. Umbrisols are the counterpart of nutrient-rich soils with a dark surface horizon (i.e. Chernozems, Kastanozems and Phaeozems).

Soil Taxonomy classifies most of these soils as Entisols and Inceptisols.



Above: Umbrisol from the northeast of the Russian Federation that has developed under a forb-grass meadow; this soil has a Podzol-like morphology with a characteristic, organic-rich, dark topsoil over a thin pale layer on top of a brownish subsoil. (INS)

Below: Umbrisols are mostly found under permanent grasslands in mountainous areas with cool humid climates. Umbrisols occur above the actual tree line in the Himalayan and Central Asian mountain ranges. (PD)

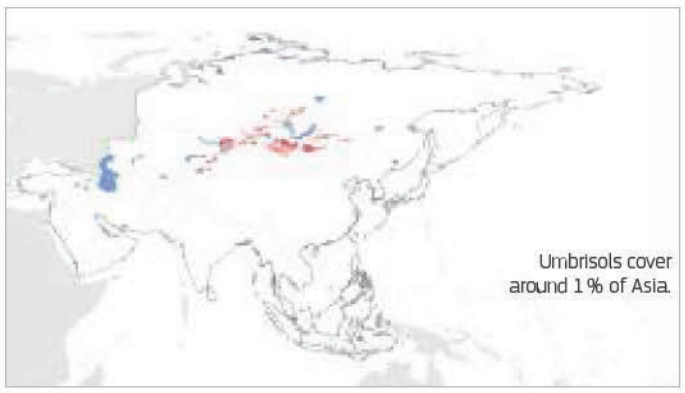


Strengths: Occurring in humid areas, suitable for woodland. Climate change mitigation through carbon sequestration.

Weaknesses: Acidity.

Opportunities: Require heavy investment to make them productive. Natural acidity must be countered with lime.

Threats: Erosion risk for cultivation on slopes.



Vertisols

Clay-rich soils that develop deep, wide cracks upon drying (from Latin *vertere*, to turn).

Vertisols are clayey soils that exhibit wide cracks which open and close periodically upon drying and wetting. This is caused by the presence of the clay mineral, montmorillonite, which takes up water when it becomes wet (and expands) and releases the water again upon drying out (shrinks). This process brings material from the surface into the subsoil giving rise to a 'mixed or churned' soil (see page 51). Vertisols are widespread in lowland areas such as floodplains.

Soil Taxonomy classifies most of these soils as Vertisols.



Above: Black Vertisol from Thailand. The photo shows wedge-shaped structural elements (sphenoids) with smoothened surfaces formed by shear stresses on moistening (typical for Vertisols). (EM)

Below: Characteristcs polygonal cracks on the surface of a Vertisol in Türkiye. (MAC)



Strengths: Vertisols can be highly productive provided the right land management measures are taken.

Weaknesses: As most Vertisols occur in level areas water movement in the soil is limited and during wet periods water can stagnate on the surface. Heavy to work when wet. Swelling and shrinkage may destroy the foundation of structures (e.g. roads, irrigation canals)..

Opportunities: Raised beds made out of the surface layer, which is often crumbly, are good seed beds as the water drains quickly into the adjacent furrows. .

Threats: Can be susceptible to extreme weather conditions (e.g. droughts, prolonged rainfall).





Physical weathering is an important soil-forming factor. Not only does breaking rocks into smaller and smaller pieces make it easier for plants to become established, physical weathering exposes greater surface area, which in turn facilitate increased chemical reactions. This image from Salavan Province in the north of the Lao People's Democratic Republic shows the build of debris slopes under an exposure of bedrock. Depending on the degree of soil-forming processes, such soils would be classified as Regosols or Cambisols. (PT)



A consequence of soil erosion is the production of sediments that can be transported by running water to other locations. Where the water flows end, sediments are deposited, sometimes covering existing soils. This photograph from Gujarat State in India clearly shows a Vertisol that has been buried by basaltic alluvium. The Vertisol clearly shows the characteristic cracking, slickensides and wedge-shaped structure that form due to the presence of swelling clays. Similar features, but less developed, can also be seen in the layer covering the Vertisol. (ICAR NBSS&LUP, Nagpur)

Mapping soils in Asia

Soil survey or soil mapping is the process of identifying and delineating areas which have similar soil characteristics.

One of the problems with mapping soils is that they form a continuum where changes in characteristics reflect the interaction between soil-forming factors (pages 33-41) and processes (pages 44-51). Sometimes these changes occur over just a few metres. More often, changes occur gradually and can only be recognised over long distances. Thus, boundaries between different types of soil or soil properties are often diffuse making it difficult to show true changes on a map, where sharp lines are drawn to separate one soil type from another.

Why map soils?

Soil mapping can be carried out for a number of purposes:

- To provide information to assist land and environmental management (e.g. for farmers) by identifying the natural capacity of the soil;
- To provide strategic information on the current status of soil quality (e.g. for national policy development);
- To provide a framework for extrapolating the results of local studies and soil monitoring networks;
- To demonstrate how local and national soil variability fits into the global pattern (trans-national policy).

The type or range of information required for each of these purposes is varied, although there is often overlap between them. Because of this, the techniques used to map soil and the information gathered during the survey can be very different, depending on the purpose of the mapping. In general, there are two broad approaches to surveying soils. General Purpose surveys attempt to quantify and delineate a wide range of soil properties, most often associated with soil classes, so that they can be used for many different applications. Such surveys tend to cover large areas such as individual river basins, regions or countries. In contrast, Specific Purpose surveys focus on quantifying the amount and spatial variation of a specific soil property or attribute. For example, the nutrient content, water-holding capacity and texture. Such mapping is carried out within relatively small areas such as experimental plots or areas of land where a particular activity occurs or a specific incident may have contaminated the soil.

Soil mapping – current trends and the future

Since the 1980s, soil surveying has increasingly embraced a range of highly-sophisticated computer-based tools. The use of remote and proximal sensing technology (i.e. sensors and cameras mounted on aircraft and satellites), global positioning systems (GPS) to fix the information collected during fieldwork, hand-held tablets to log field observations and soil databases to store information are all now used routinely by soil survey organisations. By using Geographic Information Systems (see page 170), all these data can be brought together in a single computing environment to speed up the production of soil maps in an accurate and precise manner.

Already, the use of apps on smart phones and drones has augmented the data provided by satellites and aircraft. In fact data from higher spectral and spatial resolution sensors on satellites, coupled with novel geo-statistical software and artificial intelligence, are increasingly used to supplement information captured by traditional field surveys.

How are soil maps made?

Soil maps are traditionally based on field observations that support interpretations of how and where soil characteristics, and therefore, soil types change between observation points. Such interpretation is based on conceptual models of how local soil-forming factors and processes determine the variation of soil characteristics across the landscape. For most of the soil maps created during the previous century, these conceptual models were never explicitly defined or quantified, they were simply based on the experience of the soil surveyors and observations of local soil variation. With the advent of digital and information technologies, these conceptual models are increasingly being quantified and made more consistent [95].

Whatever the approach, robust field observations are the key to making good soil maps. The location of each inspection point is chosen by the field surveyor to provide information as to how the soil characteristics being mapped vary in relation to the local geology, landscape, vegetation and climate – all factors used to develop the conceptual model of soil spatial variation. Often, inspection points are located on a straight line that crosses the landscape where the topography (how slopes vary across the landscape creating different land forms) and geology vary the most. In other cases, where the landscape has little variation, inspection points are located more randomly. In some cases, particularly for national 'inventory' purposes, observation points are located at predetermined intervals on a standard grid, for example, at 10 km intervals.

At each inspection point, soil characteristics are examined either by digging a pit to reveal a profile or by using an auger (a handheld screw drill) to extract soil samples. Both techniques generally sample to a depth of 1.5 to 2 m, less if bedrock is encountered. Each sample point is geo-referenced and the characteristics of the soil are entered onto recording sheets or a logger (increasingly a tablet or smart phone), often in the form of symbols or 'shorthand' notes.

The information recorded for each layer (known as horizons) generally includes the thickness, colour, texture, pH, size and shape of soil structures, presence of carbonates, stones, nature of boundaries, and so on [96]. Often, soil samples are taken for more detailed laboratory analysis.

Once a number of field observations have been made, the field surveyor begins to develop a conceptual model of the relationships between soil characteristics and local topography, climate, parent material and land use. Tentative boundaries are sketched between different soil areas and the changes in soil characteristics between these boundaries are checked by further field observation. This process usually results in amendments being made to both the conceptual model used to interpolate between points and the boundaries placed on the field map sheets. By the end of the field survey, a set of field map sheets showing the boundaries between different soil areas will have been finalised.







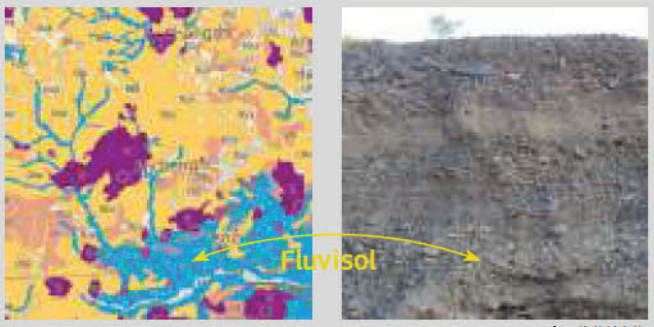
Collecting soil data in the Republic of Korea, from top to bottom: Measuring soil pH in reclaimed soils (LC); preparing to collect samples from a soil profile (LC); the use of drones is opening a new frontier in soil mapping by making it possible map soil properties of land that is difficult to access (RDA); Overall, the status of regional soil survey in many parts of Asia is unsatisfactory given pressing challenges such as food security, water scarcity, climate change and land degradation, that require current soil data.

Soil maps

The following section of the atlas contains a series of maps showing the regional distribution of the WRB Reference Soil Groups across Asia.

As illustrated by the diagram below, a soil map depicts areas where soil properties, according to the classification scheme used, are similar. Hence, the light blue tones on the map correspond to the soil profile shown, while the pink and brown areas correspond to other soil types.

A soil map is a two-dimensional expression of a three-dimensional object, so only spatial or geographical changes in the soil properties are represented.



(MHAM)

Soil survey in Asia

Unfortunately, many Asian countries have very limited detailed mapping of their soil resources. What exists is of variable age and quality and rarely correlated with other countries. Most countries have a small-scale general soil map. For some, the only national coverage is still the Soil Map of the World at a scale of 1:5 Million which was produced by FAO and UNESCO in the 1970s! In most countries, detailed soil information for regional or project planning is not available. For example, only Thailand and the Republic of Korea have been mapped at scales of 1:50 000.

The table below shows the coverage of soil maps for selected Asian countries. It is clear that knowledge for regional planning (i.e. 1:100 000 and 1:250 000) is largely incomplete, making it difficult to identify high-potential areas or, conversely, critical problem areas and their priority for more detailed inventories. At the same time, soil maps for specific projects, at scales around 1:25 000, only cover very small areas. Soil maps suitable for operational aspects (i.e. farm level), usually at scales larger than 1:25 000, are rare and limited to specific projects.

Scale	Coverage	Countries / Regions
Small scale (> 1:1 000 000)	Complete	China, Japan, Republic of Korea, Democratic People's Republic of Korea, Thailand, Viet Nam, Philippines, Mongolia, Malaysia, Bangladesh, Sri Lanka, Iraq, Iran, Afghanistan, Russian Federation
	Partially	Cambodia, Pakistan, Myanmar, Bhutan, Nepal
	Very limited	
Exploratory (1:250 000 – 1:1 000 000)	Complete	China, Japan, Republic of Korea, Democratic People's Republic of Korea, Thailand, Viet Nam, Philippines, Cambodia, Malaysia, Myanmar, India, Turkey, Syrian Arab Republic, Lebanon, Iran
	Partially	The rest
	Very limited	
Reconnaissance (1:100 000 - 1:250 000)	Complete	Japan, Republic of Korea, Democratic People's Republic of Korea, Philippines, Mongolia, Malaysia, Bangladesh, Sri Lanka, Jordan
	Partially	China
	Very limited	The rest
Semi-detailed (1:25 000 – 1:100 000)	Complete	Thailand, Republic of Korea
	Partially	China, Japan, Viet Nam, Philippines, Lebanon, Jordan, Iraq
	Very limited	The rest
Detailed (1:10 000 – 1:25 000)	Complete	Republic of Korea
	Partially	China, Japan and some others
	Very limited	The rest
Very detailed (< 1:10 000)	Complete	Republic of Korea
	Partially	Japan and a few others
	Very limited	The rest

National soil survey coverage in selected Asian countries.

Legend

WRB Reference Group:

AC	**Acrisols**
AB	**Albeluvisols**
AL	**Alisols**
AN	**Andosols**
AT	**Anthrosols**
AR	**Arenosols**
CL	**Calcisols**
CM	**Cambisols**
CH	**Chernozems**
CR	**Cryosols**
DU	**Durisols**
FR	**Ferralsols**
FL	**Fluvisols**
GL	**Gleysols**
GY	**Gypsisols**
HS	**Histosols**
KS	**Kastanozems**
LP	**Leptosols**
LX	**Lixisols**
LV	**Luvisols**
NT	**Nitisols**
PH	**Phaeozems**
PL	**Planosols**
PT	**Plinthosols**
PZ	**Podzols**
RG	**Regosols**
SC	**Solonchaks**
SN	**Solonetz**
ST	**Stagnosols**
TC	**Technosols**
UM	**Umbrisols**
VR	**Vertisols**
GC	**Glaciers**
WR	**Water bodies**

Qualifiers:

aa	**Aluandic**: Andic properties but where aluminium is associated with organic acids, pH < 5 (only in Andosols).
ab	**Albic**: A bleached, light-coloured, subsurface horizon from which clay, iron, aluminium and organic matter has been removed and only uncoated coarser fractions (sand and silt) remain.
ac	**Acric**: accumulation of low activity clay in the subsoil; low cation exchange capacity.
ad	**Aridic**: Found in deserts with low organic carbon and evidence of deposition or removal of fine particles by wind; generally high pH.
ai	**Argic**: A subsurface horizon with distinctly higher clay content than the overlying horizon.
ak	**Anthric**: High levels of organic matter and evidence of long-term human activities, such as cultivation and/or addition of organic matter.
an	**Andic**: High levels of iron and aluminium, high phosphate retention, feels light and fluffy, low pH (only in Andosols).
ao	**Acroxic**: High levels of aluminium and low levels of base cations (only in Andosols).
ap	**Abruptic**: Having an abrupt change in texture within 100 cm of the surface.
aq	**Anthraquic**: Showing evidence of waterlogging as a result of impeded drainage due to an artificially-created compacted layer.
ar	**Arenic**: Having a loamy fine sand or coarser layer, at least 30 cm thick, within 100 cm of surface.
br	**Brunic**: Having a layer at least 15 cm thick, which meets certain alteration criteria of the cambic horizon but lacks the cambic texture criteria, starting within 50 cm of the surface.
ca	**Calcaric**: Having 2 % or more calcium carbonate between 20 and 50 cm depth.
cb	**Carbic**: Having a layer with illuvial amorphous substances composed of organic matter and aluminium that does not become redder on ignition (burning) (only in Podzols).
cc	**Calcic**: Having a layer with 15 % or more carbonate present, mostly in the form of fine particles or concentrations, that is at least 15 cm thick.
ccn	**Endocalcic**: A calcic horizon starting between 50-100 cm from the surface.
ce	**Clayic**: Having high clay content in a layer at least 30 cm thick, starting within 100 cm of the surface.
ch	**Chernic**: Having a very dark, thick and well-structured surface horizon with high base saturation and moderate to high levels of organic matter.
cl	**Chloridic**: A saline horizon that contains secondary enrichment of soluble chloride salts (only in Solonchaks).
cm	**Cambic**: Having a subsurface horizon showing evidence of alteration with respect to the underlying material, starting within 50 cm from the surface.
cn	**Carbonatic**: A saline horizon, with a pH of 8.5 or more, and high levels of carbonates (only in Solonchaks).
co	**Colluvic**: Having material formed by sedimentation as a result of human-induced erosion.
cr	**Chromic**: Having a reddish coloured subsurface layer, at least 30 cm thick.
ct	**Cutanic**: Having clay coatings on the surfaces and pores in a clay accumulation horizon.
cy	**Cryic**: Having evidence of regular freezing conditions that are manifest through the presence of visible ice or distorted layers (cryoturbation) within 100 cm of the surface.
du	**Duric**: A subsurface horizon showing nodules or concretions that are weakly cemented by silica (SiO_2).
dy	**Dystric**: Having a base saturation of less than 50 % between 20 and 100 cm from the surface.
ek	**Ekranic**: Having consolidated, human-made material, that is derived from an industrial process, starting within 5 cm of the surface (only in Technosols).
et	**Entic**: A loose spodic horizon without the presence of an albic horizon (only in Podzols).
eu	**Eutric**: Having a base saturation of 50 % or more between 20 and 100 cm from the surface.
eun	**Endoeutric**: Having a base saturation of 50 % or more between 50 and 100 cm from the surface.
fg	**Fragic**: Having a dense subsurface horizon with structural units that are hard penetrate for roots to penetrate, within 100 cm from the surface.
fi	**Fibric**: Organic material, two-thirds of which consists of recognisable plant tissue after rubbing, within 100 cm from surface (only in Histosols).
fl	**Ferralic**: A highly weathered horizon dominated by low activity clays and highly resistant minerals, such as (hydr)oxides of Fe, Al, Mn and titanium (Ti), within 100 cm from the soil surface.
fo	**Folic**: Well-aerated, mostly undecomposed, organic material, at least 10 cm thick, within 40 cm of the surface, which is not saturated for long periods.
fr	**Ferric**: A horizon where water saturation-induced reduction-oxidation processes causes segregation of Fe and/or Mn to such an extent that discrete nodules have formed and the intermodular matrix is largely depleted of iron. Occurs within 100 cm of the soil surface.
fv	**Fluvic**: Receiving regular inputs of river, marine or lacustrine sediments, and shows stratification in a layer at least 25 cm, within 100 cm of the surface.
ge	**Gelic**: Having a layer with a soil temperature of 0 °C or less, for two or more consecutive years, within 200 cm of the surface.
gl	**Gleyic**: Having colour patterns that are evidence of reduction-oxidation processes due to groundwater, within 50 cm of the surface.
gld	**Bathygleyic**: Having colour patterns that are evidence of reduction-oxidation processes due to groundwater, below 100 cm from the surface.
gln	**Endogleyic**: Having colour patterns that are evidence of reduction-oxidation processes due to groundwater, between 50 and 100 cm from the surface.
gp	**Gypsiric**: Having at least 5 % gypsum, between 20 and 50 cm of the surface.
gr	**Geric**: Having a very low cation exchange capacity (nutrient holding and supply) in some layers within 100 cm of the surface.
gs	**Glossic**: Showing tonguing of a dark, organic-rich horizon into an underlying layer.
gy	**Gypsic**: Having a gypsum-rich horizon within 100 cm of the surface.
gz	**Greyic**: Having a dark coloured layer, with some uncoated coarse grains at shallow depth (within 5 cm of the mineral soil surface).
ha	**Haplic**: Having no other applicable qualifier.
hf	**Hydrophobic**: Water-repellent, water stands on a dry soil for 60 seconds or more (only in Arenosols).
hg	**Hydragric**: Having a low infiltration rate and reduction-oxidation colour patterns due to the presence of a plough pan or puddled layer.
hi	**Histic**: Having a surface, or shallow subsurface, horizon consisting mostly undecomposed organic matter that is regularly saturated by water.
hm	**Hemic**: Organic material, less than two-thirds of which is recognisable plant tissue after rubbing, within 100 cm of the surface (only in Histosols).
hu	**Humic**: Having relatively high concentration of well decomposed organic matter.
hy	**Hydric**: Having the capacity to store large volumes of water (only in Andosols).
ir	**Irragric**: Having a layer that builds up gradually through the long-term application of irrigation water that contains high levels of sediment.
jk	**Hyperskeletic**: Stony layers, having less than 20 % fine earth averaged over a depth of 75 cm from the soil surface or to hard bedrock, whichever is shallower.

jz	**Hypersalic**: Significant accumulation of soluble salts that result in high pH and high electrical conductivity (EC > 30 dS m^{-1}), within 100 cm of the soil surface.
le	**Leptic**: Having continuous rock within 100 cm of the surface.
led	**Bathyleptic**: Having continuous rock below 100 cm from the surface.
len	**Endoleptic**: Having continuous rock starting between 50 and 100 cm from the surface.
lep	**Epilleptic**: Having continuous rock starting within 50 cm of the surface.
li	**Lithic**: Having continuous rock within 10 cm of the surface (only in Leptosols).
lv	**Luvic**: Accumulation of high activity clays in the subsoil, but with high cation exchange capacity.
lx	**Lixic**: Accumulation of low activity clay in the subsoil, but with high cation exchange capacity.
mo	**Mollic**: Having a thick, dark, surface horizon that is rich in humus and has a neutral pH.
mz	**Mazic**: Massive structure and hard to very hard consistence in the upper 20 cm of the soil (only in Vertisols).
na	**Natric**: Having a dense subsurface horizon with higher clay content than the overlying horizon and a high level of Na and/or Mg, and often with strong columnar or coarse prismatic structure, within 100 cm of the soil surface.
ni	**Nitic**: Having a clay-rich subsurface horizon with a nutty structure and shiny ped faces, within 100 cm of the surface.
nu	**Nudilithic**: Having continuous rock at the surface (only in Leptosols).
ns	**Endosalic**: Significant accumulation of soluble salts that result in high pH and high electrical conductivity (EC > 15 dS m^{-1}), starting between 50 and 100 cm from the soil surface.
os	**Ortsteinic**: Having a cemented spodic horizon (only in Podzols)
pe	**Pellic**: Having a very dark surface horizon, with a moist Munsell value of 3.5 or less and a chroma of 1.5 or less (only in Vertisols).
ph	**Pachic**: Having a dark-coloured organic-rich horizon, that is 50 cm or more thick.
pl	**Plinthic**: A subsurface horizon that consists of an iron-rich, humus-poor mixture of kaolinitic clay with quartz and other constituents, that hardens irreversibly on exposure to repeated wetting and drying.
pp	**Petroplinthic**: Having a cemented hard horizon, in which Fe is an important cement and organic matter is absent, within 100 cm of the surface.
pr	**Protic**: Showing no soil horizon development.
ps	**Petrosalic**: Having a layer, 10 cm or more thick, which is cemented by salts more soluble than gypsum, within 100 cm of the surface.
pt	**Petric**: Having a strongly cemented or indurated layer, starting within 100 cm of the soil surface.
px	**Pisoplinthic**: Having a horizon containing nodules that are strongly cemented with Fe and/or Mn, starting within 100 cm of the soil surface.
ra	**Reductaquic**: Saturated with water during the thawing period that, at some time of the year, creates reducing conditions above a frozen horizon (only in Cryosols).
rd	**Reductic**: Having no oxygen in 25 % or more of the soil volume as a result of gaseous emissions (e.g. methane, carbon dioxide), within 100 cm of the surface (only in Technosols).
ro	**Rhodic**: Having a dark red (Munsell hue that is redder than 5 YR, a value of less than 3.5 when moist) subsurface layer, that is at least 30 cm thick, within 150 cm of the soil surface.
rs	**Rustic**: Having a spodic horizon that turns redder when heated (in Podzols).
ru	**Rubic**: Having a dark red subsurface layer, that is at least 30 cm thick, within 100 cm of the surface (only in Arenosols).
rz	**Rendzic**: Having a thick, dark surface horizon that is rich in humus and a neutral pH, that contains or overlies material with high amount of a calcium carbonate (40 % or more).
sa	**Sapric**: Having organic material consisting of recognisable plant tissue, within 100 cm of the surface (only in Histosols).
sc	**Solodic**: Having a layer, at least 15 cm thick, with a strong columnar or coarse prismatic structure that does not have 15 % or more exchangeable sodium plus magnesium, within 100 cm from the surface.
sd	**Spodic**: Having a subsurface horizon with an accumulation of Al with Fe and/or organic matter that have been moved to deeper layers.
se	**Sideralic**: Having a low cation exchange capacity.
sf	**Sulfidic**: Having sulphur-rich, acidic material, in waterlogged areas.
si	**Someric**: Having a dark, organic matter-rich surface horizon with moderate thickness (< 20 cm).
sk	**Skeletic**: Having > 40 % (by volume) gravel or other coarse fragments over a depth of 100 cm from the surface.
sn	**Silandic**: Having one or more layers, cumulatively 30 cm or more thick, with andic properties (only in Andosols).
so	**Sodic**: Having 15 % or more exchangeable sodium plus magnesium within 50 cm of the surface.
st	**Stagnic**: Having periods with stagnation of surface water, causing reducing conditions, within 50 cm of the surface.
sz	**Salic**: Having high amounts of soluble salts, within 100 cm of the surface.
td	**Tidalic**: Flooded by tidal water but not covered by average low tides.
tf	**Tephric**: Having freshly-ejected volcanic material (e.g. ash, cinders, pumice) at a shallow depth.
ti	**Thionic**: Having an extremely acidic horizon, that is rich in sulphur or sulphides, within 100 cm of the surface.
tn	**Transportic**: Having a layer, 30 cm or more thick, of material that has been moved from a source area outside the immediate vicinity of the soil by intentional human activity.
tu	**Turbic**: Having cryoturbation features (e.g. mixed material, disrupted soil horizons, involutions, frost heave, cracks or patterned ground) within 100 cm from the surface.
ty	**Takyric**: Heavy-textured surface layers in periodically flooded soils under arid conditions.
um	**Umbric**: Having a thick, dark organic matter-rich surface horizon with low base saturation.
vi	**Vitric**: Having layer(s), 30 cm or more thick, containing a limited to moderate amount of allophane, imogolite or organo-metalic complexes resulting from the weathering of volcanic ash.
vr	**Vertic**: Having a subsurface horizon dominated by swelling and shrinking clays, and evidence of movement of soil masses within 100 cm of the surface.
vt	**Vetic**: Having very low levels of cation exchange capacity (and thus plant nutrients) in some layers within 100 cm of the surface.
wc	**Hypocalcic**: Having low levels of secondary calcium carbonates.
xa	**Xanthic**: Having a yellowish coloured, highly-weathered subsurface horizon with low cation exchange capacity.
ye	**Yermic**: Having a surface horizon with rock fragments embedded in a loamy layer occurring in wind-blown arid areas.

How to use the legend

On the more detailed map sheets (pages 90-163), polygons are labelled with a series of letters in the form of two CAPITAL LETTERS and two lower case letters (in some cases, there can be three lower case letters).

If we take as an example, the label 'ACha'.

The first pair of letters denote the WRB Reference Group (e.g AC = Acrisol) while the second pair of letters denote the quailifer (e.g. ha = haplic).

When you want to know the name of a soil from the map, first look up the capital letters in the first column on this spread to find the relevant Reference Group. Then look for the codes for the qualifiers.

In this case,

- **AC = Acrisol**
- **ha = haplic**
- **Soil name = Haplic Acrisol**

In some instances, a third lower case letter may be used, generally this extra letter is used to indicate the depth of occurrence, or to express the intensity of soil characteristics. Their code (known in WRB as SPECIFIERS) is always added after the qualifier code. The specifiers are combined with other elements into one word, e.g. Endoskeletic. A triple combination (e.g. Epihyperdystric) is allowed.

The following specifiers are possible:

(..b) - Thapto. Having a buried horizon within 100 cm of the surface (given in combination with the buried diagnostic horizon, e.g. Thaptomollic).

(..c) - Cumuli. Having a repetitive accumulation of material of 50 cm or more at the soil surface (e.g. cumulinovic and cumulimollic).

(..d) - Bathy Horizon. Property or material starting between 100 and 200 cm from the soil surface.

(..h) - Hyper. Having a strong expression of certain features.

(..n) - Endo Horizon. Property or material starting between 50 and 100 cm from the soil surface.

(..p) - Epi Horizon. Property or material starting within 50 cm of the soil surface.

(..o) - Ortho. Having a typical expression of certain features (typical in the sense that no further or meaningful characterisation is made).

(..r) - Para. Having a resemblance to certain features (e.g. Paralithic).

(..t) - Proto. Indicating a precondition or an early stage of development of certain features (e.g. Protothionic).

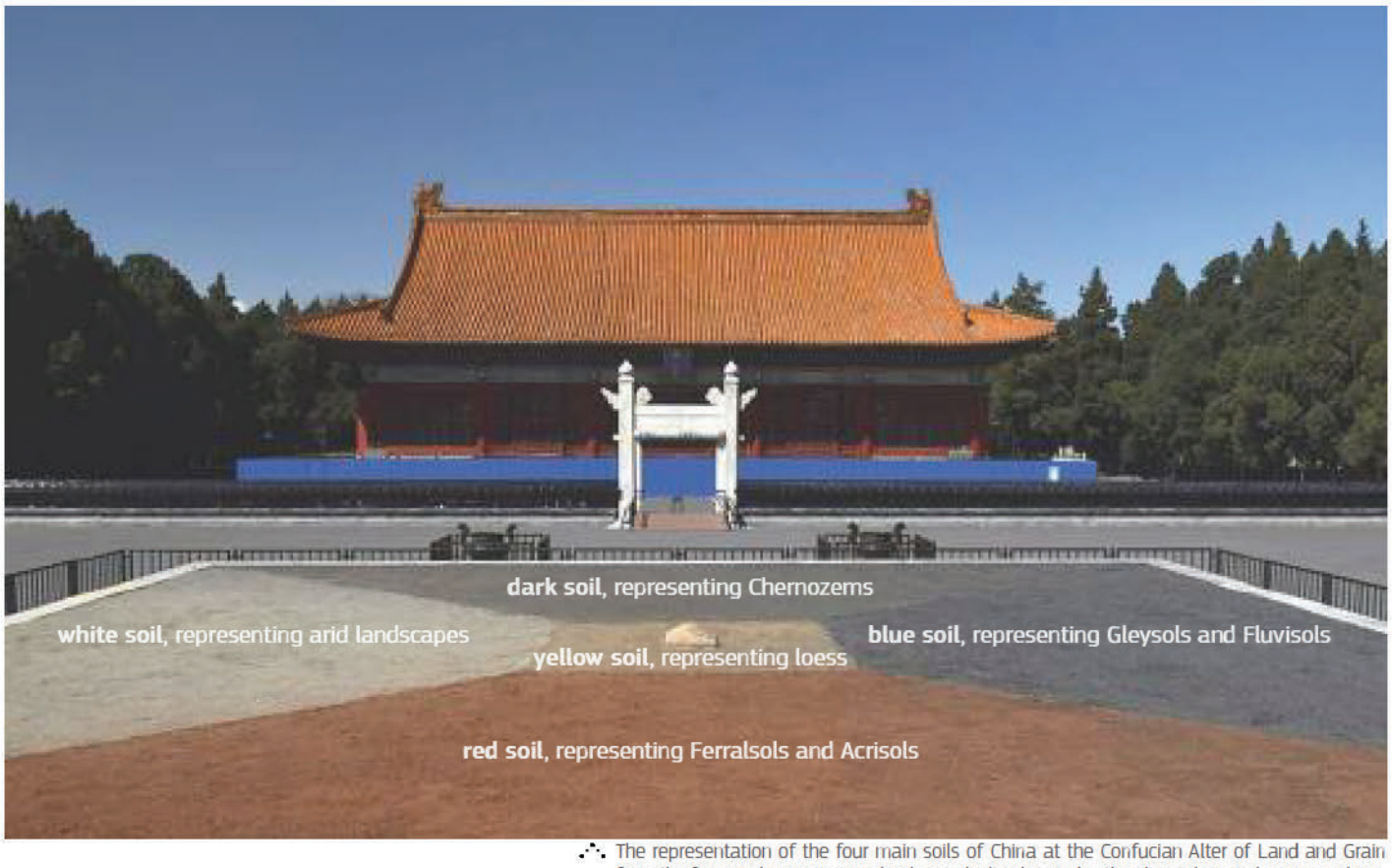
(..w) - Hypo. Having a weak expression of certain features.

Map Scales

A scale of a map indicates the relation of the size of the map with the size of the area on the ground. For example, one centimetre on a map with a scale of 1:100000 is equivalent to 100000 cm (1 km) on the ground.

Maps that are sufficiently detailed to show the positions of individual plots of a few hectares in size have scales from 1:5000 (1 cm:50 m) to 1:25000 (1 cm:250 m), and are considered large-scale maps. At a regional or national level, the most suitable maps are at medium scales, usually 1:100000 (1 cm:1 km) or 1:500000 (1 cm:5 km).

Most of the maps shown in this atlas give a continental perspective and are based on maps compiled at scales smaller than 1:1000000 (1 cm:10 km). Such maps are referred to as small scale.



The representation of the four main soils of China at the Confucian Alter of Land and Grain from the former Chinese Imperial Palace, which is located in the Zhongshan Park, Beijing, China. Nearest to the camera, the brown soils correspond to Chernozems. (VCG/ChinaDaily.com)



The Altar of Land and Grain (see above) as viewed from space. The four colours, representing the different soil types, are clearly visible. (Google Maps Imagery @2023 CNES/Airbus Maxar Technologies)



Dark Chernozems are found in China's northeastern provinces of Heilongjiang, Jilin and Liaoning. (FAO/Yuxing Tong)



Saline soil in the arid west of China. (MK)





Fertile soils on the floodplains of Eastern China. (pxhere/PD)

Centre: Loess landscape near Hunyuan, Datong, Shanxi Province, China (Till Niermann)



Acrisol from the humid tropics of southeastern China. (EM)

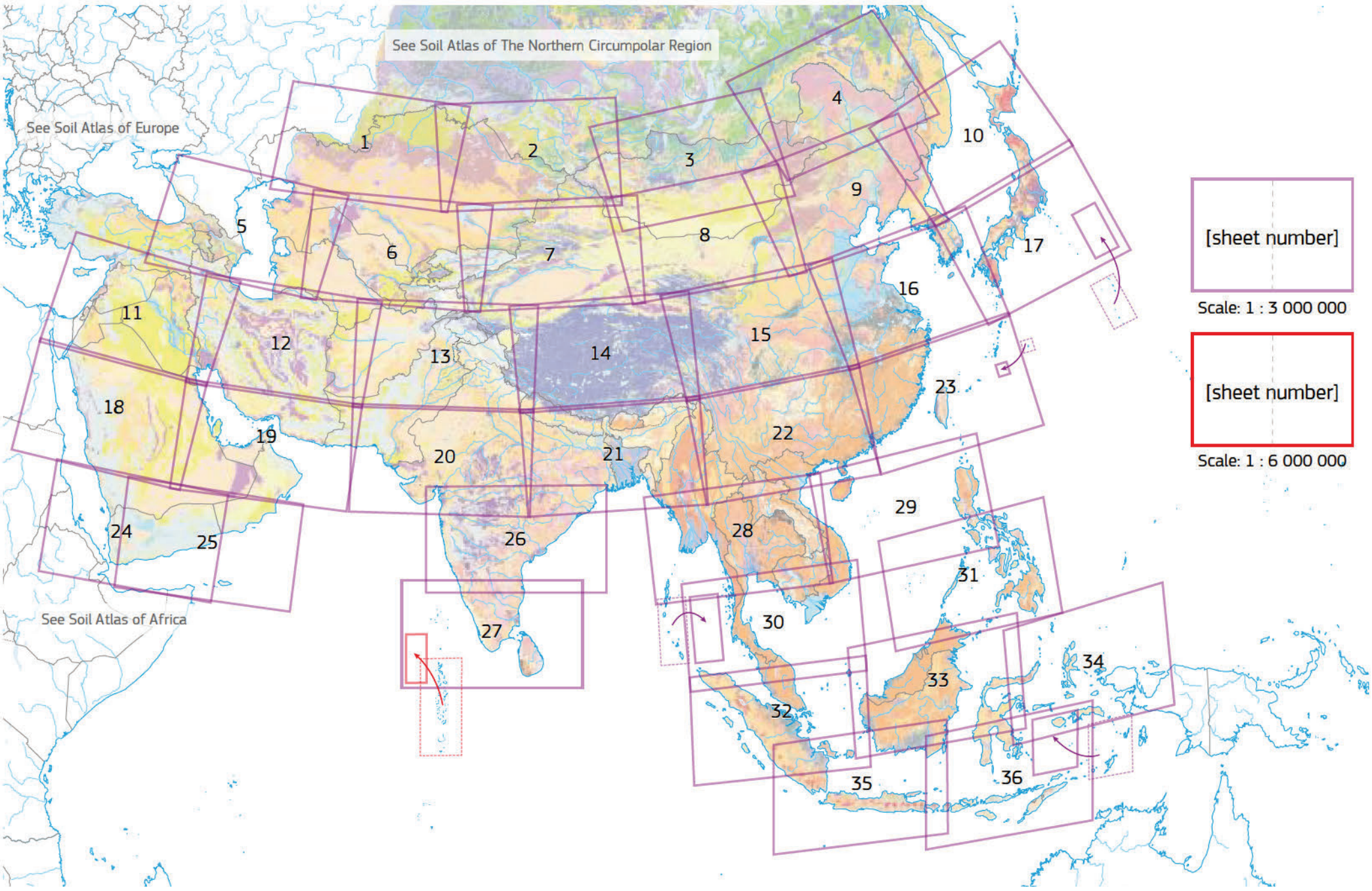
The first soil map?

As part of the transfer of the capital city from Nanjing to Beijing in 1421, the Emperor Zhu Di commissioned a monument in the centre of the new Imperial Garden known as the Altar of Land and Grain. At the altar, emperors made offerings to the gods of the land and grain from 1421 to 1911. Many people consider this to be one of the earliest soil maps.

The altar takes the form of a raised square. The sides are 6 m long. The space is divided into four trapezium-shaped sectors, arranged around a central square. Each sector is covered with a soil of different colour and origin.

The **central square** is filled with loess, which is regarded as the typical soil parent material for China. The **northern sector** is filled with a dark soil, which represents the Chernozems that are typical of north-eastern China. The **southern sector** is filled with a red soil, representing the Ferralsols and Acrisols that are found in the humid topical climate in the south of the country. The **western sector** is filled with a light coloured soil representing the arid landscapes of the Gobi Desert. Finally, the **eastern sector** is filled with a bluish muddy soil, which is typical of the Gleysols and Fluvisols that are found on the coastal plains facing the Yellow and East China Seas.

Index to map sheets



Legend:

International boundary ————————

Disputed boundary ••••••••••••••••••••

National capital ▢ DHAKA

Locality (by population)

200 000+ ○ Kolkata

100 000–200 000 ○ Sittwe

25 000–100 000 ○ Tezpur

0–25 000 ○ Paro

General maps:

SCALE 1 : 3 000 000

1 CENTIMETRE = 30 KILOMETRES; 1 INCH = 47.3 MILES

0 100 200 km

0 50 100 miles

PROJECTION: Lambert Azimuthal

Maldives inset (Sheet 27):

SCALE 1 : 6 000 000

1 CENTIMETRE = 60 KILOMETRES; 1 INCH = 94.6 MILES

0 200 400 km

0 100 200 miles

PROJECTION: Lambert Azimuthal

Clarifications:

Dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Source: Lovell Johns Ltd modified to comply with UN, 2020.

Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

The boundary of the West Bank and the Gaza Strip denote the Armistice Demarcation Line.

Due to the mapping of distinct national data, the representation of urban areas can vary from one map to another.

Regional map texts

The subdivision of the Asian continent into regions on the following pages is done purely to provide a more detailed overview of the soil patterns that the map on this spread. The groupings of countries are based on definitions used by the United Nations Statistics Agency (UNSD) for statistical purposes and does not imply any assumption about political or other affiliations of countries and territories.



Overview maps: the major soil types of Asia

This map shows the main soil types for Asia. Covering an area of almost 44.6 million km², Asia is Earth's largest continent. Stretching from the Arctic to the Equator and from the Pacific Ocean to the Mediterranean Sea, Asia occupies about 30% of the total land surface of the planet and is home to 60% of the world's population.

A broad north-south zonal pattern of soil groups can be observed, reflecting major climatic zones. Long and very cold winters in the north give rise to permafrost-affected Cryosols of the tundra regions, in places extending into the boreal forests. To the south, low temperatures inhibit the decay of vegetation to form extensive Histosols together with waterlogged Gleysols, especially on the low-lying plains of Siberia.

As temperatures rise towards the south, large expanses of coniferous boreal forests are denoted by Podzols, which have developed on coarse-grained, quartz-rich deposits. Increasing clay content of soils is indicated by Albeluvisols and Luvisols.

Further south again, the broad grassland belt of the steppe is denoted by Phaeozems, Chernozems and Kastanozems. These are soils with well-defined organic-rich topsoils that have developed in silty loam and reflecting a decreasing precipitation gradient to the south.

In fact, large parts of Asia, including much of the north, experience a relatively dry climate, often coupled with extremes of temperatures. The overall aridity and high temperatures of the west means that poorly developed soils, with low soil organic matter levels and low water retention capacity and elevated levels gypsum (Gypsisols) and carbonates (Calcisols) are widespread. Desert areas with sand dunes are denoted by Arenosols which are interspersed by Regosols, and Leptosols, often denoting mountains or rock outcrops. Cambisols, displaying only the slightest signs of soil development, are common. Saline soils (Solonetz and Solonchaks) are characteristic of depressions in arid areas and are particulary evident throughout western and central Asia.

Asia is also a mountainous continent. Containing the world's highest peaks, the various ranges of the Himalayans extend from Myanmar in the east to Afghanistan in the west. They separate the Indian Sub-continent from the high Tibetan Plateau. They are a barrier to drainage and dominate the monsoonal weather patterns of southern Asia. Poorly developed and shallow, stony Regosols, Leptosols, and Cambisols highlight mountainous regions, often closely reflecting the characteristics of the underlying geology. Erosion is widespread, especially on steep slopes. Higher elevations with low temperatures are denoted by Cryosols, often in conjunction with glaciers.

A hot and humid climate supports rainforests over much of southeastern Asia. Deep chemical weathering gives rise to iron and aluminium-rich Ferralsols and Acrisols, with Lixisiols emerging in drier conditions.

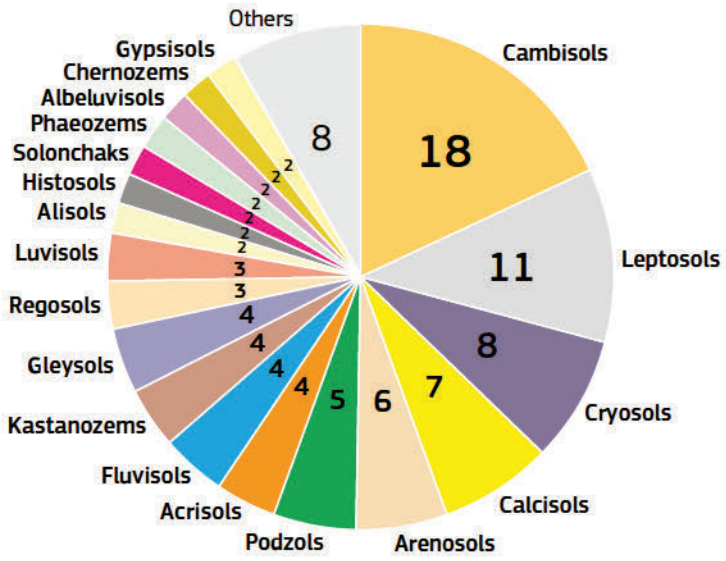
Some soils are azonal, which means they can be found across Asia. In this sense, Fluvisols denote where soil development is associated with the movement of water associated with rivers, lakes and tides. Their occurrence on the map clearly defines the main river networks of Asia. Flow conditions tend to determine their characteristics with medium to fine-grained and layered soils reflecting regular flood events in broad floodplains while coarse and unsorted soils are found in alluvial fans and dry channels that are prone to flash floods in arid regions. Several rivers form major deltas at their mouths where fine-grained, often waterlogged soils form (Gleysols, Stagnosols) alongside Fluvisols. Mangroves are a common feature of the inter-tidal zone of many southern coasts of Asia. In addition to coastal protection against storms and floods, mangrove soils store significant levels of organic carbon.

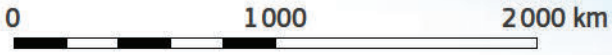
Clay-rich Vertisols that shrink and swell with changes in moisture content are also distributed across climatic zones as they reflect the weathering of base-rich rocks (such as basalt) or the deposition in floodplains of these weathering products. There are extensive areas on the Deccan Plateau of India.

Increasing urbanisation and industrial development leads to the formation of Technosols. While important locally, these soils are not very evident at the scale of this map.



Common soil types of Asia (%):





Scale note:

Scale is only accurate at the centre of the projection. The scale decreases with the distance from the centre along the radii and increases from the centre perpendicularly to the radii.





- Acrisols
- Albeluvisols
- Alisols
- Andosols
- Anthrosols
- Arenosols
- Calcisols
- Cambisols
- Chernozems
- Cryosols
- Durisols
- Ferralsols
- Fluvisols
- Gleysols
- Gypsisols
- Histosols
- Kastanozems
- Leptosols
- Lixisols
- Luvisols
- Nitisols
- Phaeozems
- Planosols
- Plinthosols
- Podzols
- Regosols
- Solonchaks
- Solonetz
- Stagnosols
- Technosols
- Umbrisols
- Vertisols

- Glaciers
- Water bodies

Regional-scale soil maps

Western Asia

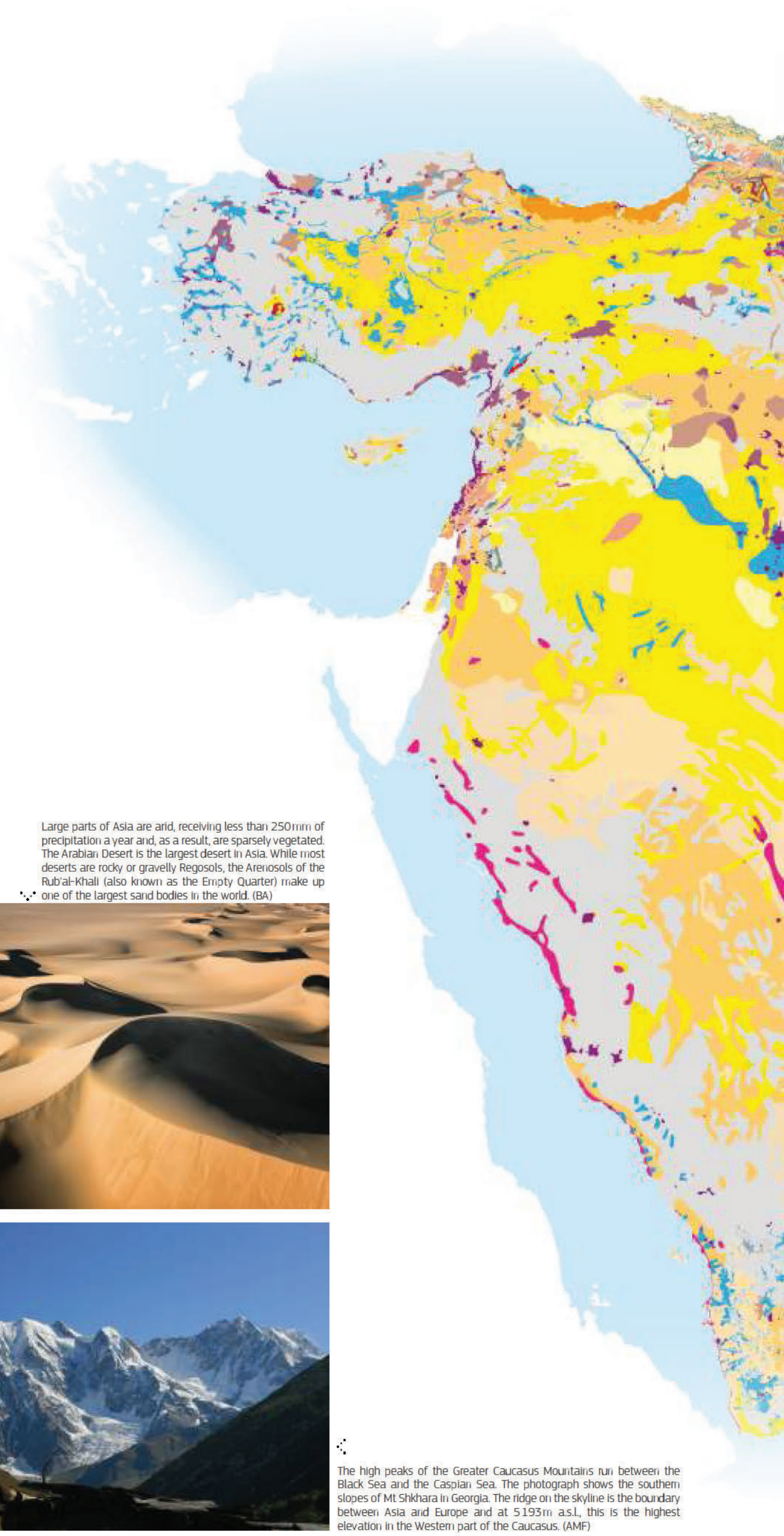
For the purposes of this Atlas, the term Western Asia refers to a generally arid area of around 6 million km² (accounting for around 13% of Asia) consisting of Armenia, Azerbaijan, Bahrain, Cyprus, Georgia, the Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, the Syrian Arab Republic, Türkiye (excluding East Thrace), the United Arab Emirates and Yemen. While over 310 million people live in this region (and rapidly growing), population densities range from over 1500 people per km² in Bahrain to just 12 in Saudi Arabia, reflecting the high degree of urbanisation in many countries and the rugged nature of the landscape in others.

Much of the region is mountainous with several high plateaus. Mount Ağrı (Ararat) in Türkiye rises to 5137m a.s.l. while elevations in the Zagros Mountains on the Iran-Iraq border and the Yemeni Highlands exceed 3000m a.s.l. In comparison, the Dead Sea, located in the Jordan Valley, lies at 418m below sea level, making it the lowest point on the surface of the Earth. Gravelly and sandy deserts tend to occur in depressions, often in conjunction with salt lakes. The Rub' al Khali covers the southern third of the Arabian Peninsula and is one of the world's largest sandy deserts. Major rivers include the Tigris, Euphrates, and Jordan while extensive coastlines are found on the Mediterranean, Black, Red and Caspian Seas.

Western Asia primarily experiences hot and arid or semi-arid climates, where elevated temperatures and a lack of water are major constraints to land use and key factors in soil development. However, there are regional exceptions that give rise to fertile floodplains and large expanses of woodland and grasslands. Along the Mediterranean coast, temperatures are lower than in the Arabian Peninsula and winters are cool and humid. It is worth reflecting that many plants that make up a significant part of our diets were first cultivated in this region (e.g. wheat, barley, certain legumes, olives, grape vines, as well as cherry and peach trees). Where water comes to the surface (or close to the surface), oases can support intensive cultivation in otherwise arid conditions.

The overall aridity means that the region generally displays soils that are poorly developed with low soil organic matter levels and low water retention but with elevated levels of salts (including gypsum and carbonates). The large sand seas are denoted by Arenosols, which are interspersed by Regosols, and Leptosols, often denoting mountains or rock outcrops. Many soils show alluvial characteristics, reflecting their formation with running water. Fluvisols reflect the flow characteristics, being generally fine-grained and layered in broad floodplains reflecting regular flood events, while often coarse and unsorted in alluvial fans and dry channels that are prone to flash floods.

Key issues affecting soils in Western Asia are inherently low organic matter and nutrient content, limited water-holding capacity, soil erosion (especially by wind), surface crusting, salinisation (often related to irrigation practices).

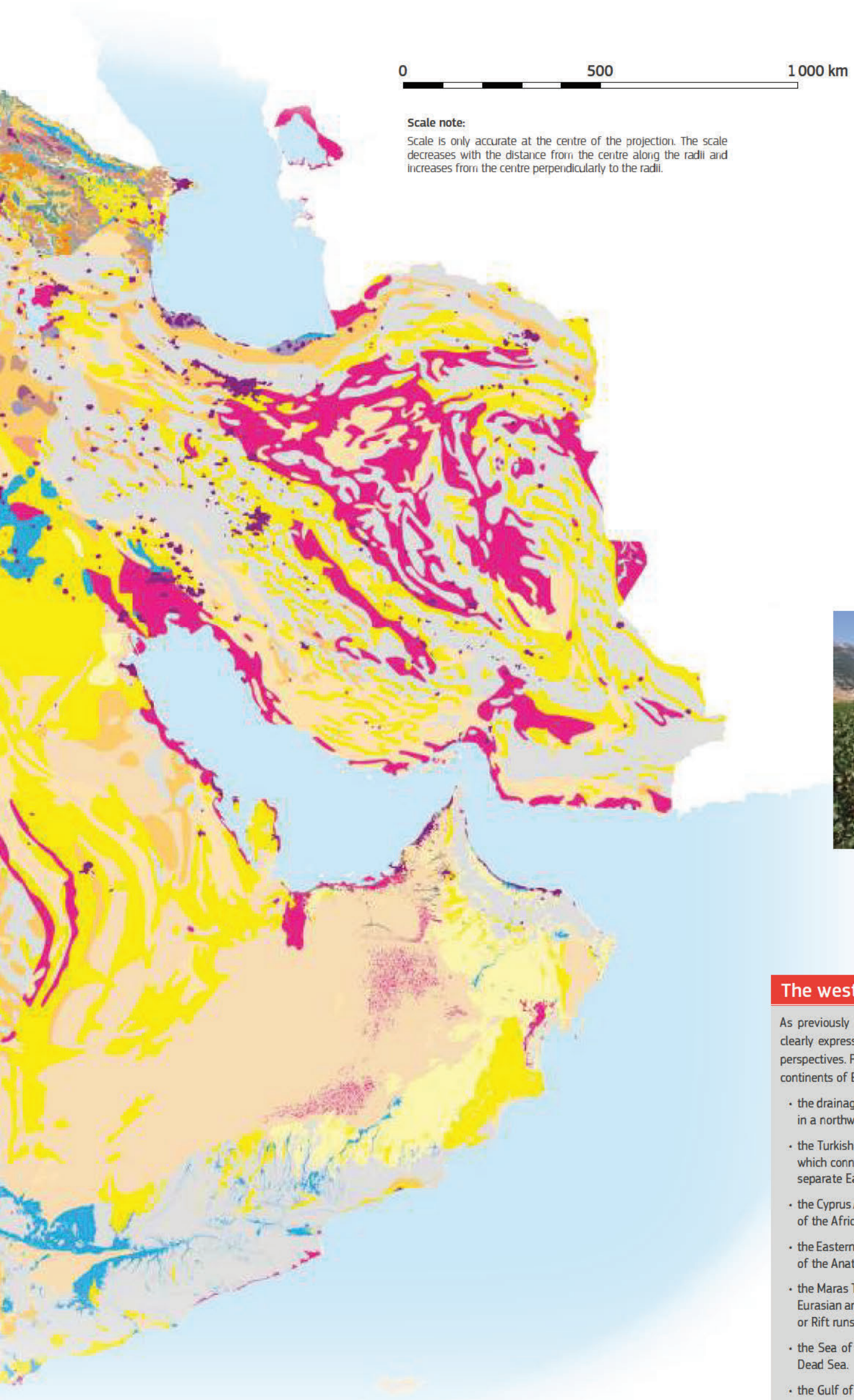


Large parts of Asia are arid, receiving less than 250mm of precipitation a year and, as a result, are sparsely vegetated. The Arabian Desert is the largest desert in Asia. While most deserts are rocky or gravelly Regosols, the Arenosols of the Rub'al-Khali (also known as the Empty Quarter) make up one of the largest sand bodies in the world. (BA)

The Euphrates is one of the most historically important rivers of Western Asia. From its source in Türkiye, the Euphrates flows through the Syrian Arab Republic and Iraq to join the Tigris in the Shatt al-Arab, which empties into the Arabian Gulf. Annual flooding has resulted in fertile Fluvisols on its floodplains, which through the help of irrigation have been intensively cultivated for centuries. This photograph illustrates the close dependency between the river and agriculture near to the Syrian-Iraqi border. (HG)



The high peaks of the Greater Caucasus Mountains run between the Black Sea and the Caspian Sea. The photograph shows the southern slopes of Mt Shkhara in Georgia. The ridge on the skyline is the boundary between Asia and Europe and at 5193m a.s.l., this is the highest elevation in the Western part of the Caucasus. (AMF)



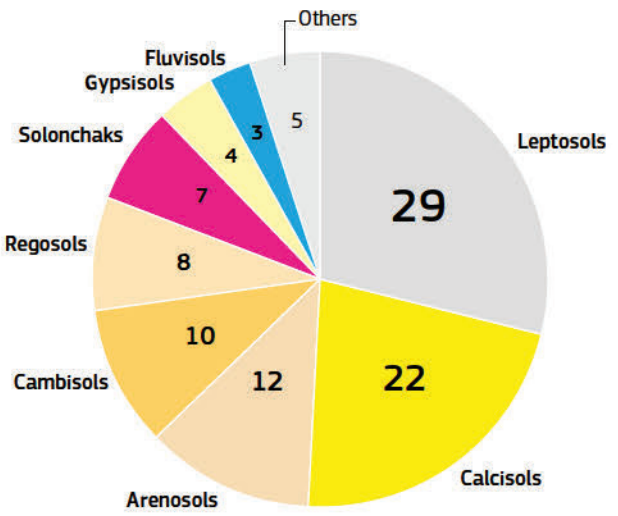
0 500 1 000 km

Scale note:

Scale is only accurate at the centre of the projection. The scale decreases with the distance from the centre along the radii and increases from the centre perpendicularly to the radii.



Common soil types of Western Asia (%):





The Beqaa Valley is a fertile, enclosed plain situated between Mount Lebanon to the west and the Anti-Lebanon Mountains to the east. It forms the northeastern most extension of the Great Rift Valley, which stretches from the Syrian Arab Republic to the Red Sea. A Mediterranean climate means wet, cold winters and dry, warm summers, coupled with fertile soils, makes it an important agricultural area. (SY)

The western boundary of Asia

As previously mentioned, the westernmost edge of Asia is often not clearly expressed, with definitions often reflecting cultural or historical perspectives. For the area shown on this map, Asia is delimited from the continents of Europe and Africa by:

- the drainage divide of the Greater Caucasus mountains, which extend in a northwesterly direction from the Caspian Sea to the Black Sea.
- the Turkish Straits, consisting of the Dardanelles and the Bosphorus, which connect the Aegean and Mediterranean seas to the Black Sea, separate East Thrace from Asian Türkiye.
- the Cyprus Arc, a curved ocean depression that reflects the movement of the African Plate relative to the Anatolian Plate.
- the Eastern Anatolian Fault, which facilitates the westward movement of the Anatolian Plate from the Arabian Plate.
- the Maras Triple Junction*, which marks the junction of the Anatolian, Eurasian and the Arabian Plates, from which the Dead Sea Transform or Rift runs southwards along the coast of Syria and Lebanon.
- the Sea of Galilee and Hula depressions, the Jordan Valley and the Dead Sea.
- the Gulf of Aqaba to the Red Sea.

*** The epicentre of the large earthquake that struck southern and central Türkiye and northern and western parts of the Syrian Arab Republic in February 2023, resulting in the deaths of over 60 000 people, was located about 40 km southwest of the town of Maras.**

Central Asia

Central Asia covers a landlocked area of around 4 million km² (around 9% of Asia), extending from the eastern shore of the Caspian Sea to the western border of China. It consists of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Over 70 million people live in this region, with around half of them in Uzbekistan. Outside the large cities, population densities are relatively low.

While the western part of the region is generally low-lying and gently undulating, the high mountains of the Pamir and Tian Shan ranges in the south and east are the westernmost extension of the Himalayan mountain belt. Glaciers, together with permanent snow and ice cover, are widespread. Several peaks rise to over 5 000 m. The highest peak, Jengish Chokusu on the Kyrgyzstan–China border, reaches 7 439 m.

In contrast, the Karagiye Depression in southwestern Kazakhstan drops to 132 m below sea level, is the lowest point in Central Asia while the surface of the Caspian Sea is also below sea level (-28 m). With a length of over 1 200 m and an average width of around 300 km, the Caspian Sea is the world's largest lake.

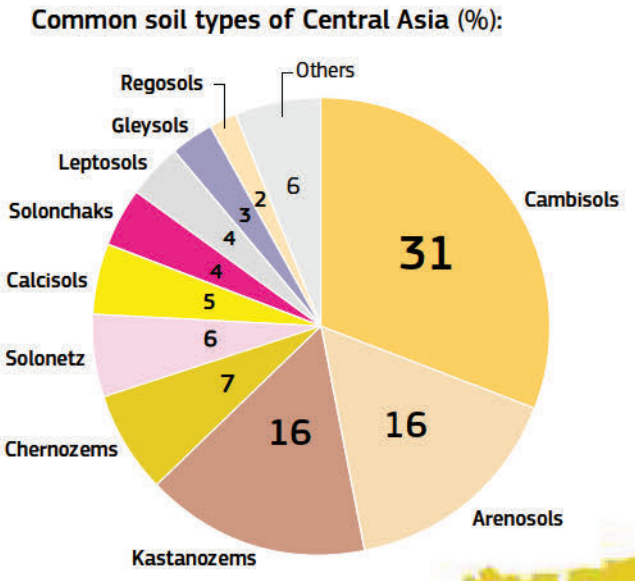
As a landlocked region, Central Asia experiences a strong continental climate with marked temperature fluctuations. Summers are mostly hot and sunny while winters are cold or cool. Much of the region, especially in the west, displays arid or semi-arid characteristics as precipitation is generally low. Higher precipitation levels are restricted to snow on mountainous areas in the southeast during the winter months. More temperate conditions are found in the northern parts. Strong seasonal winds mean that dust storms and wildfires are common.

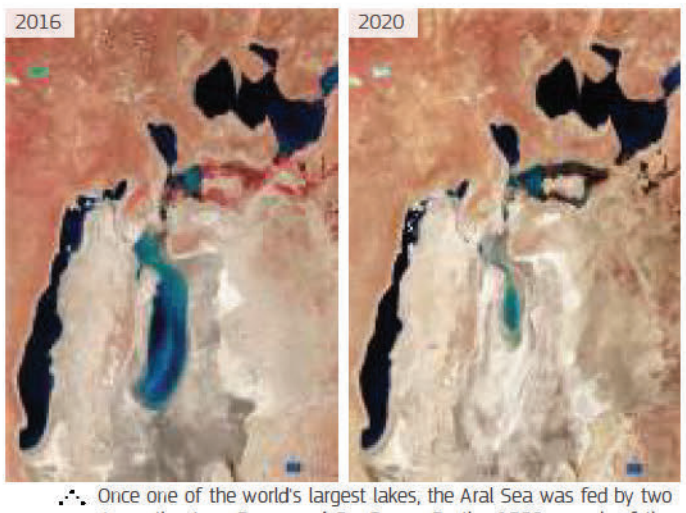
The general aridity of the areas is reflected by the presence of deserts such as the sandy Kyzylkum and the Karakum. The vast desert area with sands and salt flat that appeared at the place of the Aral Sea is now called Aralkum.

Northern Central Asia consists of treeless grassy plains that are part of the Eurasian Steppe Belt.

Major rivers of Central Asia include the Amu Darya, Syr Darya, Irtysh, Tejen and the Ural (which in turn marks the northwestern border between Asia and Europe). Apart from the Ural, these rivers originate in the high mountains of the south and east (the Irtysh has its source in the Altai Mountains on the border regions of Mongolia and China. Most rivers in Central Asia drain to closed basins such as the Aral and Caspian Seas (known as endorheic). One exception is Lake Zaysan through which the Irtysh flows to northwards towards the Ob River and the Arctic Ocean.

Lake Balkhash in southeastern Kazakhstan is one of the largest lakes in Asia and the 15th largest lake in the world. An interesting characteristic is that the lake's western part is fresh water and has a yellow-gray colour, while the eastern half is as salty as seawater and has a bluish colour.





Once one of the world's largest lakes, the Aral Sea was fed by two rivers, the Amu Darya and Syr Darya. By the 1960s, much of the water from these rivers was diverted to irrigate the introduction of cotton cultivation to the region. Consequently, the Aral Sea began to contract. By 2005, it had become a series of smaller lakes, covering only 10% of its former area. This pair of images from the Sentinel-3 satellite show the continued reduction in area between 2016 and 2020. (ESA)



A major landscape of Asia is the steppe, an ecoregion characterised by open grassland plains. The Kazakh or Central Steppe extends from the Urals to the Altai Mountains of northwestern China. A semi-arid climate means that there is insufficient precipitation to support trees although shrubs can be common depending on the season, latitude or elevation. Steppe soils are typically Chernozems, which grade to Kaztanozems when the climate becomes drier. (CA)

0 500 km

Scale note:

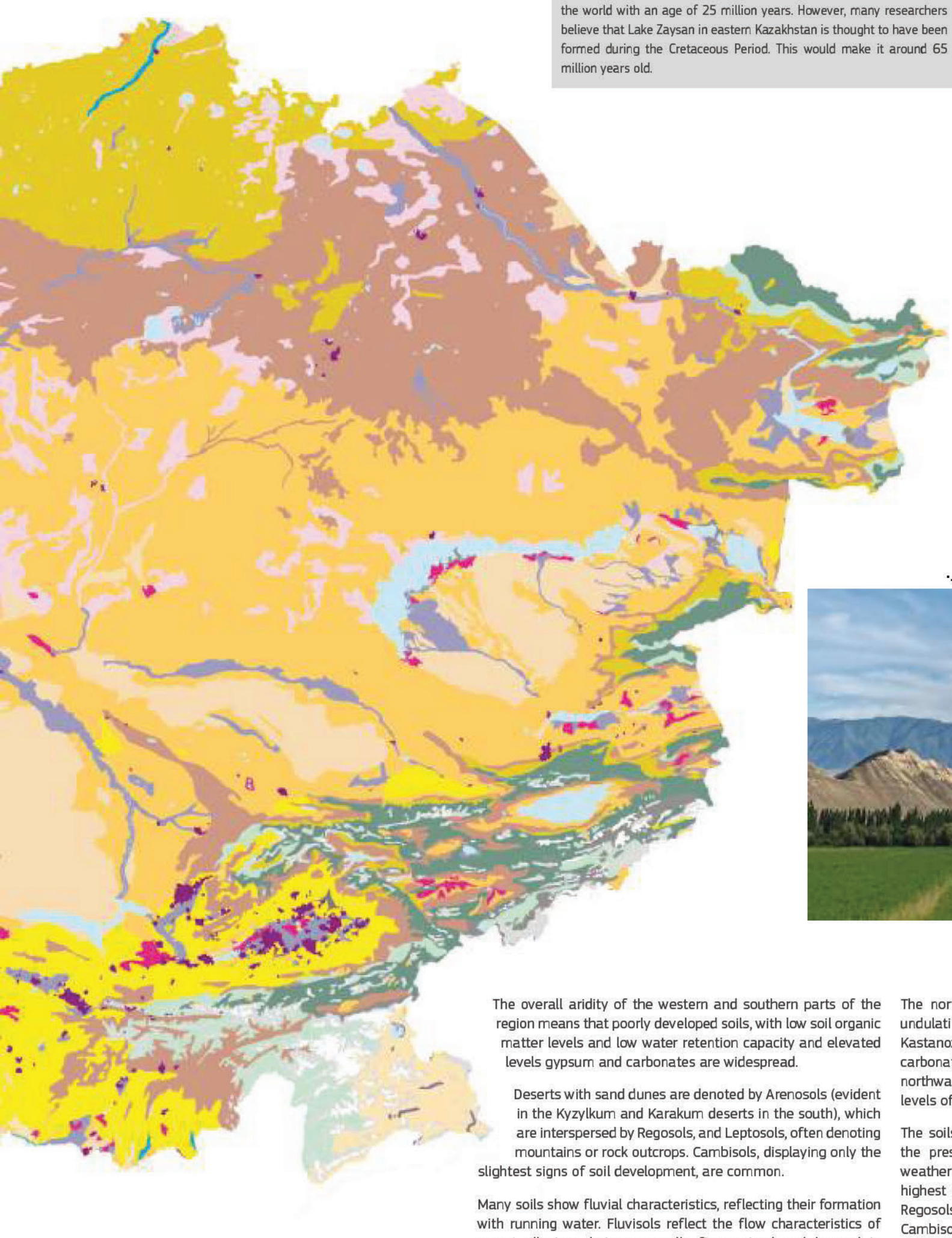
Scale is only accurate at the centre of the projection. The scale decreases with the distance from the centre along the radii and increases from the centre perpendicularly to the radii.

How old are lakes?

Probably most people never think about the age of lakes! Some lakes are temporry and only exist in seasons with high levels of precipitation. Others may only have existed for hundreds of years, perhaps due to landslides blocking a rivers or ground movements from earthquakes. Others may have existed for thousands of years, perhaps reflecting the retreat of glaciers at the last Ice Age.

Lake Baikal, in southeast Siberia, is often regarded as the oldest lake in the world with an age of 25 million years. However, many researchers believe that Lake Zaysan in eastern Kazakhstan is thought to have been formed during the Cretaceous Period. This would make it around 65 million years old.





The Fergana Valley is a 300 km long depression running across eastern Uzbekistan, southern Kyrgyzstan and northern Tajikistan between the Tien-Shan Mountains to the north and the Gissar-Alai mountains to the south. The valley is characterised by fertile Fluvisols that have formed in the floodplain sediments of the Naryn and Kara Darya Rivers. Historically, the Fergana Valley was an important destination on the Silk Road for goods and people travelling from China to the Middle East and Europe. (PXFUEL)



The overall aridity of the western and southern parts of the region means that poorly developed soils, with low soil organic matter levels and low water retention capacity and elevated levels gypsum and carbonates are widespread.

Deserts with sand dunes are denoted by Arenosols (evident in the Kyzylkum and Karakum deserts in the south), which are interspersed by Regosols, and Leptosols, often denoting mountains or rock outcrops. Cambisols, displaying only the slightest signs of soil development, are common.

Many soils show fluvial characteristics, reflecting their formation with running water. Fluvisols reflect the flow characteristics of recent alluvium, being generally fine-grained and layered in broad floodplains reflecting regular flood events, while often coarse and unsorted in alluvial fans and dry channels that are prone to flash floods. Saline soils are typical of depressions in the western and northern plains while a significant proportion of irrigated land in the region is affected by elevated levels of salt.

The northern part of the region is characterised by a gently undulating grassy steppe landscape. In the southern drier parts, Kastanozems with organic-rich topsoils and high secondary carbonates are extensive. Where precipitation levels increase northwards, Kastanozems grade to Chernozems with higher levels of organic matter.

The soils of eastern and southern parts of Central Asia reflect the presence of high mountains and dominance of physical weathering processes. Patchy Cryosols are found at the highest elevations often in combination with poorly developed Regosols. Leptosols highlight the close presence of bedrock while Cambisols are found on lower slopes where vegetation cover is more developed. Luvisols are also found on slopes in areas where an excess of precipitation supports the movement of clays from the topsoil to the subsoil.

Key issues affecting soils in Central Asia are inherently low organic matter and nutrient content, limited water-holding capacity, soil erosion (especially by wind), surface crusting, salinisation (often related to irrigation practices).

Southern Asia

Southern Asia covers an area of around 5 million km² (around 11% of the Continent), consisting of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka. With around 2 billion people living in the region, (and rapidly growing), the soils of Southern Asia need to feed more than a quarter of the world's population. While the region contains some of the highest population densities in the world (Bangladesh has more than 1000 people per km²), mountainous Bhutan has a population density of around 20 people per km².

Southern Asia displays enormous topographic extremes. The peaks of the Himalayas are the highest in the world. Mount Everest on the China-Tibet border is the highest point on Earth at 8848 m above sea level. In fact, all 14 independent mountain peaks that are more than 8000 m above sea level are located in the Himalayan and Karakoram mountain ranges of Asia. It should be noted that Bhutan and Nepal record an elevation range of more than 7000 m and 8000 m respectively!

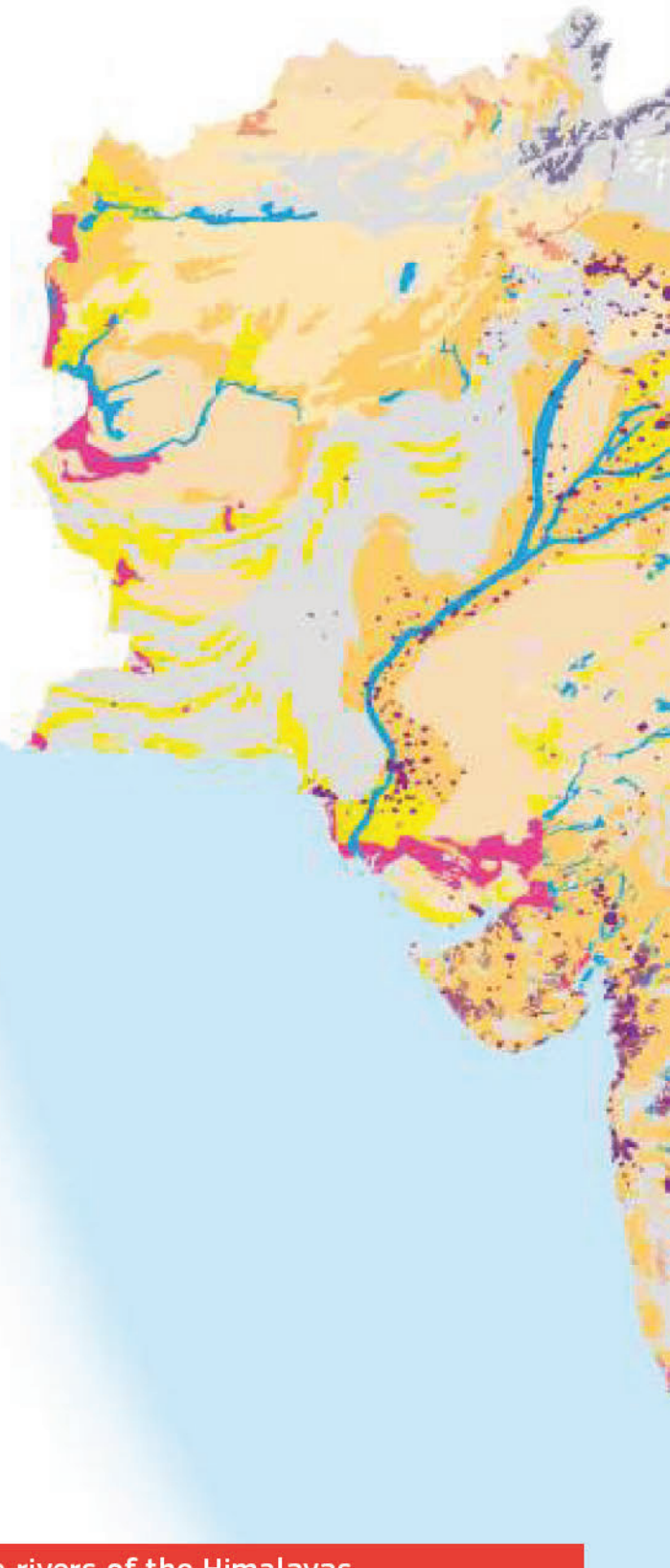
The Himalayas are a relatively recent phenomenon (from a geological perspective) reflecting tectonic activity over the past 40 million years. Tectonically, the region is dominated by the Indian Plate, whose northward movement at a rate of 67 mm per year. This movement is responsible for the uplift of the Himalayas, which continue to rise by about 5 mm each year. An interesting observation is that there are no volcanoes in Himalayas as the Indian Plate has overridden the Eurasian Plate without subduction to the mantle.

It is worth noting that this enormous, elevated region contains over 15000 glaciers, making it the largest store of ice and snow outside of the Polar Regions. This feeds many of the main rivers of Asia, such as the Indus, Brahmaputra and the Ganges, which in turn support agriculture on a series of interconnected plains throughout Bangladesh, northern India and Pakistan. The Brahmaputra is the 15th longest river in the world and when combined with the Ganges, has the 3rd highest discharge (only the Amazon and Congo are greater). Large deltas are found where the floodplains of major rivers flow into the sea. Large parts of these plains, especially in Bangladesh, are low-lying and prone to flooding, especially during monsoons or typhoons.

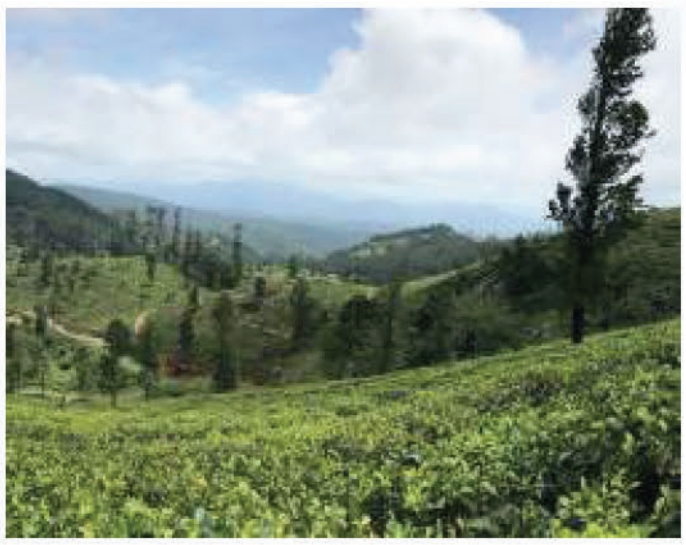
To the south of the Himalayas, the Indian Sub-Continent extends into the Indian Ocean, flanked by the Arabian Sea and the Bay of Bengal. The Deccan Plateau gives higher ground to large parts of Western and Central India that decreases in elevation towards the east.

The extensive shifting sand dunes, together with numerous salt lakes, characterise the Thar Desert that lies on the border of India and Pakistan. The sand is highly mobile due to strong winds that are linked to the monsoon.

To the northwest, Afghanistan is an mountainous country with arid plains in the north and the southwest, which are separated by the highlands of the Hindu Kush Mountains.











Top left: Southern Asia contains the highest mountain peaks on the planet. The Himalayas are one of the main controls on the monsoon rains while the Karakorum Range, spanning the borders of China, India and Pakistan, is the most heavily glaciated part of the world outside of the Polar Regions. With an elevation of 8611 m a.s.l., K2 is the second highest peak in the world. (SVY)

Top right: Tea is a traditional crop of southern Asia. The young leaves of *Camellia sinensis*, which are harvested for tea, require well-drained, slightly acidic soil (i.e. no calcium carbonate) with a porous subsoil that permits the free movement of water as tea plants cannot grown in waterlogged conditions. This image from Sri Lanka shows how tea plantations are located in the sloping ground where natural drainage is ensured. Warm summers and frequent rains promote rapid leaf growth. (UV)

Bottom left: Flooding regularly affects low-lying coastal areas as a result of monsoon rains, high tides or storm surges linked to cyclones. There are concerns that such floods are getting more severe due to climate change, which is also causing sea levels to rise. Flooding in Bangladesh in 2016, triggered by heavy monsoon rains, affected almost 4 million people. (NH)

Bottom right: The massive lava flows of the Deccan Plateau have led to the formation of Vertisols, characterised by their dark black color and capacity to crack a swell according to their moisture content. The picture shows tumeric cultivation in Vertisols. To combat the relatively dry conditions, farmers have developed a range of systems to store monsoonal rains for several months. (AD)

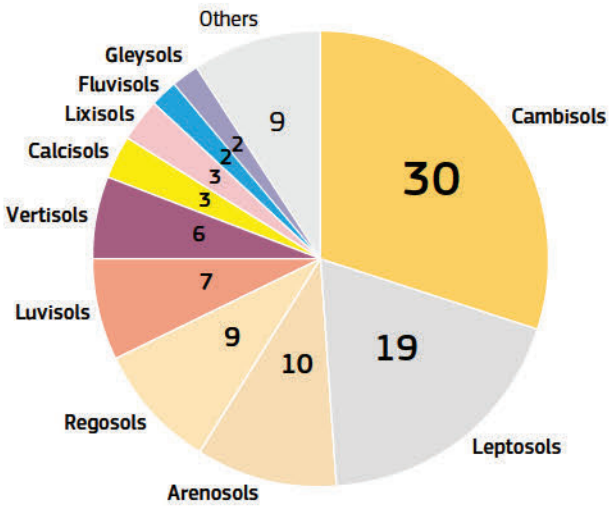
The rivers of the Himalayas

An interesting feature of the Himalayas is that despite its high eleveation, in many cases they do not act as a physical watershed like most mountain ranges. Several major rivers (such as the Indus, Brahmaputra, Sutlej, Alaknanda and the Bhagirathi) rise north of the crest line and flow southwards through deep gorges than can be up to 5000 m deep. This means that they drain both the northern and southern slopes of the Himalayas!

It is believed that these rivers are probably older than the mountains they cross. This situation has developed because the Himalayas were uplifted so slowly that the existing rivers had no difficulty in continuing to flow through their channels. Increasing uplift of the Himalayas enabled them to cut their valleys more rapidly. As a result, uplift and gorge development went on in parallel resulting in completely developed river systems flow across the Himalayas.



Common soil types of Southern Asia (%):



Scale note:

Scale is only accurate at the centre of the projection. The scale decreases with the distance from the centre along the radii and increases from the centre perpendicularly to the radii.

The climate of Southern Asia varies considerably from hot and humid equatorial in the south to polar in the high elevations of the north. This variety is modified locally by elevation as well as proximity to the sea and the seasonal impact of the monsoons.

The western part of Southern Asia experiences hot and arid or semi-arid climates, where elevated temperatures and a lack of water are major constraints to soil development and land use. To the east and the south, increasingly humid conditions give rise to fertile floodplains and large expanses of grasslands and woodlands. Southern parts tend to have hot in summers and receive rain during monsoon periods.

The northern Indo-Ganges plains also have hot summers but are much cooler in winter.

Broadly speaking, five main soils types are found in southern Asia.

The hot and humid equatorial and sub-tropical climates support extensive chemical weathering, which gives rise to highly leached, coarse-textured, yellow and red-coloured Luvisols and Lixisols, with high levels of iron and aluminium oxides. These soils lack carbonates and have a low pH, and are generally found in valleys and gently undulating terrain.

The steeply sloping land of mountainous areas are denoted by poorly developed, shallow Leptosols, Cambisols and Regosols, that are generally stoney and acidic in nature. Organic matter levels are often low. Under forests, distinctive dark brown Umbrisols, Cambisols and Luvisols can develop. Cryosols are found at higher elevations, in conjunction with glaciers and ice fields (generally above 3 000 m a.s.l.).

The aridity of the west gives rise to poorly developed soils with low soil organic matter levels and low water retention. Elevated levels of salts (Solonchaks, Solonetz), including carbonates (Calcisols), are common in the Thar Desert. The large sand seas and dunes are denoted by Arenosols, which are interspersed by Regosols, and Leptosols, often denoting mountains or rock outcrops. Many soils show alluvial characteristics, reflecting their formation with running water.

Fluvisols reflect the flow characteristics, being generally fine-grained and layered in broad floodplains reflecting regular flood events, while coarse and unsorted in alluvial fans that are prone to flash floods. Soils of the Indus-Ganges-Brahmaputra plain are highly fertile. Gleysols are common in depressions or where the watertable is high while Tidalic Fluvisols denote areas under mangroves.

Large parts of the Deccan Plateau are characterised by clay-rich Vertisols that swell and crack when wet or dry. Traditionally, these soils have been intensively cultivated for cotton.

Southeast Asia

Southeast Asia refers to an area of around 4.5 million km^2 (around 10% of Asia) that extends southwards from China towards Australia. It consists of Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste, and Viet Nam. The Andaman and Nicobar Islands (India) are also considered as being part of the region. More than 650 million people live here. While the western part of New Guinea is part of Indonesia, geologically the island sits on the Australian tectonic plate.

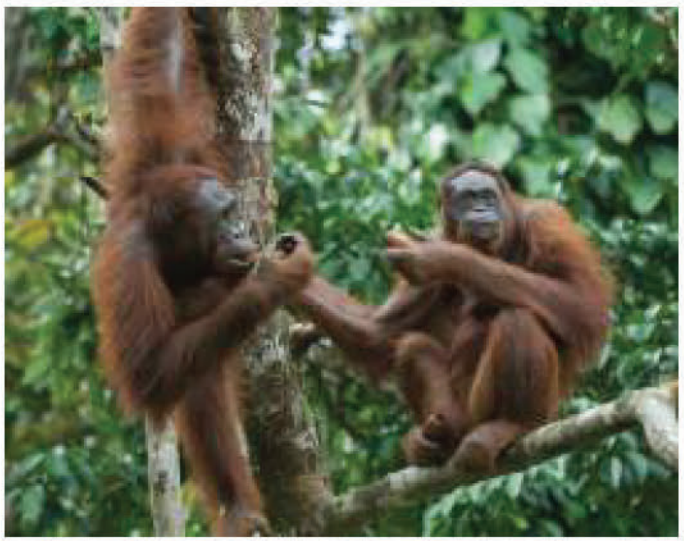
Climatically, southeastern Asia is characterised by a constantly hot and humid climate with generally high levels of precipitation. Most countries experience a distinct wet and dry season reflecting monsoonal wind patterns. Northern parts of the Lao People's Democratic Republic, Myanmar and Viet Nam are slightly more temperate. The region also has many islands and archipelagos where maritime influences are important locally. The mainland part consists of a mountainous northern region with a series of mountain ranges extending southwards separated by large plains and plateaus. Several large rivers (e.g. Mekong, Irrawaddy, Chao Phraya, Red) drain the area, often spreading into large deltas as they reach the sea. The fertile floodplains along these rivers give rise to Fluvisols that are highly suited for rice cultivation. Central Cambodia is dominated by a low-lying plain formed by the flooding of the Tonlé Sap (or Great Lake). To the west, the Malay Peninsula has a mountainous core with coastal plains, with a distinctive limestone landscape the around the Thai-Malaysian border. The island chains of the Indonesia, Malaysia and the Philippines reflect their volcanic origin as three tectonic plates meet in this region. Active volcanoes are common with many islands having mountainous centres, from which short rivers flow across narrow coastal plains to the sea.

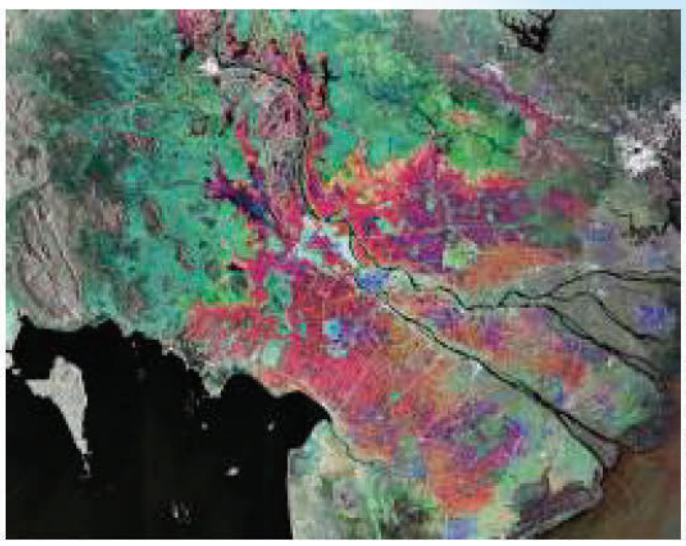
The hot and humid equatorial climates support extensive chemical weathering, which gives rise to highly leached, coarse-textured, yellow and red-coloured Acrisols and Ferralsols with high levels of iron and aluminium oxides. These acidic soils lack carbonates and nutrients, and are found in gently undulating terrain. The high precipitation along the equator also gives rise to freely draining acidic Podzols while Gleysols and Stagnasols are widespread along the floodplains of rivers. Organic Histosols are widespread in the lowlands of Indonesia and Malaysia. Rocky mountains and ridges are depicted by Leptosols.

Fertile Andosols have developed on the ash and lava of volcanoes of Sumatra and much of Java.



Volcanic activity affects large parts of southeastern Asia. In fact, Indonesia has more volcanoes than any other country (147, of which 76 are active). Mount Bromo, in the photograph, is one of a chain of volcanoes that runs the length of the Indonesian island of Java. Ash from an ongoing eruption covers the upper part of the cone. Volcanoes are caused by the movement of tectonic plates as they come together or separate. Andosols, which form in volcanic materials such as ash and pumice, are valued as fertile soils despite the obvious hazards. (SM)

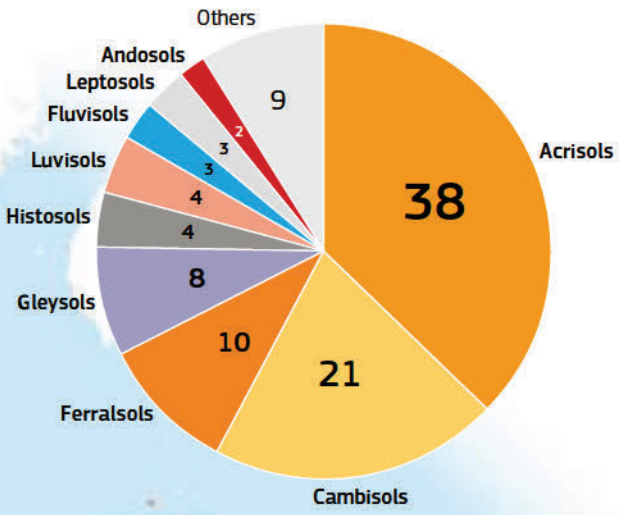




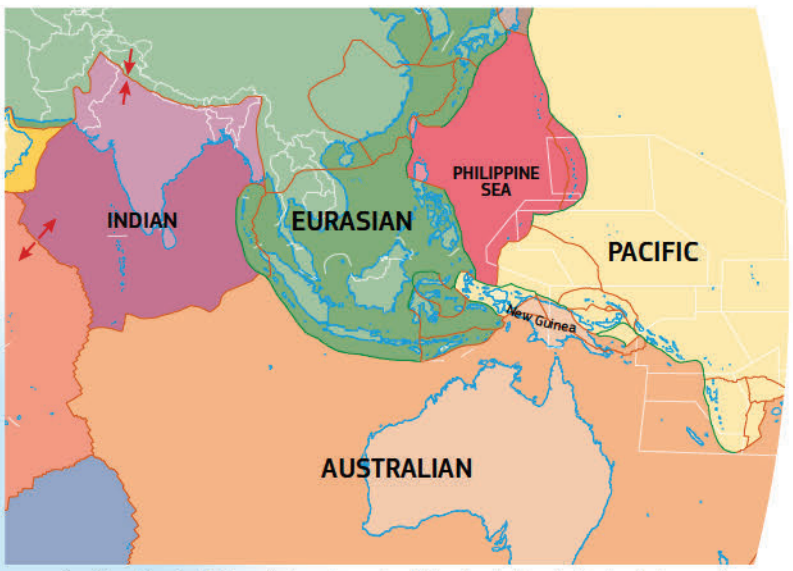
Left: Rainforests are typical of much of Southeast Asia. Despite their dense and varied vegetation, soils of rainforests are often lacking in nutrients. the Highly acidic, coarsely textured, free-draining Ferralsols, together with Acrisols, tend to be covered in a thin organic-rich surface horizon that can be lost very quickly if the natural vegetation is cleared. Such soils support trees such as Dipterocarpaceae, which provide habitats for a range of animals such as these orangutans in Malaysia (PG).

Right: Several rivers in Asia have developed large deltaic plains. This occurs when flowing water with large amounts of sediment meets waterbodies with lower energy levels. This causes the river to drop its sediment load, which over time, builds outwards in a characteristic triangle or fan shape. This satellite image shows Viet Nam's Mekong Delta as it fans out into tributaries and empties into the South China Sea. Fine-grained Fluvisols and waterlogged Gleysols on deltas are ideal for rice cultivation. The different shades of red, purple and blue reflect different stages of rice growth. The rice grown on the Mekong Delta makes Viet Nam the world's third biggest rice exporter, after Thailand and India. Ho Chi Minh City is visible as a white patch in the upper right corner. The grey areas at the end of the delta are mangroves. (ESA)

Common soil types of Southeast Asia (%):







The island of New Guinea is part of the Australian tectonic plate, on the boundary with the Pacific, Philippine and Eurasian plates. The movement of the plates against each other gives rise to volcanoes and earthquakes. (LJ)

0 500 1 000 km

Scale note:

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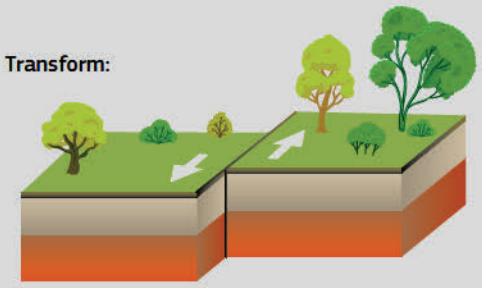
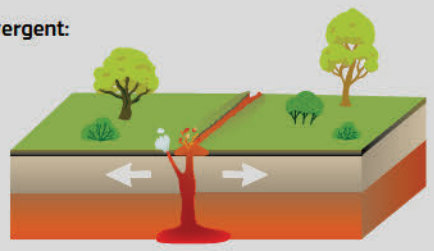
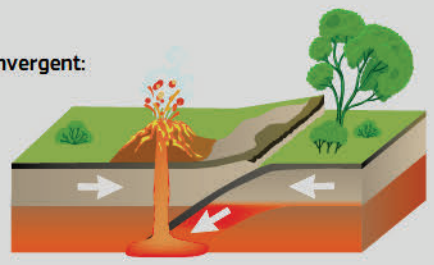
Tectonic plate boundaries

Tectonic plates tend to occur in three types:

- **Transform boundaries** occur where two plates slide past each other along transform faults. In this case, plates are neither created nor destroyed. Such boundaries tend to be characterised by strong earthquakess can occur along a fault. The San Andreas Fault in California is an example of a transform boundary exhibiting dextral motion.
- **Divergent boundaries** occur where two plates move away from each other. This type occurs at mid-ocrean ridges where ocean crust is formed or in rift valleys on continental crusts. Such boundaries are marked by small volcanoes and/or shallow earthquakes.
- **Convergent boundaries** occur where two plates slide toward each other to form either a subduction zone (one plate moving underneath the other which results in the melting of rocks) or a collision of two or more continents (e.g. the Himalayas). Such boundaries are marked earthquakes, volcanoes and a deep ocean trench, the latter two often in the form of an arc.







(JRC/LJ after USGA)

Eastern Asia

For the purposes of the Atlas, Eastern Asia refers to an area of around 12 million km² (around 27 % of Asia), consisting of China, the Democratic People's Republic of Korea, Japan, Mongolia and the Republic of Korea - it should be noted that 9.5 million km² are occupied by China alone. While the region is separated from Central, Southern and Southeast Asia by the mountains of the Tian Shan and the Himalayas respectively, the northern border follows the Mongolian Plateau and the Armur River. The Pacific Ocean forms the eastern boundary. To the north lies the cold and humid lands of Siberia.

With over 1.6 billion people living in this region, many in some of the largest cities on the planet, it may be surprising to learn that large parts are sparely populated reflecting the rugged nature of much of the landscape. In fact, Mongolia has the lowest population density of any country with just over 2 people per square kilometre. In contrast, the population density of Guangzhou in China is over 4 000 people/ km².

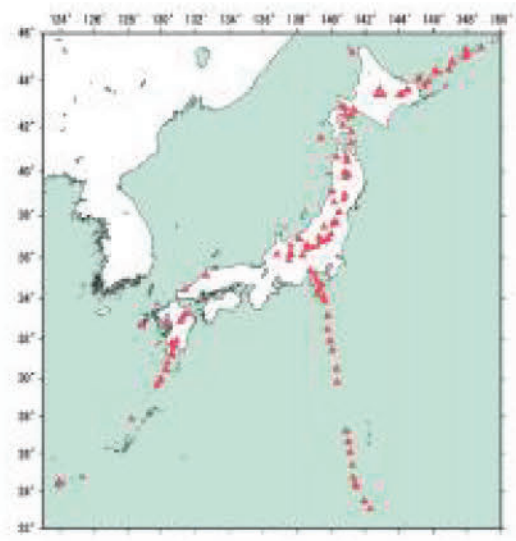
Generally, the region consists of five main landscapes. Much of the southeastern part is mountainous with several high plateaus. Mount Everest on the border between China and Nepal rises to 8848 m a.s.l. while elevations in the Tibetan Plateau exceed 4000m a.s.l.

Northern parts of the Mongolian Plateau are gently undulating grasslands that become increasingly arid towards the south, where they merge with the Gobi and Taklamakan Deserts.

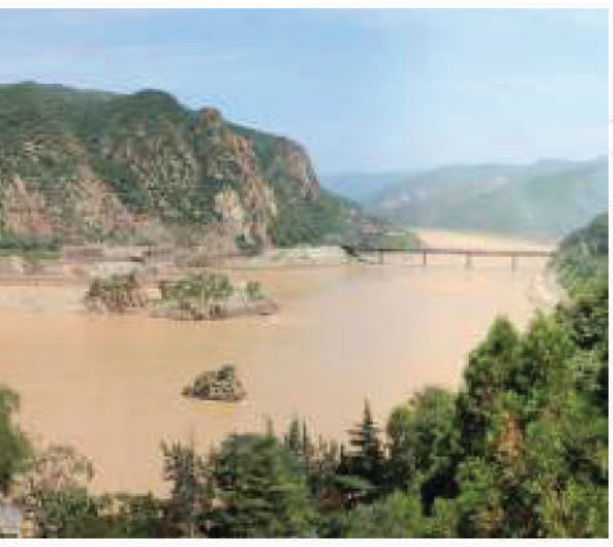
Towards the Pacific, elevations gradually decrease towards the broad lowland alluvial plains of the Yangtze and Yellow Rivers. The Korean Peninsula exhibits narrow coastal plains fronting a mountainous spine.

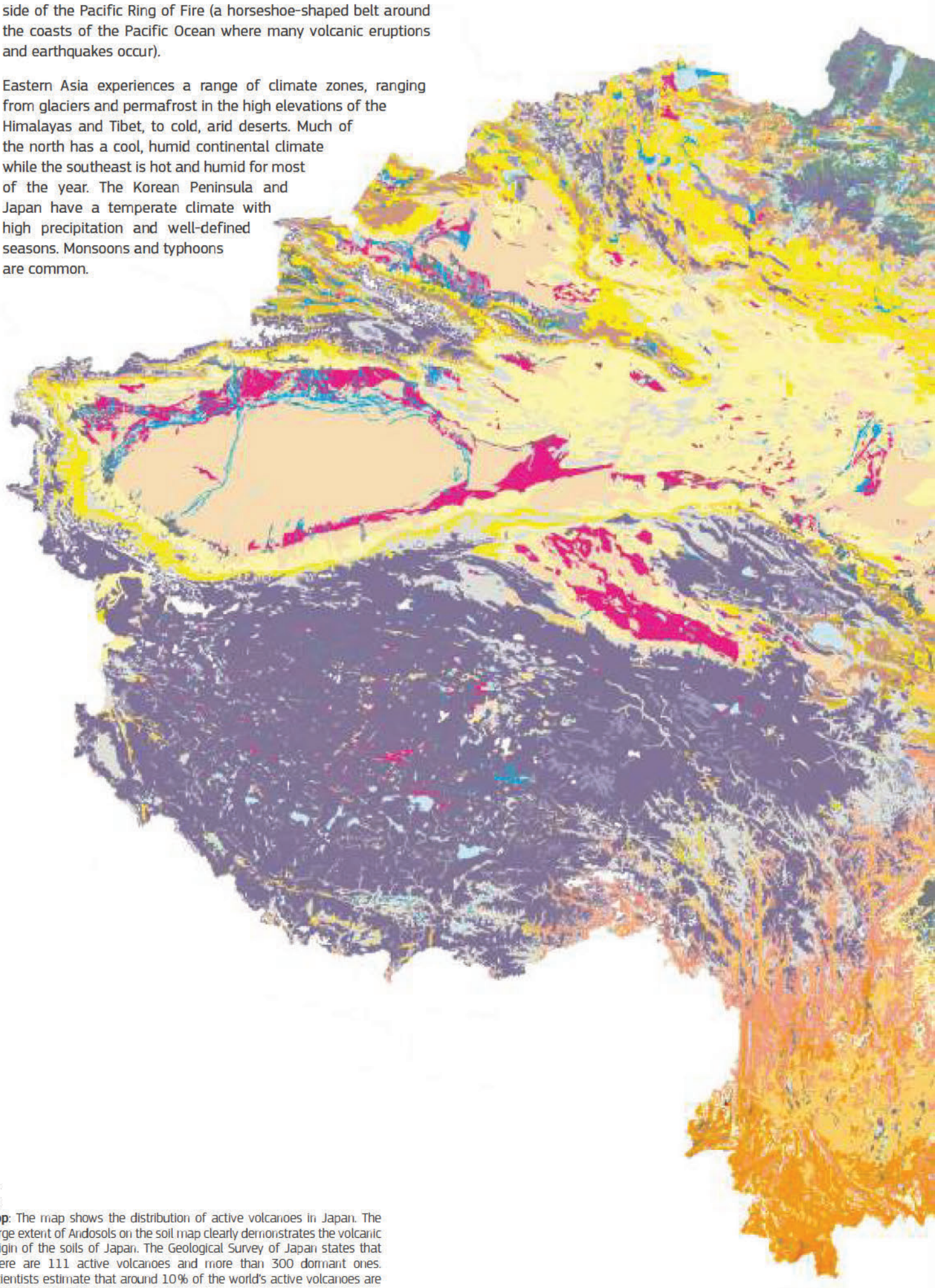
Finally, the volcanic islands of Japan and the Republic of Korea reflect the high levels of tectonic activity that denote the eastern side of the Pacific Ring of Fire (a horseshoe-shaped belt around the coasts of the Pacific Ocean where many volcanic eruptions and earthquakes occur).

Eastern Asia experiences a range of climate zones, ranging from glaciers and permafrost in the high elevations of the Himalayas and Tibet, to cold, arid deserts. Much of the north has a cool, humid continental climate while the southeast is hot and humid for most of the year. The Korean Peninsula and Japan have a temperate climate with high precipitation and well-defined seasons. Monsoons and typhoons are common.









Top: The map shows the distribution of active volcanoes in Japan. The large extent of Andosols on the soil map clearly demonstrates the volcanic origin of the soils of Japan. The Geological Survey of Japan states that there are 111 active volcanoes and more than 300 dormant ones. Scientists estimate that around 10% of the world's active volcanoes are located in Japan. [97]

Middle: Much of the central part of the Korean Peninsula is mountainous with Cambisols). This photograph is shows the landscape of Gyeonggi-do Province in the Republic of Korea. (pxhere)

Bottom: Asia is home to some of the longest rivers in the world. This brown colour of the water in this photograph of the Yellow River in Henan Province in China is due to high levels of sediment. This illustrates how rivers transport huge volumes of sediments eroded along their course. While erosion induced through human activities should be avoid, this natural process is responsible for fertile Fluvisols on floodplains and deltas that ensure food for billions of people. (FP)

Scale note:

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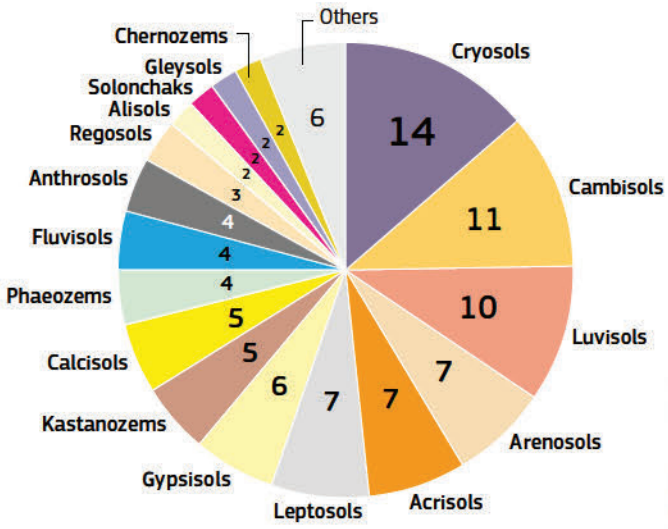
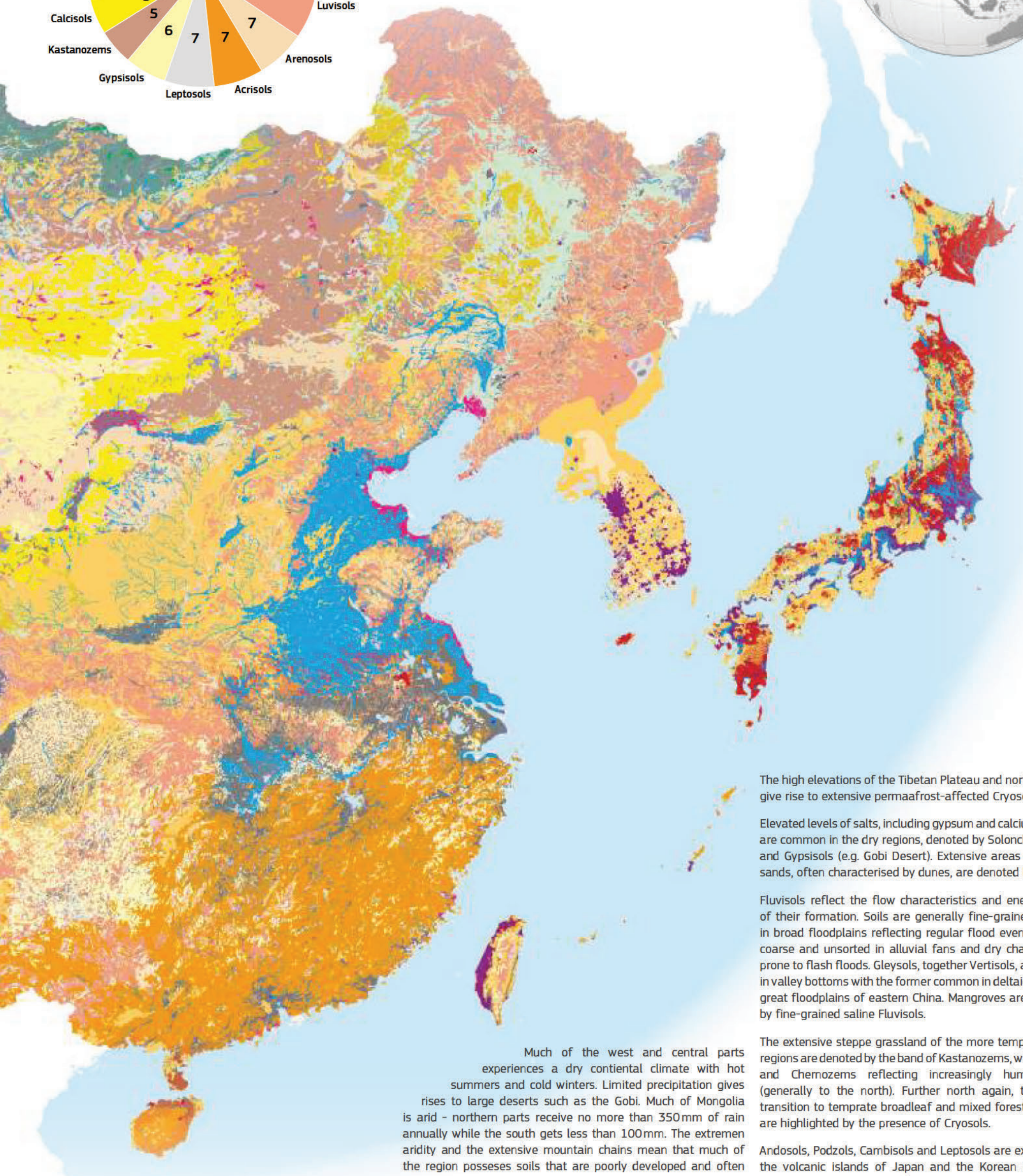
Common soil types of Eastern Asia (%):







The high elevations of the Tibetan Plateau and northern Mongolia give rise to extensive permaafrost-affected Cryosols.

Elevated levels of salts, including gypsum and calcium carbonates, are common in the dry regions, denoted by Solonchaks, Calcislols and Gypsisols (e.g. Gobi Desert). Extensive areas of wind-blown sands, often characterised by dunes, are denoted by Arenosols.

Fluvisols reflect the flow characteristics and energy conditions of their formation. Soils are generally fine-grained and layered in broad floodplains reflecting regular flood events, while often coarse and unsorted in alluvial fans and dry channels that are prone to flash floods. Gleysols, together Vertisols, are often found in valley bottoms with the former common in deltaic areas and the great floodplains of eastern China. Mangroves are characterised by fine-grained saline Fluvisols.

The extensive steppe grassland of the more temperate northern regions are denoted by the band of Kastanozems, with Phaeozems, and Chernozems reflecting increasingly humid conditions (generally to the north). Further north again, the grasslands transition to temprate broadleaf and mixed forestscold climates are highlighted by the presence of Cryosols.

Andosols, Podzols, Cambisols and Leptosols are extensive across the volcanic islands of Japan and the Korean Peninsula. The Acrisols and Luvisols of southern Japan and southeastern China reflect a hot and humid sub-tropical climate.

Much of the west and central parts experiences a dry contiental climate with hot summers and cold winters. Limited precipitation gives rises to large deserts such as the Gobi. Much of Mongolia is arid - northern parts receive no more than 350mm of rain annually while the south gets less than 100mm. The extremen aridity and the extensive mountain chains mean that much of the region posseses soils that are poorly developed and often stony, with low soil organic matter levels and low water retention capacity (generally Regosols, Leptosols, Cambisols).

Northern Asia

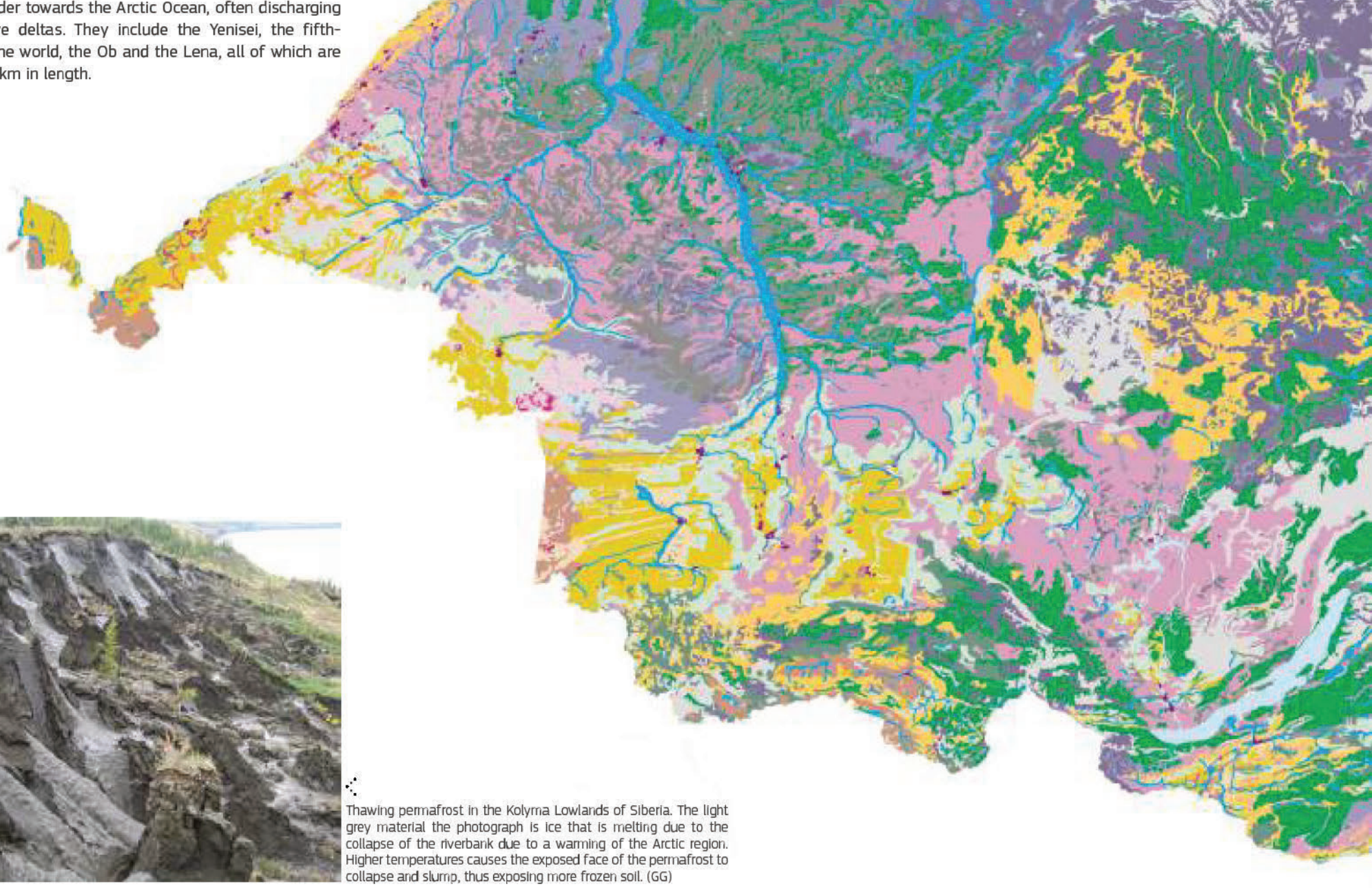
Northern Asia refers to an area of around 13 million km² consisting of the Russian regions of Siberia, the Russian Far East and Ural. The region is delimited to the west by the Ural Mountains, the traditional boundary with Europe. The north and east face the Arctic and Pacific Oceans, respectively, while the southern extent with China, Mongolia and Kazakhstan, is defined by the Armur River, the Mongolian Plateau, the Altai Mountains and the Ural River. While covering around 29% of Asia, the region is the least populated, with around 40 million people giving a population density of just three people per km². Large parts are uninhabited.

Around two-thirds of the region consists of the low-lying Siberian Plain, the higher Central Siberian Plateau, and the Central Yakutian Lowland. To the east, the East Siberian Highlands occupies the land towards the Bearing Straits. Further east, the volcanic peaks and craters of the Kamchatka Peninsula reflect the elevated levels of tectonic activity that are associated with the Pacific Ring of Fire. The large waterbody in the lower centre of the map is Lake Baikal, the world's largest freshwater lake by volume, containing over 20% of the world's fresh surface water. It is also the world's deepest lake, with an average depth of 1 642 m. Several notable rivers cross the region, flowing northwards from the southern border towards the Arctic Ocean, often discharging through extensive deltas. They include the Yenisei, the fifth-longest river in the world, the Ob and the Lena, all of which are more than 3 500 km in length.

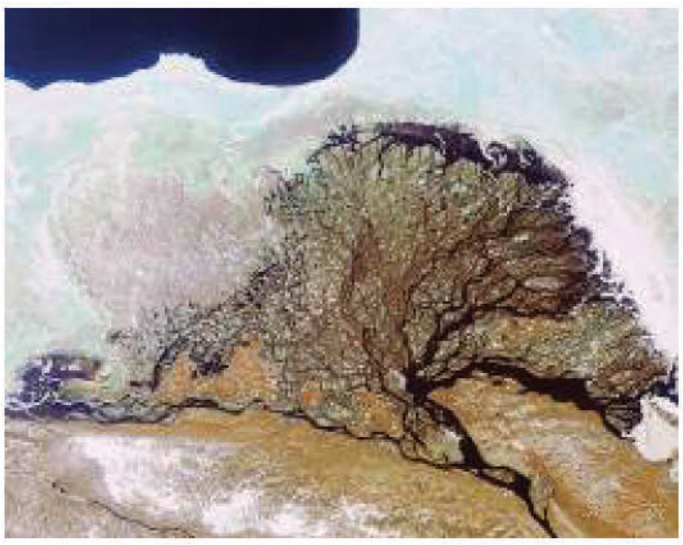
Northern Asia primarily experiences a cold continental climate, with long cold winters and short warm summers. Apart from Kamchatka and the southeastern corner, precipitation levels are generally low. Siberia is the coldest inhabited point in the Northern hemisphere, referred to as the Pole of Cold, where temperatures of almost –70 °C have been recorded.

The region is characterised by a series of broad vegetation zones running from north to south. A tundra belt running along the Arctic coastline merges into an extensive coniferous forest known as the taiga. Where the climate becomes more temperate, the taiga gives way to broadleaved and mixed forests. Further south, can be found the extensive grasslands of the steppe region.

Low temperatures in winter and the extensive presence of permafrost are the key factors in soil development. The dominant soils are Cryosols, often with high levels of organic matter, together with Histosols (in depressions and valley floors), Podzols and Albeluvisols (generally on slightly higher ground, often under conifer forests), and cover most of the region. Mountainous areas are denoted by shallow and stony Leptosols and/or Cambisols. Fluvisols denote the main river valleys and are often interspersed with Gleysols and Stagnosols. Andosols denote the volcanic parent material of the Kamchatka Peninsula, where a more humid climate gives rise to Histosols. The steppe grasslands are mostly denoted by Phaeozems.



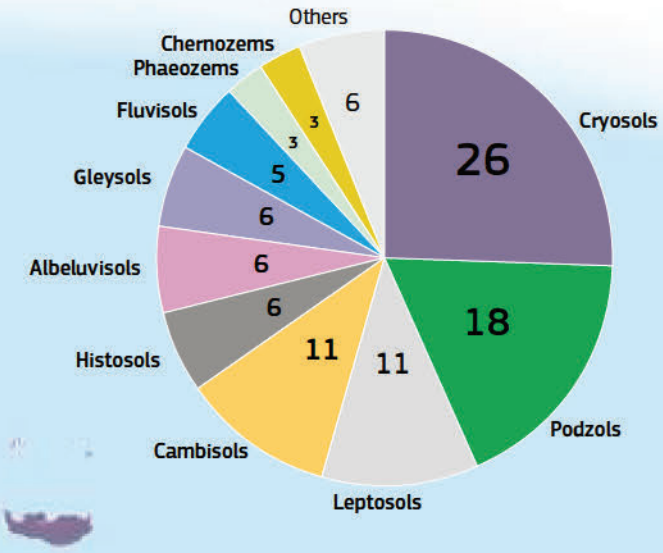
Thawing permafrost in the Kolyma Lowlands of Siberia. The light grey material the photograph is ice that is melting due to the collapse of the riverbank due to a warming of the Arctic region. Higher temperatures causes the exposed face of the permafrost to collapse and slump, thus exposing more frozen soil. (GG)







Common soil types of Northern Asia (%):





Scale note:

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Left: This image, captured by the MERIS sensor on the ENVISAT satellite, shows the delta of the Lena River on the northern coast of Siberia. Although the image is from June, coastal waters and small lakes on the delta are still frozen. The main channel, visible in dark brown, splits into several smaller channels before meandering towards the sea. The delta, shown as Fluvisols and Gleysols on the map, is the result of sediments carried by the waters of the Lena as it flow through the flat Siberian plain. The dark blue area in the upper left is open water, where several icebergs can be seen (white specks). (ESA)

Centre: Boreal forests, made up of coniferous trees such as pines, spruces, and larches, cover enormous swathes of northern Asia. The cold climate of northern Asia, coupled with large tracts of flat terrain, gives rises to extensive peatlands. Low temperatures, and permanently waterlogged conditions, mean that plant remains decay slowly and accumulate in wetlands known as mires. On the map, these correspond to Histosols. The green stripes in the photograph, from the floodplain of the Bolshoy Yugan River in Western Siberia, are pine trees growing along low ridges, which are separated by shallow depressions in which peat is forming (brown coloured areas). Unlike the forest peatlands of Southeast Asia, northern peatlands are derived from grasses, mosses, liverworts and lichens. (TB)

Right: Soils tends to be slightly acidic due to the release of fulvic acid from needle leaves as they decompose. They are shown as Podzols and Albeluvisols on the map. (TB)

Explanatory text (not on map spread)

Sheet 2 | NE Kazakhstan, N China, W Mongolia, S Russian Federation (pp92-93)

This map shows the soils of northeastern Kazakhstan, southwestern Siberia in the Russian Federation, a small part of western Mongolia and the Altay Prefecture of northwestern China. The large river flowing northwards through the centre of the map is the Yenisei, the fifth-longest river in the world that drains into the Arctic Ocean. The large waterbody to the east on the Mongolian-Russian border is Lake Uvs (the largest in Mongolia) while along the southwestern edge of the map, Lake Balkhash is one of the largest lakes in Asia and 15th largest freshwater body in the world. Many of the lakes shown on this map lie in closed depressions where no rivers flow out (scientifically known as an endorheic basin). This means that their waters are slightly saline.

The right side of the map covers the juncture of the Altai and Mongolian-Altai Mountains, which mark the boundary between the higher Eastern Steppe regions of Central Asia and the lower Western Steppe. The peaks of the Altai reach over 4000m a.s.l., with permanent snow fields and glaciers. Beyond the mountains, elevations drop to the Western Steppe regions of the West Siberian Plain, which extends as a semi-arid grassy and forested plain all the way to Hungary and the mouth of the Danube River in the west. The land here is generally less than 100m above sea level for thousands of kilometres.

The climate is severely continental with long, cold winters and short, warm summers. January temperatures range from −14°C to −32°C while in July temperatures often reach 24°C or higher. In western areas, particularly at higher elevations, annual precipitation is around 1000mm, which decreases towards the east and south. Glaciers and permafrost are found on the highest peaks of the Altai Mountains.

Soils follow a distinctive zoning pattern, reflecting differences in climate with latitude and altitude which lead to differences in organic matter content and pH. Under the extensive grasslands, dark deep organic-rich Chernozems occupy a broad belt running west to east in the northern half of the map. Phaeozems tend to denote wooded sloping ground while drier conditions are reflected by Kastanozems. The rocky terrain to the north of Lake Balkhash is denoted by extensive Cambisols with Kastanozems on wooded sloping terrain.

Fluvisols and Gleysols are found along the major river valleys, the latter reflecting the presence of a shallow water table. The linear pattern of Gleysols marks the Irtysh River as it flows from the Altai Mountains in China in lower left corner of the map, through Lake Zaysan and then northwestwards past the city of Semey in Kazakhstan. To the north (not shown on the map), the Irtysh joins the Ob River to become the world's seventh longest river system. In the eastern part of the map, the Fluvisols denote the floodplain of the Ob River – the Anuy and Biya tributaries are especially evident.

Umbrisols along the border between Kazakhstan and the Russian Federation define the Altai Mountains while Cryosols denote the higher elevations of the Mongolian Plateau.

The profusion of Solonchaks and Solontez on the map clearly shows that much of the area is affect by high salinity levels (especially around the numerous closed basins). Solonetz are clay-rich soils characterised by an accumulation of sodium salts below the surface horizon that develop in arid climates in parent materials that are either naturally enriched in sodium minerals or are influenced by saline waters (often groundwater). In contrast Solonchaks are defined by a high accumulation of soluble salts and the absence of any distinct subsurface horizons. Solonchaks are formed through the evaporation of saline water bodies, usually in closed drainage basins. Solonetz and Gleysols in the north of the map denote the Barabinsk lowland where shallow saline lakes (e.g. Chany Lake) occur in combination with a high watertable.

The linear Arenosol features trending northeast-southwest, to the west of the Ob River represent "fossil" dune systems and fluvial sand deposits, possibly the remnants of a large glacial flood event.

Sheet 3 | Central Mongolia, S Russian Federation (pp94-95)

This map shows the soils of Central Mongolia and a part of southern Siberia. The large waterbody in the upper centre of the map is Lake Baikal, the world's largest freshwater lake by volume, containing over 20% of the world's fresh surface water. It is also the world's deepest lake, with an average depth of 1642m. Lake Khuvsgu, to the southwest of Lake Baikal, is over 1600m a.s.l., 262m deep and the second-most voluminous freshwater lake in Asia. On the left side of the map, the series of saline lakes (including Uvs Lake) highlights a series of endorheic basins (i.e without rivers flowing out of them) that is known as the Great Lakes Depression.

As with Sheet 4 and 5, this map marks the transition between the colder, permafrost affected soils of northern Asia and the dry conditions of the Gobi to the south. The main geographic feature of the map is the extensive grasslands of the steppe region (see map sheets 1-2 and 4). The map covers the western end of the high Mongolian Plateau and Eastern Steppe, which is separated from the Western Steppe by the Altai Mountains (just beyond the western extent of this sheet). Extending around 2500km from east to west and about 800km from north to south, the elevation of the Eastern Steppe ranges from 1000 to 1500m, dropping to the south and the east through a series of east-west mountain ranges, tablelands and plains. The Khangai Mountains in southern Mongolia rise to over 3000m a.s.l. To the south, increasingly arid conditions mark the beginning of the Gobi Desert while to the north, most of the land is mountainous and covered by dense boreal conifer forests. The climate is cold continental with short warm summers and very cold winters. Lower temperatures across the Mongolian Plateau reduce evaporation thus enabling the low levels of precipitation to support sparse grasslands. Annual precipitation across the central Mongolia range between 250-500mm decreasing to the south but increasing slightly to the north. Levels can be greater at higher elevations where precipitation often falls as snow.

The pattern of soils broadly follows the latitudinal change in climate. To the north, very cold winters gives rise to a patchwork of Cryosols and Podzols, the latter reflecting acid soil conditions under extensive boreal forests of larch, birch and pine. Further south, the map is dominated by the steppe soils. Under extensive grasslands and deciduous forests, dark deep organic-rich Chernozems occupy a broad belt running west to east. In regions with higher precipitation, increased leaching gives rise to Phaeozems, while to the south, drier conditions are reflected by more calcareous Kastanozems. The arid conditions of the Gobi Desert and high salt content of parent materials gives rise to extensive Calcisols, Gypsisols and Solonetz, together with poorly developed Cambisols and Regosols. Umbrisols along the border with the Russian Federation denote the Western and Eastern Sayan Mountains as well as further east, the Yablonviy Range. Cryosols indicate the presence of permafrost on higher elevations. This pattern can also be seen on the Khangai Mountains further to the south. Leptosols along the southern edge of the map denote the bare rocks of the Mongol- and Gobi Altai Mountains of the Gobi Desert. Fluvisols denote the main river systems of the area. While many flow into closed saline basins where the waters evaporate to form Solonchaks, the Selenge River flows via Lake Baikal, flows all the way to the Arctic Ocean. Similarly, the Onon River in the northeastern part of the map is a tributary of the Shilka and Amur River, which empties into the Pacific Ocean forming the tenth longest river system in the world.

Sheet 4 | NE China, E Mongolia, S Russian Federation (pp96-97)

This map shows the soils occurring in eastern Mongolia, the northern part of the North China Region (i.e. the northern parts of the Inner Mongolia and Heilongjiang Provinces), and the southeastern part of the Russian Far East region. This map marks the transition between the colder, permafrost affected soils of northern Asia and the dry conditions of the Gobi to the south. The main geographic feature of the map is the extensive grasslands of the steppe region (see map sheet 3).

The Greater and Lesser Khingan Mountain range, denoted by the inverted-Y shape in the centre of the map divides the flat lowlands of the Manchurian Plain to the east from the high Mongolian Plateau to the west. The mountains have an average elevation of around 1500m a.s.l. The eastern side has a notable escarpment that is cut by several rivers while the western side has gentler slopes. To the north, the Stanovoy Mountains run along the border between Russia and China. The Mongolian Plateau gradually increases in elevation to the west before meeting the barrier of the Altai Mountins (not on this sheet). This means that conditions on the Eastern Asia Steppe are colder and drier than those to the west.

The Greater Khingan mountains form an important climatic divide. They block precipitation from the southeast winds. This gives annual precipitation of around 500mm annually on the east that contrasts sharply with the much drier conditions to the west. The northern end of the range, on the border with the Russian Federation, experiences extremely severe winters with mean temperatures close to −30°C. Further north, permafrost is widespread. To the south, temperatures are higher but precipitation is lower. The western side of the map has a more humid continental climate with long, dry and very cold winters while summers are short, warm and wet.

The pattern of soils shown on the map broadly follows the latitudinal change in climate. To the north, very cold winters gives rise to a patchwork of Cryosols and Pdozols, the latter reflecting acid soil conditions under extensive tiga forests of larch, birch, aspen and pine. Further south, Albeluvisols reflecting intense periglacial activity in the past. The southern third of the map is dominated by the steppe soils. Chernozems on sloping ground grade in to Phaeozems on valley floors and in lower landscape settings. As conditions become drier to the south, Kastanozems are more prevalent.

The Khingan Mountains are shown by Luvisols while the Stanovoy Mountains by Cambisols and Leptosols. Fluvisols denote the main river systems of the area which are mostly tributaries of the Amur River that forms the border between the Russian Federation and China. The distinctive pattern in the northwest corner of the map are the Shika and Argun Rivers.

Sheet 6 | S Kazakhstan, Uzbekistan, Tajikistan, W Kyrgyzstan (pp100-101)

This map shows the soils of southern Kazakhstan, Uzbekistan, Tajikistan and western Kyrgyzstan. The Aral Sea lies in the top left corner of the map while the water body in the upper right corner is Lake Balkhash, one of the largest lakes in Asia and 15th largest freshwater body in the world. Like the Aral Sea, Lake Balkhash lies in a closed basin where no rivers flow out. This means that its waters are slightly saline. Historically, the Aral Sea was the world's fourth largest lake until it began shrinking after the rivers that fed it were diverted in the 1960s for irrigation projects.

The major geographical feature running across the lower right-hand side of the map is the western end of the Tien Shan Mountains, which splits either side of the fertile Fergana Valley and the Syr Darya River. The southern side of the Feranga Valley is flanked by the Alay Range, which in turn drops to the broad Gissar Valley that runs east to west across much of northern Tajikistan.

Most of the remaining area shown by the map is a gently undulating, dry plain that stretches from the Kopet Dag mountain range on the border between Turkmenistan and Iran (lower left corner of the map) to Lake Balkhash. Much of the land is covered by shifting sands and dunes of the Kyzylkum Desert (mostly lying across the border between Uzbekistan and Kazakhstan) and the Karakum Desert (which lies just east of the Caspian Sea in Turkmenistan – see map sheet 5). Elevations are in the order of 300m a.s.l.

The climate for most of the area shown on the map is arid continental, with moderately cold winters and hot summers. Average temperatures in January are below freezing but can reach over 35°C during the summer months. Temperatures fall with elevation such that many of the high peaks in the southeast of the map have permanent snow, ice and glaciers. Most of the region is very dry, with average annual precipitation less than 200 mm, falling mostly in winter. Precipitation is slightly higher in the southeast.

The three distinctive tracts of Gleysols running broadly northwestwards across the plains correspond to the floodplains of the Amu Darya (broadly following the border between Turkmenistan and Uzbekistan), the Syr Darya (which flows through the Feranga Valley in the east) and the Chu (which dries up before it becomes a tributary of the Syr Sarya). Both the Amu Darya and the Syr Darya flow into the Aral Sea. The diversion of these two rivers is one of the main reasons for the Aral Sea to shrink.

The large extent of Arenosols in the centre of the map between the mountains of Tajikistan and the Aran Sea denotes the Kyzylkum Desert with extensive mobile dune systems. Rocky outcrops are characterised by calcareous Cambisols while depressions are highlighted by the presence of saline Solonchaks. To the southwest, the other large expanse of Arenosols marks the Karakum Desert while to the northeast, Arenosols (as dunes) also flank the southern side of the Chu River valley in Kazakhstan. Gleysols and Solonchaks can be found along the floor of the Feranga Valley, while coalescing alluvial fans are shown as Calcisols.

The map clearly shows that much of the area is affect by high salinity levels (especially around the Aral Sea and central Kazakhstan). Solonetz are clay-rich soils characterised by an accumulation of sodium salts below the surface horizon that develop in arid climates in parent materials that are either naturally enriched in sodium minerals or are influenced by saline waters (often groundwater). In contrast Solonchaks are defined by a high accumulation of soluble salts and the absence of any distinct subsurface horizons. Solonchaks are formed through the evaporation of saline water bodies, usually in closed drainage basins. Due to the huge loss of water, the eastern basin of the Aral Sea is now called the Aralkum Desert, which is characterised by extensive Solonchaks.

The high ground of the Tian Shan and Pamir Mountains in the southeast are shown as Leptosols, Cryosols and glacier. Slightly more humid and temperate conditions support the development of Kastanozems and Phaeozems, with occasional Chernozems, on wooded slopes of ridges and valleys.

Sheet 7 | W China (Xinjiang), SE Kazakhstan, E Kyrgyzstan (pp102-103)

This map shows the soils of northwestern China (the province of Xinjiang), southeastern Kazakhstan and eastern Kyrgyzstan. Two important geographical features are shown on the map. The first is the arid Tarim Basin, the oval area in the lower part of the map, which contains the Taklamakan desert. The other feature, running across the centre of the map, is the Shan Mountain range, an extension of the Himalayas that run westwards into Kyrgystan while in the east, they merge with the Atlai Gobi Mountains of Mongolia. Jengish Chokusu on the Kyrgyzstan–China border reaches an elevation of 7439m. To the north of the Shan Mountains, the land drops through a piedmont landscape to the plains of southern Kazakhstan. The large water body in the upper part of the map is Lake Balkhash, one of the largest lakes in Asia and 15th largest freshwater body in the world. The upper right corner of the map sheet covers the high mountains and plateau of Mongolia.

Most of the lowland areas have an extreme arid continental climate with long, very hot summers and long, severely cold winters. Average temperatures in January are around -15°C but climb to 27°C in July. Annual precipitation is only around 120mm, falling mostly in the summer months. Towards the northwest, conditions become more humid (annual precipitation is around 700mm) with lower summer and higher winter temperatures. Temperatures decrease with altitude across the Tien Shan Mountains where permafrost is typical above 2700m.

Generally, much of the map reflects the arid conditions that characterise most of the area. The oval area of Arenosols in the centre of the map denotes the Taklamakan desert, the world's 2nd largest sand sea with dunes reaching 100m in height. On its fringes, saline Solonchaks and Fluvisols denote closed drainage basins and ephemeral river channels (e.g. the Tarim River that used to flow to the Lob Nor Depression, now a dried-up lake) while Calcisols and Gypsisols are widespread on alluvial plains and fans, reflecting the overall dryness of the area. To the north, the main mountain chain of the Tien Shan is shown as a band of Leptosols and Calcisols, with glaciers on the highest peaks. Cryosols are also found on the mountains of Mongolia in the upper right corner. To their south, Gypsisols, Calcisols and Regosols mark the barren western end of the Gobi Desert, often in the form of coalescing alluvial fans. The Turpan Depression (just north of the letter 'N' in CHINA), lies 154m below sea level and is the second lowest depression on the surface of the planet. The Anthrosols on the edge of of the depression indicates that the area is heavily irrigated for agriculture using underground aqueducts.

The pattern of Gleysols on the southeast side of Lake Balkhash, reflect the floodplains and low-lying deltas of the Ili and Karatal Rivers as they flow through the sandy Arenosols of the Saryesik Atyrau Desert. Solonetz and Solonchaks are common in depressions and along the shores of the lakes.

Chernozems, Kastanozems, Phaeozems and Umbrisols throughout the map reflect increased soil development with higher levels of organic matter content on wooded slopes of hills and ridges.

Sheet 8 | S Mongolia (Gobi Desert), N China (Gansu, W Inner Mongolia) (pp104-105)

This map is centred on the Gobi Desert, which covers much of southern Mongolia as well as the Gansu and Inner Mongolia Provinces of the North China Region. The Gobi lies at an elevation of 1500m a.s.l. between the Taklamakan Desert in the west, the Greater Khingan Mountains in the east of Inner Mongolia, and the northern edges of the Tibetan Plateau to the south. Towards the north, the desert climbs in elevation through a series of tablelands and plains separated by east-west trending mountain ranges (such as the Gobi Altai Mountains) into the steppe region of Mongolia.

Most of the map has a cold, arid or semi-arid climate with long, dry, very cold winters and short, warm summers. Frosts are common and snow is often blown in from Siberia by strong winds in winter. While average summer temperatures are around 30°C, they can reach 40°C but drop to below -20°C in winter. Extreme changes in temperature can also be experienced between night and day. Annual precipitation is generally less than 200mm in the central part of the desert, generally falling in summer. The steppe region has a slightly more temperate climate with precipitation increasing towards the east. Dust storms are common.

The soil patterns on the map reflect increasingly arid conditions from north to south. The Cryosols and Umbrisols on the northern edge of the maps reflects the elevation of the Khangai/Hangayn Mountains while those a little further south, the high peaks of the Gobi Altai Mountains (Mt Ih Bogd reaches almost 4000m a.s.l.). The Kastanozems and Phaeozems in the upper right part of the map denote the edge of the dry steppes of central Mongolia. Southwards, precipitation decreases markedly while temperatures increase, giving rise to the classic pattern of Calcisols, Gypsisols, Arenosols and Solonchaks of the Gobi Desert along the Mongolian-China border. In fact, much of the Gobi Desert is sand free. The large patch of Arenosols in the centre of the map denotes the Ala Shan Desert. Leptosols and Cryosols on the southern edge of the map denote the Qilian Mountains, which form the northern edge of the Tibetan Plateau that keeps precipitation from the Indian Ocean from reaching the Gobi. At their base, Anthrosols mark oasis along the Hexi Corridor, the route of the Silk Road. The oval of Cryosols, Leptosols, Kastanozems and Calcisols on the left-hand side of the map denote the eastern end of the Tien Shan mountain range and the start of the Taklamakan Desert. The Fluvisols in the centre of the map mark the dry channels of the Mulin and Tuing Rivers that drain into a closed depression on the border with Mongolia. The Fluvisols in the east denote the course of the Yellow River as it flows northwards and then eastwards around the dry grasslands (Kastanozems) and dunes of the Ordos Plateau. Cambisols in the lower right corner denote the beginning of the Loess Plateau, a series of mini-plains, ridges and hills formed by the accumulation of wind-blown dust (loess) originally from nearby deserts that became compacted over time under arid climates.

Sheet 9 | NE China (E Inner Mongolia, Liaoning, Jilin), Democratic People's Republic of Korea (pp106-107)

This map is centred on the Bohai Sea, and shows the soils of northeastern China (including the provinces of Liaoning, Jilin and Inner Mongolia) and the northern part of the Korean Peninsula. The major geographical features of the map are the large, low-lying deltas of the Yellow and Hai rivers, as well as the Liao, make up the North China Plain. To the north, the steppe plains of Inner Mongolian Plateau and the eastern margins of the Gobi Desert are evident.

Beyond the lowland coastal plains of China, the terrain rises rather dramatically towards Inner Mongolia in the west. To the north, the Liao Valley forms extensive alluvial plains that merge into the North Eastern Plain. Most of Inner Mongolia consists of a plateau averaging around 1200m a.s.l that is covered by extensive loess and sand deposits. Along the border between China and the Democratic People's Republic of Korea, the Changbai Mountains peaks exceed 2000m in elevation. Most of the Democratic People's Republic of Korea is composed of mountain ranges that are separated by deep and narrow valleys. A series of wide coastal plains can be found on the western side of the Korean Peninsula, while those on the east coast are narrower.

Most of the map experiences a humid continental climate with hot, humid summers and cold winters (average temperatures below freezing in January around 25°C in July. Precipitation tends to occur during the summer months, reflecting the southeastern monsoon winds that brings moist winds from the Pacific. Towards the northwest, the steppes of Inner Mongolia are characterised by a cold arid climate, with decreasing precipitation levels (<500mm).

Fluvisols along the coast denote the flat alluvial sediments of the highly fertile North China Plain and the Liao Delta. These are often found with Gleysols and saline Solonchaks nearer the coast and along flat valley floors. Increasing clay content on undulating terrain gives rise to Luvisols while higher ground is denoted by Cambisols and poorly developed Regosols (especially on the mountains of Korea). The grassland soils of the Manchurian or Northeastern Plain are denoted by Kastanozems, with Chernozems and Phaeozems where precipitation levels are higher. Arenosols denote the sandy plains of Inner Mongolia while in the upper left corner, lime-rich Calcisols and sodium-rich Solonetz and saline Solonchaks in depressions denote the Gobi Desert.

Sheet 11 | Eastern Mediterranean region of Western Asia, Iraq, Kuwait (pp110-111)

This map shows the eastern Mediterranean region of Western Asia, consisting of Cyprus, Iraq, the western part of the Islamic Republic of Iran, Jordan, Kuwait, Lebanon, northern Saudi Arabia, the Syrian Arab Republic and southern Türkiye.. The boundary of Asia is shown by the dashed grey line. In a geological sense, Cyprus is considered part of Asia while, southern Lebanon and the extreme west of the Syrian Arab Republic are located on the African tectonic plate. The map is centered on the floodplains of the Euphrates and Tigris rivers and their confluence in the Shatt al-Arab wetlands, which discharges into the Persian Gulf. The region was historically part of the Fertile Crescent, where the productive soils helped the development of agricultural practices and technical innovations such as irrigation and the wheel!

Beyond their fertile alluvial plains (denoted by Fluvisols, Vertisols and Kastanozems), rocky deserts cover most of the land with Leptosols, Cambisols, Calcisols and Gypsisols reflecting the high summer temperatures, general aridity and low vegetation cover. Saline Solonchaks and Solonetz are widespread, especially in depressions. Along the Shatt al-Arab, much of the land is marshy. To the east and north, the land becomes increasingly mountainous with Leptosols, as typified by the Zagros Mountains that run along the Iranian-Iraqi border. Lake Urmia (in the upper right) is a closed drainage basin with saline water. It used to be the world's sixth largest saline lake but has shrunk to around 10% of its former size due to the damming of rivers that flow into it, the pumping of groundwater and a persistent drought. A part of the Caspian Sea is visible in the corner of the map sheet.

Western areas have a Mediterranean climate with hot dry summers (around 20°C) and cool winters (around 10°C) with most of the precipitation falling from October to April (around 800mm annually). Inland, summer temperatures are higher (often above 40°C) while winter temperatures and precipitation are lower (the former close to freezing at night while most places receive less than 250mm precipitation annually). Northern and eastern mountainous regions have cold winters with occasional heavy snowfalls.

Cyprus exhibits a variety of soil types, mostly low in organic matter. Mountains are characterised by shallow Leptosols, Regosols and Cambisols. The limestones of the Kyrenia Range and the sediments on the western flank of the Troodos gives rise to Calcisols. Vertisols, red-coloured (Chromic) Luvisols and a variety of Cambisols are characteristic of the lowland alluvial areas. Fluvisols are not extensive but are often gravelly, denoting seasonal river channels and alluvial fans.

Sheet 12 | Islamic Republic of Iran, W Afghanistan (pp112-113)

This map predominantly shows the soils of the northern part of the Islamic Republic of Iran, together with western Afghanistan. The water body in the upper part of the map is the southern portion of the Caspian Sea, the world's largest lake. The Caspian Sea is a closed or endorheic basin where there is no outflow to the sea. As a result, it has a salinity level approaching about a third that of seawater. The water body in the lower left corner is the upper part of the Arabian Gulf.

A rugged terrain of mountains and alluvial basins covers most of the map. The Alborz Mountains follow the southern coastline of the Caspian Sea and the border between Iran and Turkmenistan and contains the volcanic peak of Mount Damavand, which rises to 5610m a.s.l. (just to the east of Tehran). The centre of map is occupied by as the Central Iranian Plateau, which reaches an average elevation of around 900m. Closed basis give rise to salt deserts, which are typified by the Dasht-e Kavir (Great Salt Desert – the oval pattern of Fluvisols and Arenosols in the middle of the map) and the Dasht-e Lut (a little further to the southeast). Western Afghanistan is a low alluvial plain that loses elevation to the west. It is drained by the Helmand River that terminates in the saline marshes of the Sistan Basin on the Afghan–Iranian border

While the Caspian coast has a subtropical climate, eastern and central parts are arid, with less than 200mm of rain. Most areas have a hot desert climate with very hot summers and cool winters. Precipitation is very low, and mostly falls in winter. Temperatures in summer may approach 50°C.

Along the southern shores of the Caspian Sea, Solonchaks denote the saline conditions while in the lower left corner, the wetlands of the Shatt al Arab are similarly defined.

The band of Leptosols and Vertisols running diagonally across the western part of the map denotes the Zagros Mountains. To the east, a series of rocky hills (Leptosols) and salty, dry plains (Solonchaks, Calcisols) gives rise to a complex soil pattern, interspersed by saline lakes (e.g. Lake Namak). Arid and semi-arid conditions extend into western Afghanistan where extensive saline soils mark the dry salt lakes of the Sistan Basin, the internal delta of Helmand River. Arenosols in the upper right corner are from the Karakum Desert.

Sheet 13 | E Afghanistan, N Pakistan, S Tajikistan (pp114-115)

This map shows the soils of eastern Afghanistan, a part of western China, northern Pakistan and southern Tajikistan.

The northern part of this map is an area of high mountains, deep valleys, passes, and glaciers. The main ranges are the Hindu Kush (running along the border between Afghanistan and Pakistan), the Karakoram (spanning the borders of Pakistan, China, and India), and the Himalayas (to the east). With an average elevation of 4500–5000m, these mountains have many high snow-capped peaks. Tirich Mir in the Hindu Kush reaches 7708m while K2 in the Karakoram is the second highest peak in the world at 8611m. These mountains are the source of the Indus River, which flows for over 3000 km to the Arabian Sea near to the city of Karachi in Pakistan. To the south, elevations drop rapidly to the rolling lowlands of Punjab. To the northwest, a similar pattern can be seen on the flat dry plains that extend towards the border between Afghanistan and Tajikistan, Turkmenistan and Uzbekistan.

A consistent element of the climate for the area depicted on this map is aridity with large annual and daily temperature ranges. Much of the mountains and northern regions have mild summers but very cold winters. Precipitation levels are generally low everywhere, falling during December to April and as snow on higher elevations. Summer temperatures increase northwards towards the Central Asian countries. To the south, the climate is more humid with higher temperatures in the summer months. Here, the wettest month is July, with heavy rainfall and thunderstorms.

The high mountains are depicted by glaciers, Leptosols and Cryosols, with Cambisols at lower elevations. Poorly developed Regosols are extensive, reflecting the aridity of the south and west. The striking pattern of Fluvisols in the centre of the map denotes the tributaries of the Indus River, which are encircled by higher ground. A small portion of the Tarim Basin, which contains the Taklamakan Desert, can be seen in the top right-hand corner of the map (see Sheet 7) while Calcisols denote the flat low plains of northern Afghanistan. Saline Solonchaks are common.

Sheet 14 | W China (Tibet) (pp116-117)

This map shows the soils in the western and northern part of the Tibetan Plateau in western China. Located to the north of the highest peaks of the Himalayas (which run along its southern edge), Tibet is the highest region on Earth with an average elevation of over 4000m. It is often referred to as the "Roof of the World".

In essence, the Tibetan Plateau is a high-altitude dry grassland (steppe) that is cut by several mountain ranges. Many of the river systems have no outlet and result in large brackish lakes. The northern edge forms a sharp escarpment that falls rapidly to the Tarim Basin and the Taklamakan Desert. Towards the north and northwest, the plateau becomes progressively higher and colder. Average elevations exceed 5000 metres and winter temperatures can drop to -40°C. Frosts occur for more than half of the year while permafrost is found over most of the plateau. Precipitation levels are low as a result of the rain shadow effect of the Himalayas that block the passage of moist are from the Indian Ocean to the south. The climate is increasingly arid towards the west where annual precipitation is only around 100mm. Despite this aridity, the glaciers and ice fields of Tibet are the source of seven of the largest rivers on the Asian continent, which provide water to around 20% of the world's population. These include the Brahmaputra, Salween, Mekong, Yangtze, Yellow, Indus and the Irrawaddy Rivers.

Discontinuous permafrost (Cryosols) gives rise to waterlogged soils in the summer as their upper layers thaw with raising temperatures (known as the active layer). The western and southern parts of the map is known as the Lake Region as mountain ranges are separated by flat valleys that contain small lakes generally without any outlet (therefore often associated with Solonchaks).

The band of Leptosols to the north mark the Altun Shan mountains (part of the Kunlum Range) that form the escarpment that drops more than 4000m to the southern edge of the Taklamakan Desert. Calcisols and Gypsisols are found on alluvial fans that grade into Arenosols and saline Fluvisols and Solonchaks that denote the floodplains of the Tarim River, which used to flow to the Lob Nor, now a dried-up lake.

The band of Leptosols along the southern edge of the map sheet ark the high peaks of the Himalayas while the Luvisols in the lower right corner have developed on the hills of the Eastern Himalayas under high levels of precipitation.

Sheet 15 | Central China (pp118-119)

This map shows the soils of Central China (covering the Region of Tibet as well as the provinces of Sichuan, Shaanxi, Hubei and Henan). The main geographical features on the map are the Tibetan Plateau on the left, the fertile Sichuan Basin (lower centre), the Loess Plateau in the upper right and the extensive floodplains of the Yangtze on the right.

The mass of Cryosols on the left-hand side of the map denotes the highlands of the eastern part of the Tibetan Plateau. Tibet is the highest region on Earth with an average elevation of over 4000m. It is often referred to as the "Roof of the World". The part shown on the map is slightly lower in elevation and coincides with an area of complex topography, with numerous high, steep ridges being separated by deep gorges. The north-south trending ranges of the Hengduan Mountains are clearly visible as bands of Leptosols. The northeastern edge of the plateau is marked by the Qilian mountain range, after which the terrain drops in elevation to the flat plains of the Hexi Corridor and the Arenosols, Solonchaks and Calcisols of the Gobi Desert.

The eastern lowlands of Sichuan are sheltered by the surrounding mountains from the cold air from the north. A subtropical monsoon climate sees cold winters, hot summers and rainy autumns. The average daytime temperature in January is around 6°C, rising to around 26°C in July. Precipitation is around 1000mm per year, decreasing towards the west. Fogs are common. To the west, higher elevations result in long, cold winters and cool summer. On the highest peaks, conditions are alpine and even arctic with glaciers and snow throughout the year. There is a marked reduction in precipitation gradient across the Loess Plateau with the northern part being semi-arid (around 400mm of annual precipitation). The climate of Xi'an is more humid. The eastern part of the map has a humid subtropical climate with hot, humid summers, and cold, dry winters. Precipitation levels are similar to lowland Sichuan.

As depicted by the band of Luvisols and Cambisols, the rugged peaks and ridges of the Qinling Mountains continue the highlands of Tibet eastwards towards the Pacific Ocean, forming the watershed of the Yellow and Yangtze Rivers. The mountains also act as a climatic divide between the hot, arid north and the more humid south. The oval pattern of Regosols to the south marks the alluvial plains of the Sichuan Basin, which is surrounded by high mountains on all sides. Asia's longest river, the Yangtze, crosses the basin along its southern edge, leaving through a gap in the Wu Mountains known as the Three Gorges. To the east of the mountains, the large expanse of Fluvisols in the lower left corner of the map denotes the alluvial plains around Dongting Lake, which is extensively flooded by the Yangtze and Han (which joins from the north) each year.

In the upper right corner of the map, the Yellow River flows southwards until Xi'an, where it makes an abrupt turn eastwards at the edge of the Guanzhong Plain (Anthrosols, Fluvisols, Gleysols) towards the North China Plain. To the north, Cambisols denote the calcareous soils of the Loess Plateau, a series of plains, ridges and hills formed by the accumulation of wind-blown dust (loess) from nearby deserts that became compacted over time under arid climates.

Sheet 21 | NE India, S Tibet, Nepal, Bhutan, Bangladesh, W Myanmar (pp130-131)

This map shows the soils of northeastern India, Nepal, southern Tibet (China), Bhutan, Bangladesh and northwestern Myanmar. The major geographic features shown on the map include the delta of the Ganges-Brahmaputra Rivers and the mountains of the Himalayas.

The northern part of the map sees the high peaks of the Himalayas that separate the plains of the Indian subcontinent from the Tibetan Plateau. Mount Everest, the highest peak on the planet, is located on this map (just to the east of Kathmandu). To the south, the mountains drop to the flat Indo-Gangetic (in the west) and the Brahmaputra Plains (in the east). Both river systems meet to form the world's largest delta, which occupies most of Bangladesh. Several rivers flow southwards through the Himalayas to the plains through steep, narrow gorges.

The southwestern part of the map covers the eastern side of the Deccan Plateau. From about 450 m above sea level, an undulating landscape drops abruptly through a series of escarpments to the Ganges floodplain (which has an elevation of less than 200m above sea level). In contrast, most of the delta is only a few metres above sea level, which makes it vulnerable to flooding during the monsoon and tropical storm surges. To the right side of the map, the terrain and climate of northeastern India and northern Myanmar reflect a mountainous landscape. In the upper right corner of the map, the high Himalayan mountains continue towards the east, while to the south of the Brahmaputra plains, the land gradually rises in elevation in a series of parallel ranges and valley with a north-south orientation.

The high elevations of the Himalayas act as a major climatic barrier in Asia. They block the movement of cold continental air from the north during winter while forcing rain-bearing winds to drop their moisture on the southern slopes before proceeding northwards. The result is a humid tropical climate with heavy precipitation (both rain and snow) at the base of the mountains. Temperatures drop with altitude, becoming polar with permanent ice and snow at the highest elevations. Arid conditions prevail across much of the Tibetan Plateau. South of the Himalayas, most of the area shown on the map has a warm and humid climate that is heavily influenced by the monsoonal weather patterns. Average temperatures are around 26°C but can range between 15°C and 34°C. Precipitation levels are generally high and increase from west to east along the southern front of the Himalayas. Annual precipitation levels are around 2000mm (mostly falling between June to October) but this increases towards the northeast to more than 5000mm (some of the wettest places on the planet). Humidity is high throughout the year in lowland areas. Tropical storms are common, bringing heavy rainfall, very strong wind, and storm surges.

Compared to map sheet 26, we can see that the extent of Vertisols are reduced. In this region, granite is the dominant geology of the lowlands that gives rise to Luvisols and red-coloured, moderately leached, but nutrient poor Lixisols. Cambisols are common, especially on alluvial plains. Fluvisols clearly denote the floodplains of the main river systems and the mangrove forests along the coast. They are gravelly in nature at the foot of the mountain ranges where the energy levels of rivers are higher, becoming finer in texture downstream. Most of the delta is composed of Gleysols that reflect a combination of high watertable arid regular seasonal flooding. Towards the coast, Fluvisols are mostly fine silts and clays.

The border between India and Myanmar broadly follows the Patkai Mountain range, beyond which the land drops to the hilly headwaters of the Irrawaddy River, which flows from north to south on the right hand side of the map. Here, higher terrain is denoted by Cambisols, while lower undulating terrain has acidic Ferralsols, reflecting higher leaching and weathering. Nitisols are found on the Irrawaddy floodplain.

Sheet 22 | SE China (Guangxi), N Viet Nam, N Lao People's Democratic Republic (pp132-133)

This map shows the soils of southeastern China (predominantly the provinces of Guangxi, Yunnan, Sichuan and Guizhou), the Lao People's Democratic Republic, the eastern part of Myanmar and northern Viet Nam. One of the striking geographical features on the map is the highly distinctive Red River Delta. Hainan Island, the largest island in China, can be seen in the lower right corner of the map (see sheet 29)

Large portions of Guangxi have relatively low elevations, with hilly ridges and low mountainous. Elevations increase steadily through a series of plateaus and mountain ridges to northwest where the border between Myanmar and China (Sichuan and Yunnan) reflects the easternmost extent of the Himalayan chain (Mount Kawagebo, located in the upper left corner of the map reaches more than 6700m above sea level). Apart from the valley of the Red River and along the coast, the northern part of the Lao People's Democratic Republic, the northeastern part of Myanmar and most of northern Viet Nam are mountainous and cut by steep and narrow gorges. The Red River flows in a southeasterly direction for over 1000km from its source in Yunnan before discharging to the Gulf of Tonkin in Viet Nam.

The region displays variations of a humid subtropical climate with mild or warm winters (around 10°C) and temperate summers (around 21°C). To the south and southwest, the climate becomes more tropical, where temperatures regularly exceed 30°C in the warmer parts of the year. Average annual rainfall ranges from 600 to 2500 millimetres with most falling between June and August. Higher elevations have more moderate temperatures.

The soil patterns reflect a diverse combination of climate and geology. The hot and humid conditions, especially in the western and southern parts of the map, gives rise to highly weathered and leached Ferralsols, Acrisols and Cambisols that are red in colour, lack nutrients and have high levels of iron and aluminium oxides. Acidic Alisols are prevalent throughout much of Guizhou Province. Cambisols and Leptosols denote higher elevations. Histosols occur areas with impeded drainage, especially in valley floors and along the coast. A combination of Fluvisols and Gleysols denote flow regimes on the low-lying delta of the Red River, while on the left side of the map, the large area of Gleysols denotes the floodplain of the Irrawaddy River.

Sheet 1 | NW Kazakhstan, S Russian Federation



This map shows the soils of northwestern Kazakhstan and a small part of the southern part of the Russian Federation.

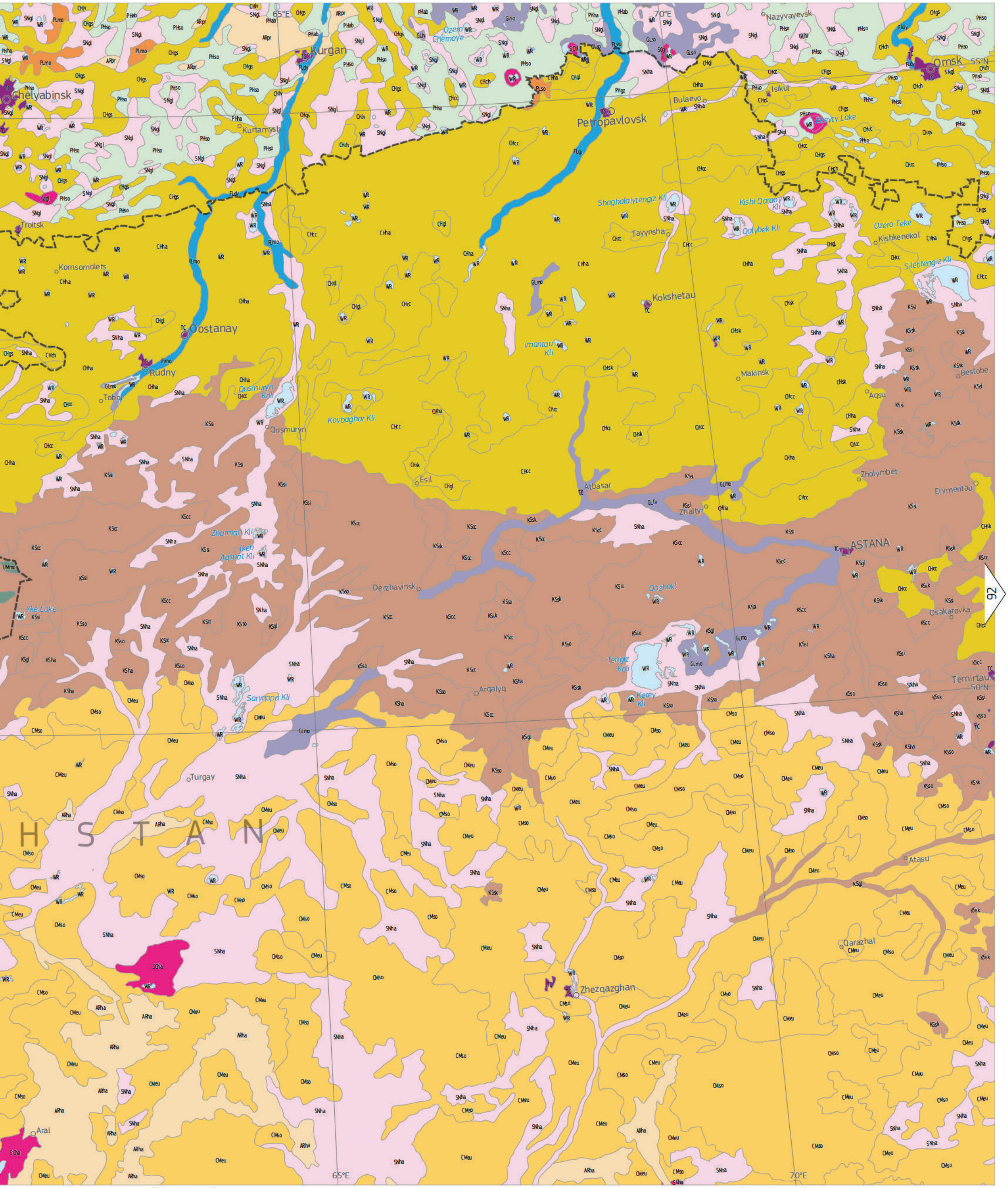
The western extent of the mapped area follows the Ural River and Ural Mountains, which define the traditional boundary between Asia and Europe. On this map, the Ural River starts in the southern part of the Ural Mountains just north of the city of Magnitogorsk. After flowing southwards for almost a third of its length, it turns westwards at Orsk for another third, before turning southwards at Uralsk for its final leg along a broad floodplain to discharge into the Caspian Sea.

At 2428km, the Ural is the 18th-longest river in Asia and the third longest river in Europe. The Ural Rivers forms a distinctive delta at its mouth. A small portion of Kazakhstan lies to the west of the Ural River and is therefore greyed out as technically it is not in Asia.

The southern extent of the Ural Mountains consists of a series of parallel valleys and ridges that gradually lower in elevation towards the south. The two water bodies at the base of the map denote the northeastern corner of the Caspian Sea and the northern extent of the Aral Sea. Both seas are closed drainage basins (i.e. there is no outflow), which means that they are slightly saline. The surface of the Caspian Sea is 28m below sea level. Historically, the Aral Sea was the world's fourth largest lake until it began shrinking after the rivers that fed it were diverted for irrigation systems.

The region experiences a dry continental climate, with long, hot summers and cold winters. Precipitation levels are generally low (generally less than 500mm), becoming more humid northwards. While the mountains are forested, the lowland plains are treeless, grassy plains.

The pattern of soil shown on the map reflects decreasing humidity towards the south. The more humid conditions in the north give rise to more vegetation and more leaching of carbonates out of the soil. This is represented by Phaeozem, with characteristics organic-rich topsoils with elevated pH levels but lacking secondary carbonates in the upper soil layers. As precipitation levels decrease, Chernozems and eventually slightly lighter Kastanozems become more evident. The more arid conditions means that they are less leached than Phaeozems and thus have higher levels of carbonates. Arenosols are found along the eastern shoreline of the Caspian Sea while the Solonchaks surrounding the Aral Sea reflect the evaporation of the previous lake. The blue linear features are Fluvisols, demarcating river systems in the region where soils have a well-developed structure and moderate levels of organic matter. Desertification is a key concern in the region.


65°E
70°E
55°N
50°N
Chelyabinsk
Troitsk
Kurgan
Kurtamysh
Petropavlovsk
Bulaevo
Nazyvayevsk
Omsk
Isikul
Ebeyty Lake
Ozero Chemoye
Shaghalalytengiz Kli
Kishi Qaraoy Kli
Qolybek Kli
Tayynsha
Ozero Teke
Kishkenekol
Siletitengiz Kli
Kokshetau
Imantau Kli
Makinsk
Aqsu
Bestobe
Ostanay
Rudny
Tobol
Qusmuryn Koli
Qusmuryn
Koybaghar Kli
Esil
Atbasar
Zholymbet
Erymentau
Zhaman Kli
Iken Aqsuat Kli
Zhaltyr
ASTANA
Derzhavinsk
Qozhaki
Osakarovka
Yke Lake
Tengiz Koli
Kerey Kli
Arqalyq
Temirtau
Saryqopa Kli
Turgay
Qarazhal
Zhezqazghan
Aral
Atasu
92
100
101

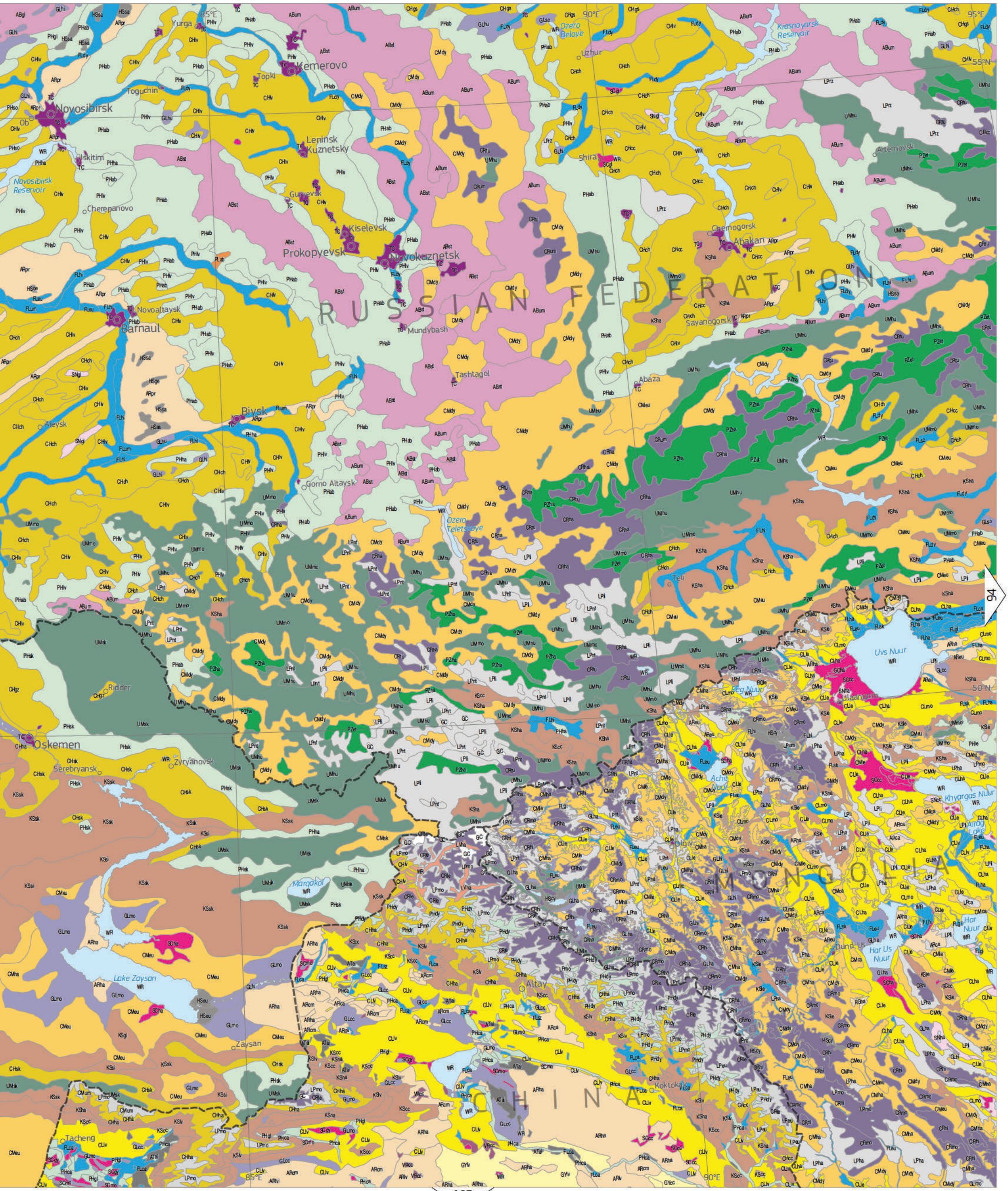
Sheet 2 | NE Kazakhstan, N China, W Mongolia, S Russian Federation



T6

102

See explanatory text on page 88


85°E
90°E
95°E
55°N
50°N
RUSSIAN FEDERATION
MONGOLIA
CHINA
Yurga
Kemerovo
Topki
Toguchin
Novosibirsk
Ob
Iskitim
Novosibirsk Reservoir
Cherepanovo
Leninsk Kuznetsky
Gurevsk
Kiselevsk
Prokopyevsk
Novokuznetsk
Mundybash
Tashtagol
Novoaltaysk
Barnaul
Biysk
Aleysk
Gorno Altaysk
Ozero Teletskoye
Ozero Beloye
Uzhur
Krasnoyarsk Reservoir
Shira
Artemovsk
Chemogorsk
Abakan
Sayanogorsk
Abaza
Tuva
Teli
Ulaangom
Uvs Nuur
Achit Nuur
Khyargas Nuur
Har Nuur
Har Us Nuur
Dund-Us
Olgiy
Altay
Koktokay
Zaysan
Lake Zaysan
Tacheng
Oskemen
Serebryansk
Zyryanovsk
Ridder
Markakol
Artog Lake
94
103

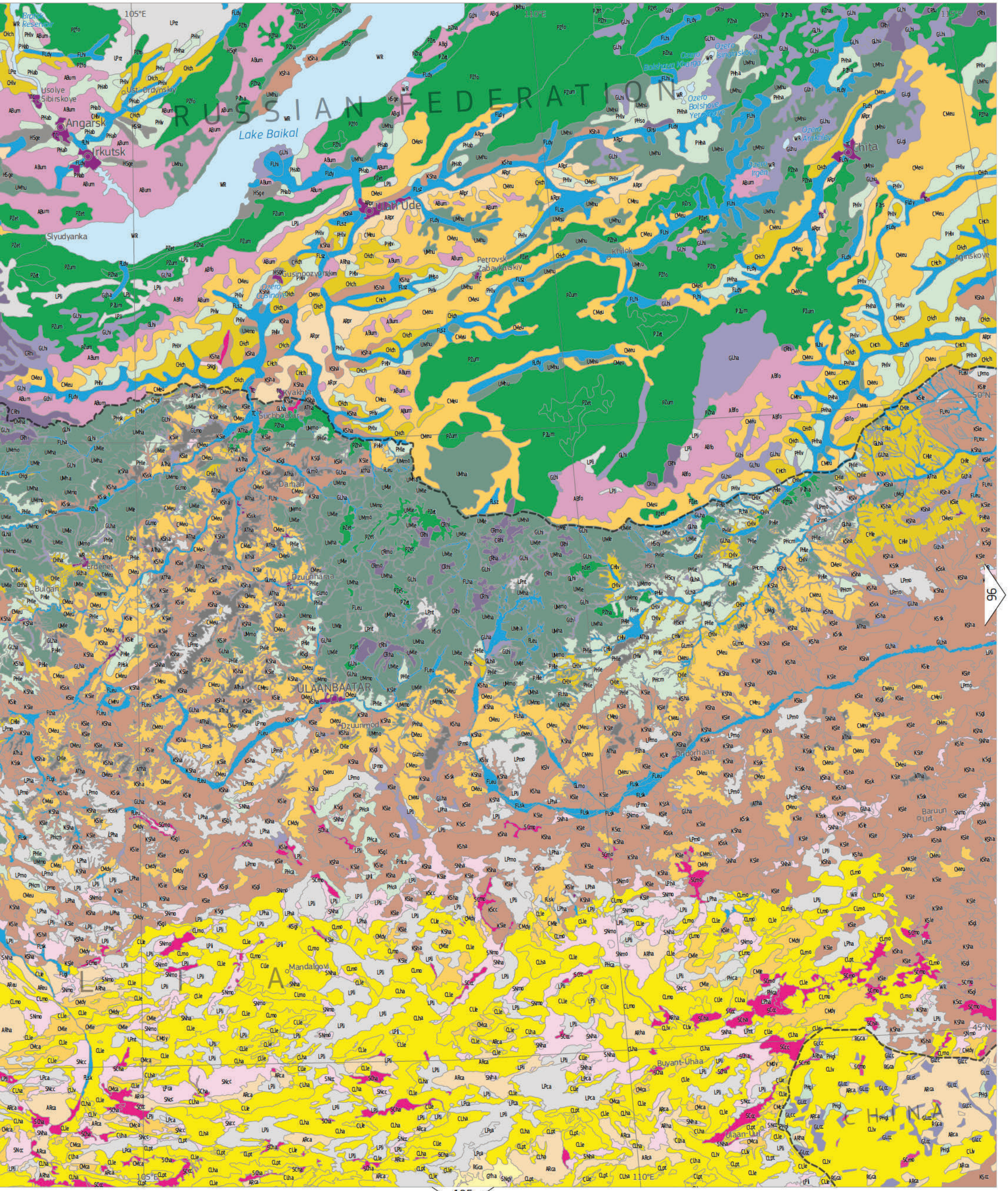
Sheet 3 | Central Mongolia, S Russian Federation



93

104

See explanatory text on page 88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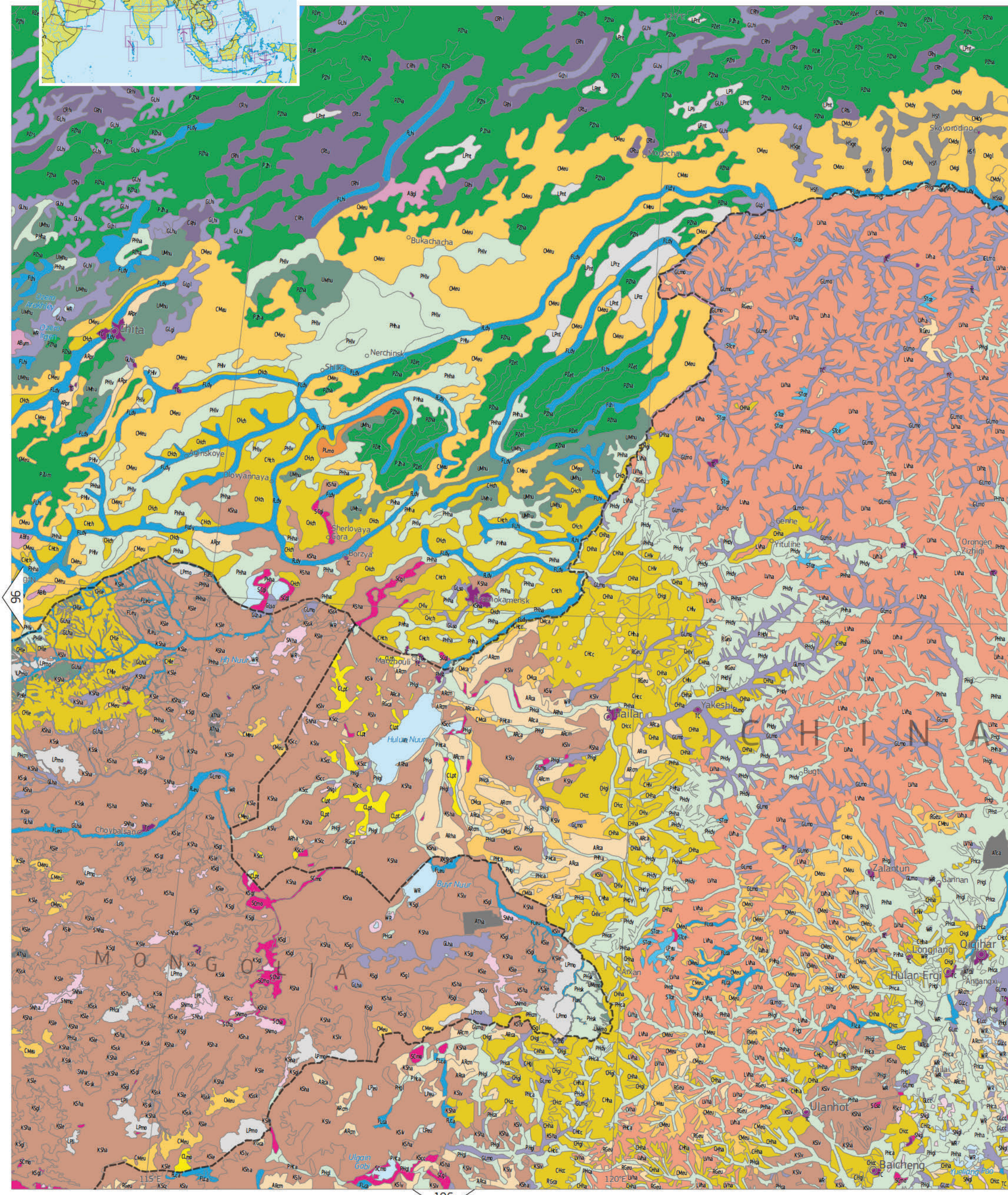
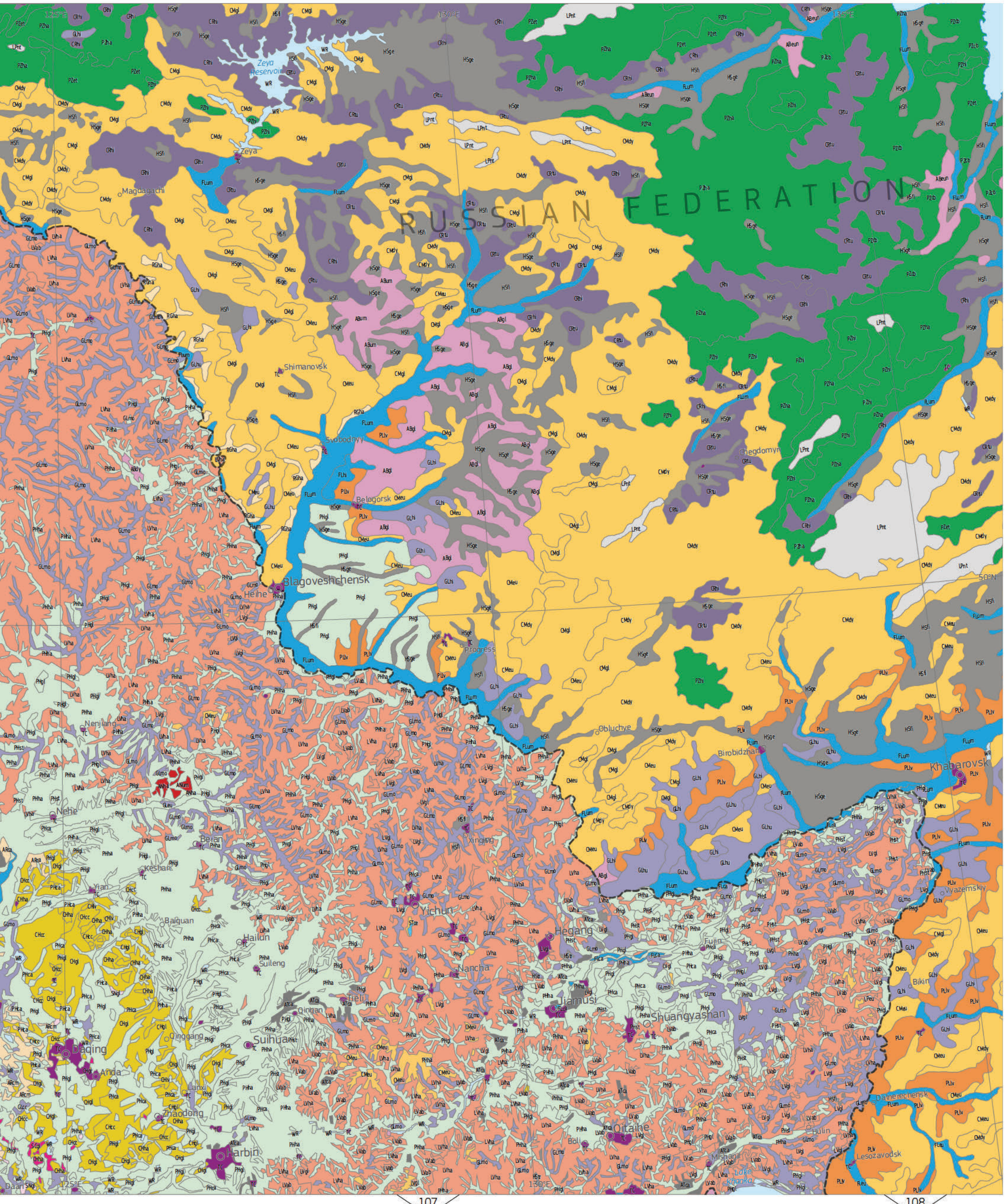
Lake Baikal
Irkutsk
Angarsk
Usolye Sibirskoye
Ust'-Ordynskiy
Slyudyanka
Ulan Ude
Chita
Petrovsk Zabaykalskiy
Khilok
Aginskoye
Ozero Gusinoye
Gusinozyorskiy
Kyakhta
Suchbaatar
Darhan
Erdenet
Bulgan
Dzuunmaraa
ULAANBAATAR
Dzuunmod
Ondorhaan
Baruun Urt
Mandalgovi
Buyant-Uhaa
Ulaan-Uul
CHINA
105°E
110°E
115°E
50°N
45°N
Brotsk Reservoir
Ozero Bolshoye Yeravnoye
Ozero Arukhley
Ozero Irgen
Bolshaya Kharga
Ozero Isinginskoye

Sheet 4 | NE China, E Mongolia, S Russian Federation





See explanatory text on page 88


RUSSIAN FEDERATION
Zeya Reservoir
Zeya
Magdagachi
Shimanovsk
Svobodnyy
Belogorsk
Blagoveshchensk
Heihe
Nenjiang
Nehe
Qiqihar
Keshan
Yian
Baiquan
Hailun
Suileng
Beian
Suihua
Qinggang
Anda
Daqing
Lanxi
Zhaodong
Harbin
Yichun
Xinqing
Tieli
Qingan
Nancha
Hegang
Fujin
Jiamusi
Progress
Obluchye
Birobidzhan
Khabarovsk
Chegdomyn
Shuangyashan
Oitaihe
Boli
Hulin
Lesozavodsk
Dalnerechensk
Vyazemskiy
Bikin
Lake Khanka
130°E
125°E
135°E
50°N
107
108

Sheet 5 | The Caucasus, Caspian Sea, W Turkmenistan, SW Kazakhstan



This map is centred on the Caspian Sea and shows the soils of the Caucasus Mountains and the western regions of Turkmenistan, Kazakhstan and Uzbekistan. The map also covers a small part of the northern part of the Islamic Republic of Iran and northeastern Türkiye.

The Caspian Sea is the world's largest lake. It is a closed basin with no rivers flowing out, which means that it is slightly saline. The Garabogazköl Lagoon on the eastern shore is one of the world's most saline water bodies, with large salt deposits at the southern and eastern shores. The western part of the Aral Sea appears in the upper right corner while a part of the Black Sea can be seen on the left side of the map.

The ridge of the rugged and snow-capped Caucasus Mountains, running from the northern coast of the Black Sea to the Caspian Sea (on the left side of the map) predominantly through Azerbaijan and Georgia, is traditionally regarded as the boundary between Europe and Western Asia. Mount Elbrus, which is in the northern side of the Caucasus, is the highest mountain in Europe! The high peaks of the Greater Caucasus are separated from the Lesser Caucasus by the valleys of the Kura (Mtkvari) and Rioni Rivers that drain to the Caspian and Black Seas, respectively. The rivers are separated by the Likhi Range, which connects the Greater Caucasus and Lesser Caucasus mountains and is the watershed of the Black and Caspian seas basins. The Armenian Plateau extends westwards into Türkiye, where it merges with the Anatolian Plateau. Lake Sevan sits in an enclosed upland basin in Armenia, where many of the high peaks are volcanic in origin (e.g. Mount Aragats).

The climate of the area shown by the map is extremely diverse. The Greater Caucasus Mountains block the passage of colder air masses from the north while the Lesser Caucasus Mountains partially inhibit the movement of dry, hot air coming from the south. These factors give rise to a more humid subtropical climate in southwest Georgia and southeastern Azerbaijan. However, most of this side of the map has a humid subtropical climate with annual precipitation ranging from 1 000–2 500 mm. Towards the Caspian Sea, winters are slightly cooler and drier while summers are warmer. Towards the southwest and into Türkiye, annual precipitation levels fall. Climatic conditions vary markedly with elevation where cooler and more humid summers and heavy snow falls in winter are more normal, especially in the Greater Caucuses.

To the east of the Caspian Sea, the climate is much more arid and continental in nature, with moderately cold winters and hot summers. Average temperatures in January are low but can reach over 35 °C during the summer months. Average annual precipitation is less than 200 mm, occurring mostly in winter.

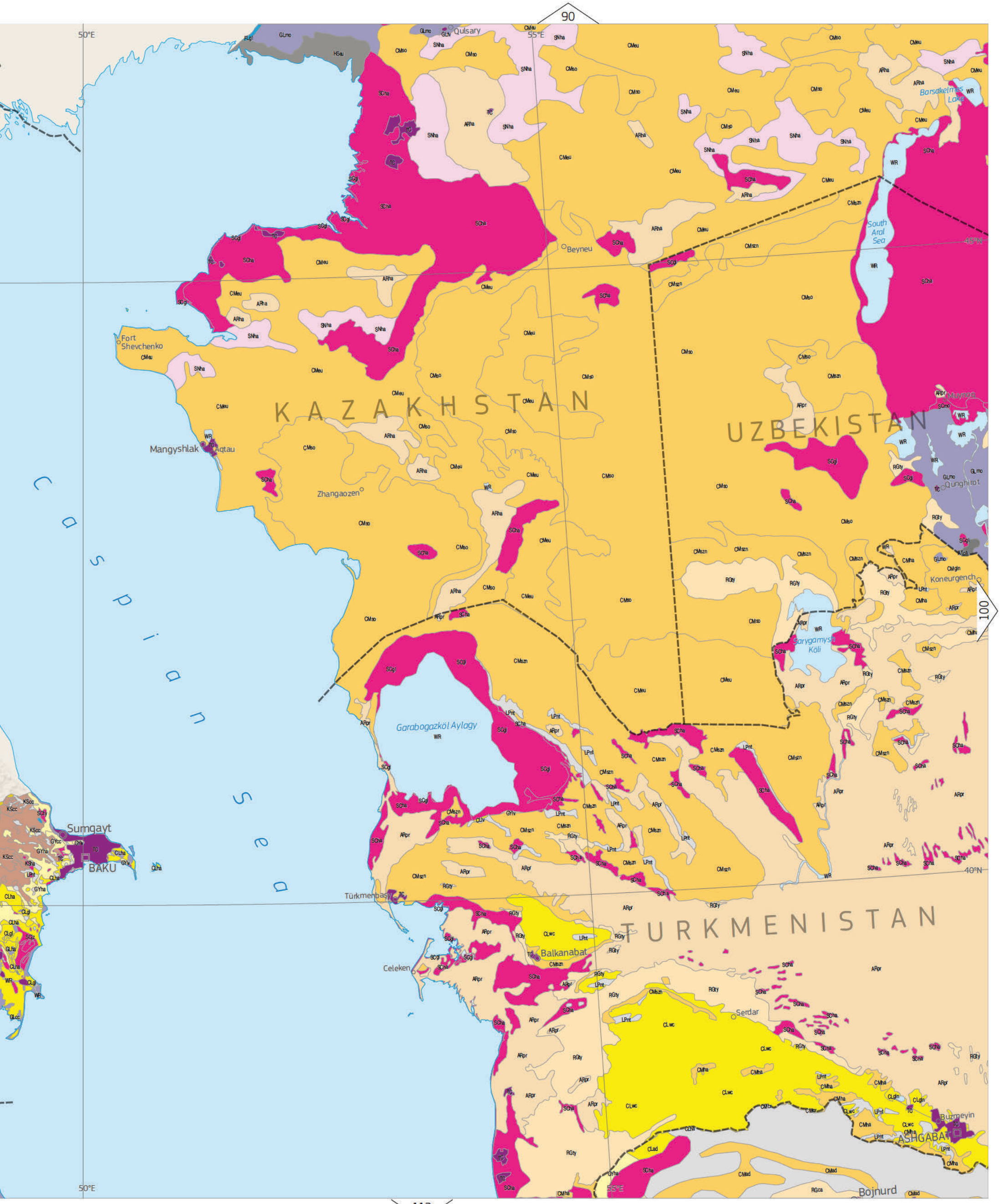
Matching the climatic divides, the soils also fall into two broad groups. On the left side of the map, the Greater Caucuses are denoted by a mixture of Leptosols, Cambisols and Regosols on higher elevations. On lower slopes, Luvisols are more evident reflecting more pedogenic development, with Kastanozems and Chernozems extensive on wooded slopes of valleys and ridges, as well as high grassland plains. Andosols and black Vertisols reflect soil development and weathering of volcanic parent materials.

Fluvisols and Gleysols denote the main floodplains of the Rioni and Kura-Aras Lowlands, although in the latter, Calcisols are widespread with occasional pockets of Solonchaks highlighting higher evaporation rates by the Caspian Sea. Acrisols along the Black Sea coast indicate intense chemical weathering and leaching, possibly reflecting past climatic conditions. Most of the plateau land in Türkiye is covered by extensive Calcisols, with Leptosols and Cambisols denoting hills and mountains (e.g the Pontic Mountains along the Black Sea coast of Türkiye).

To the east of the Caspian Sea, the large extent of Arenosols in Turkmenistan marks the Karakum Desert while the Gleysols to the south of the Aral Sea correspond to the floodplains of the Amu Darya River.

The map clearly shows that much of the area is affect by high salinity levels (especially around the Aral Sea and central Kazakhstan). Solonetz are clay-rich soils characterised by an accumulation of sodium salts below the surface horizon that develop in arid climates in parent materials that are either naturally enriched in sodium minerals or are influenced by saline waters (often groundwater). In contrast, Solonchaks are defined by a high accumulation of soluble salts and the absence of any distinct subsurface horizons. Solonchaks are formed through the evaporation of saline water bodies, usually in closed drainage basins. Due to the huge loss of water, the eastern basin of the Aral Sea is now called the Aralkum Desert, which is characterised by extensive Solonchaks.

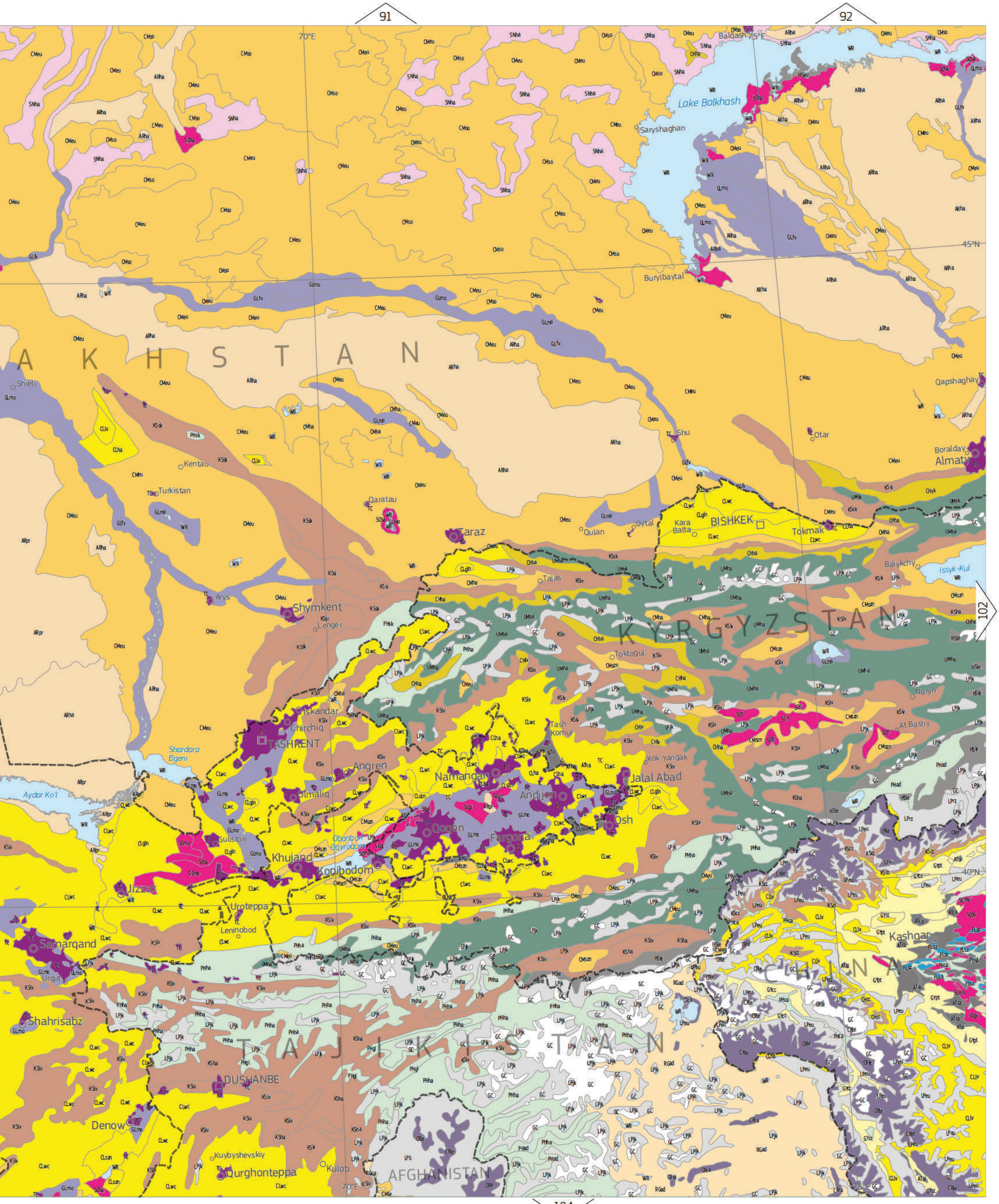
The broad band of Leptosols in the lower left corner of the map reflect immense volcanic activity (e.g. the stratovolcanoes of Sabalan in the Islamic Republic of Iran, Mount Süphan and Mount Nemrut in Türkiye) that is linked to tectonic activity around the Maras Triple Junction. This site, located to the west of Lake Van in Türkiye, marks the junction of the Anatolian, Eurasian and the Arabian Plate boundaries.


90
50°E
55°E
112
100
45°N
40°N
Qulsary
Beyneu
Fort Shevchenko
Mangyshlak
Aqtau
Zhangaozen
Sumgayt
BAKU
Türkmenbashy
Celeken
Balkanabat
Garabogazköl Aylagy
Barsakelmes Lake
South Aral Sea
Sarygamysh Köli
Koneurgench
Qunghirot
Muynoq
Serdar
Buzmeyin
ASHGABAT
Bojnurd
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
Caspian Sea

Sheet 6 | S Kazakhstan, Uzbekistan, Tajikistan, W Kyrgyzstan



See explanatory text on page 88


91
92
102
104
70°E
75°E
45°N
40°N
KAZAKHSTAN
KYRGYZSTAN
TAJIKISTAN
AFGHANISTAN
Lake Balkhash
Balqash
Saryshaghan
Burylbaytal
Shieli
Kentau
Turkistan
Qaratau
Taraz
Qulan
Oytal
Shu
Otar
Qapshaghay
Boralday
Almaty
BISHKEK
Kara Balta
Tokmak
Balykchy
Issyk-Kul
Naryn
At Bashy
Kok Yangak
Jalal Abad
Osh
Fargona
Andijon
Namangan
Angren
Tash Komur
Toktogul
Talas
Arys
Shymkent
Lenger
Iskandar
Chirchiq
TASHKENT
Shardara Bgeni
Aydar Ko'l
Guliston
Khujand
Konibodom
Oboribori Qayroqum
Jizzax
Uroteppa
Leninobod
Samarqand
Urgut
Shahrisabz
DUSHANBE
Denow
Kuybyshevskiy
Qurghonteppa
Kulob
Arys
Kashgar

Sheet 7 | W China (Xinjiang), SE Kazakhstan, E Kyrgyzstan



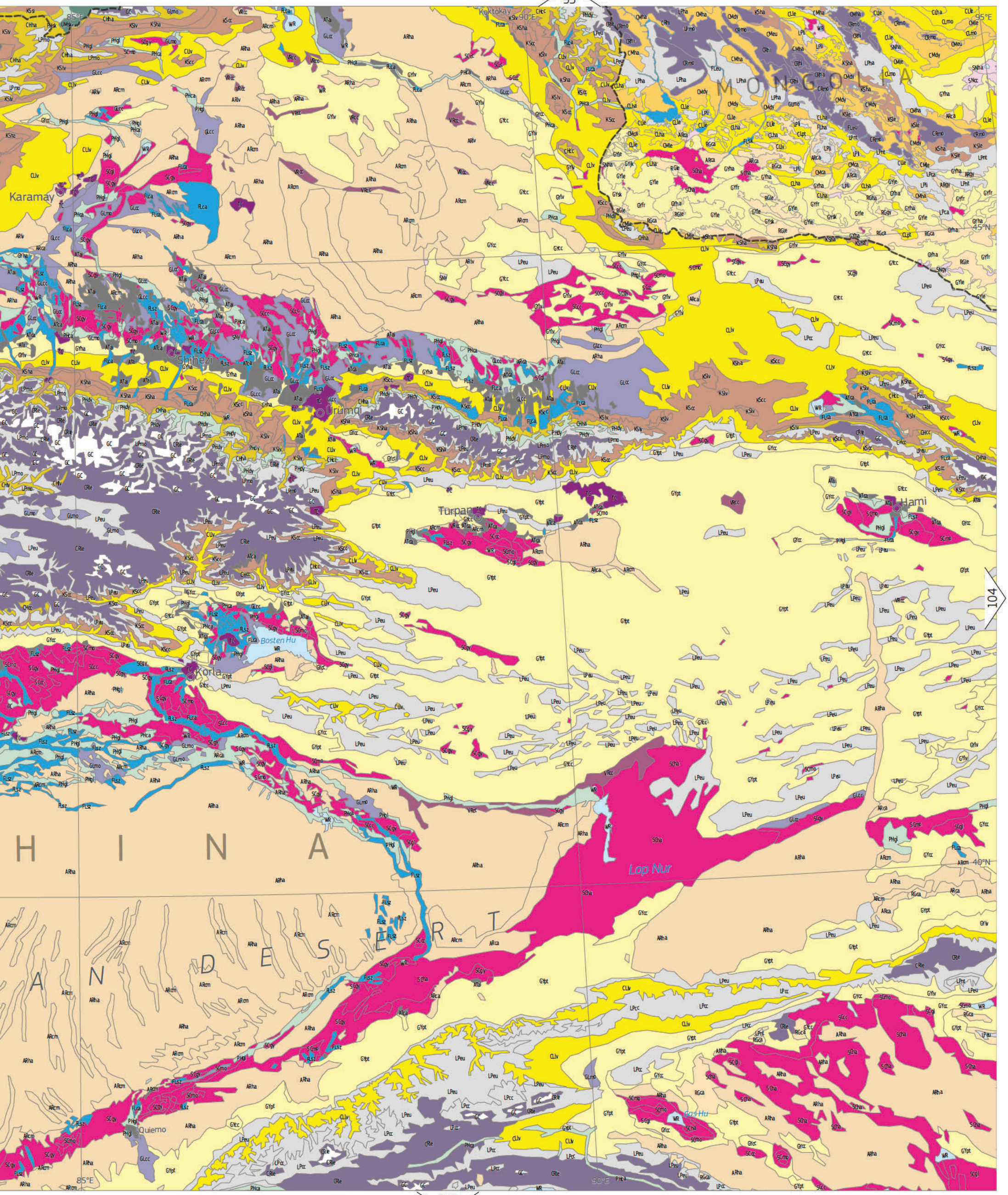
92

101

115

116

See explanatory text on page 88


93
104
117
85°E
90°E
95°E
45°N
40°N
Karamay
Shihezi
Urumqi
Turpan
Hami
Korla
Bosten Hu
Lop Nur
Qaidam Pendi
Qaidam Pendi
MONGOLIA
CHINA
TAKLIMAKAN DESERT

Sheet 8 | S Mongolia (Gobi Desert), N China (Gansu, W Inner Mongolia)

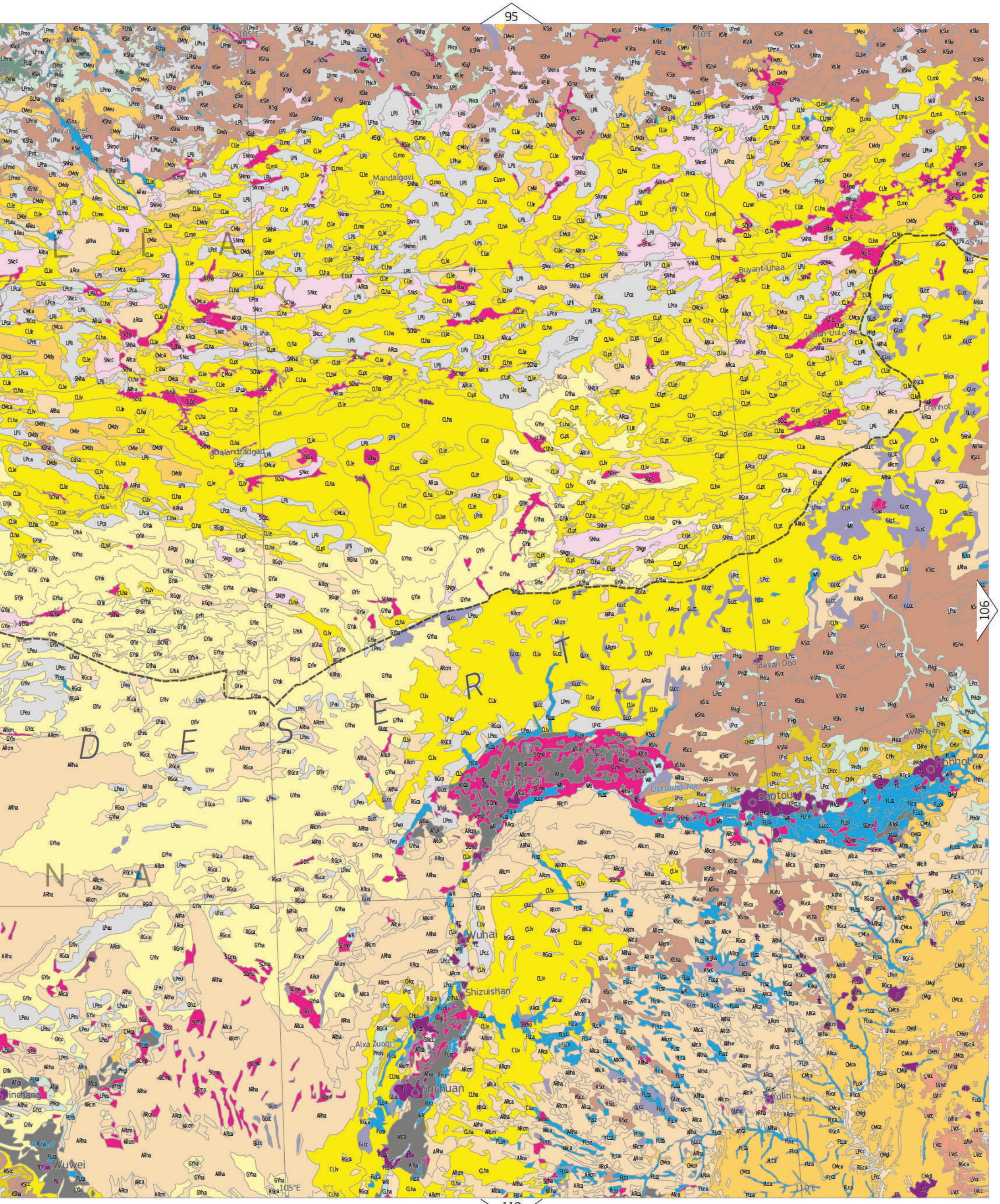


94

103

118

See explanatory text on page 88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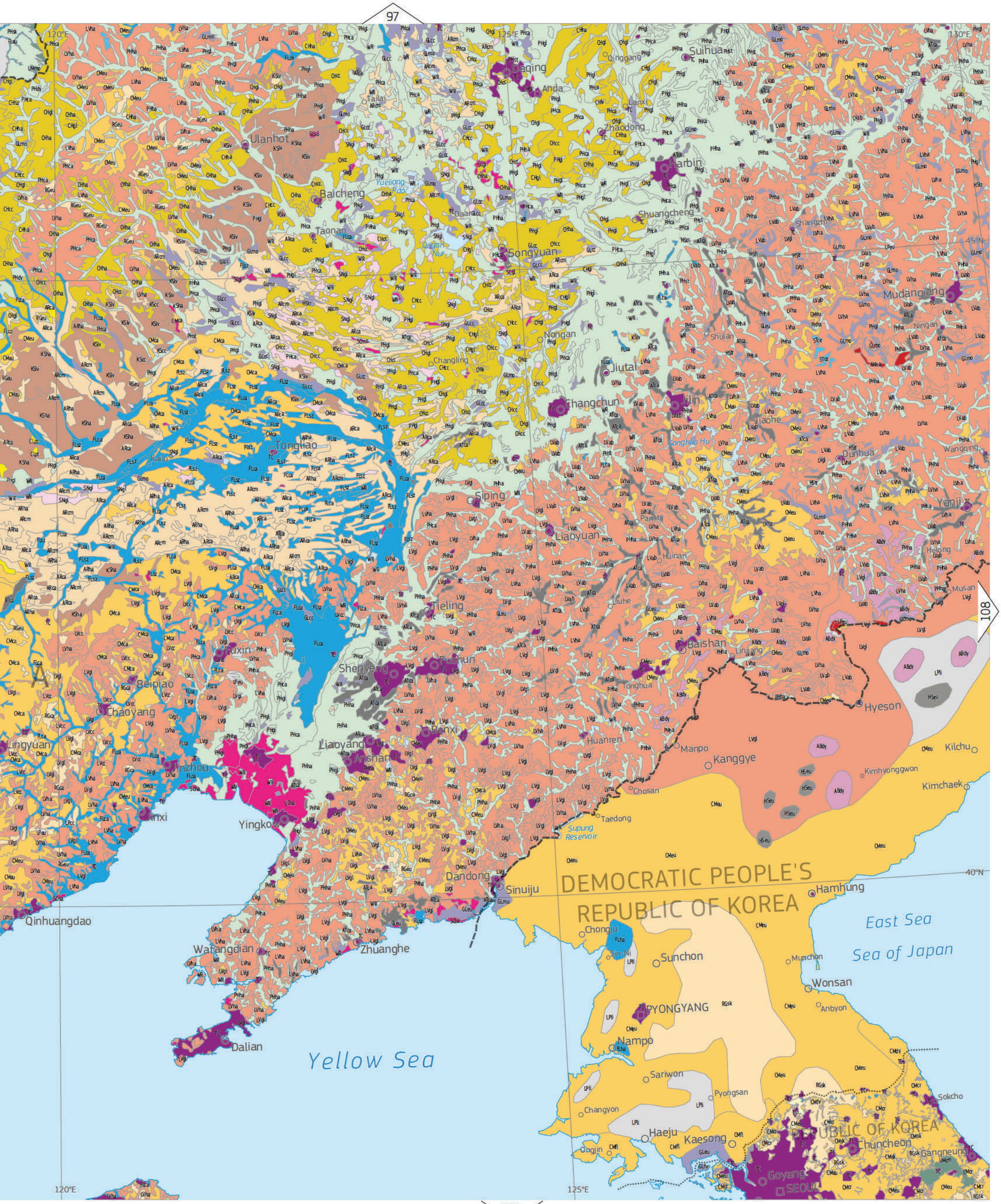
106
119
105°E
110°E
45°N
40°N
Aryayheer
Mandalgovi
Dalandzadgad
Buyant-Uhaa
Ulaan-Uul
Erenhot
Bayan Obo
Baotou
Hohhot
Wuchuan
Ulansuhai Nur
Hangin Houqi
Wuyuan
Wuhai
Shizuishan
Yinchuan
Alxa Zuoqi
Yulin
Qinchang
Wuwei
DESERT
NA

Sheet 9 | NE China (E Inner Mongolia, Liaoning, Jilin), Democratic People's Republic of Korea



See explanatory text on page 89


97
108
121
120°E
125°E
130°E
45°N
40°N
Ulanhot
Baicheng
Taonan
Tailai
Daqing
Anda
Qinggang
Suihua
Zhaodong
Lanxi
Harbin
Shuangcheng
Shangzhi
Mudanjiang
Ningan
Shulan
Nongan
Changling
Songyuan
Fuyu
Qagan Nur
Yueliang Pao
Daan
Jiutai
Changchun
Jilin
Jiaohe
Dunhua
Wangqing
Yanji
Helong
Musan
Tongliao
Kailu
Siping
Liaoyuan
Panshi
Huinan
Liuhe
Tieling
Fuxin
Shenyang
Fushun
Baishan
Linjiang
Tonghua
Hyeson
Beipiao
Chaoyang
Benxi
Huanren
Manpo
Kanggye
Kimhyonggwon
Kilchu
Kimchaek
Lingyuan
Jinzhou
Liaoyang
Anshan
Yingkou
Jinxi
Chosan
Taedong
Supung Reservoir
Dandong
Sinuiju
Qinhuangdao
Wafangdian
Zhuanghe
Dalian
Yellow Sea
DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
Chongju
Sin-Ni
Sunchon
PYONGYANG
Nampo
Sariwon
Pyongsan
Changyon
Haeju
Kaesong
Onjin
Munchon
Wonsan
Anbyon
Hamhung
East Sea
Sea of Japan
REPUBLIC OF KOREA
Chuncheon
Gangneung
Goyang
SEOUL
Sokcho



This map is centered on the northern part of the East Sea and shows the soils along the northeastern coast of the Korean peninsula, the eastern part of the Jilin and Heilongjiang Provinces in northeastern China, the Primorsky Krai Region of the Russian Federation, together with Hokkaidō and the northern part of Honshu Islands of Japan.

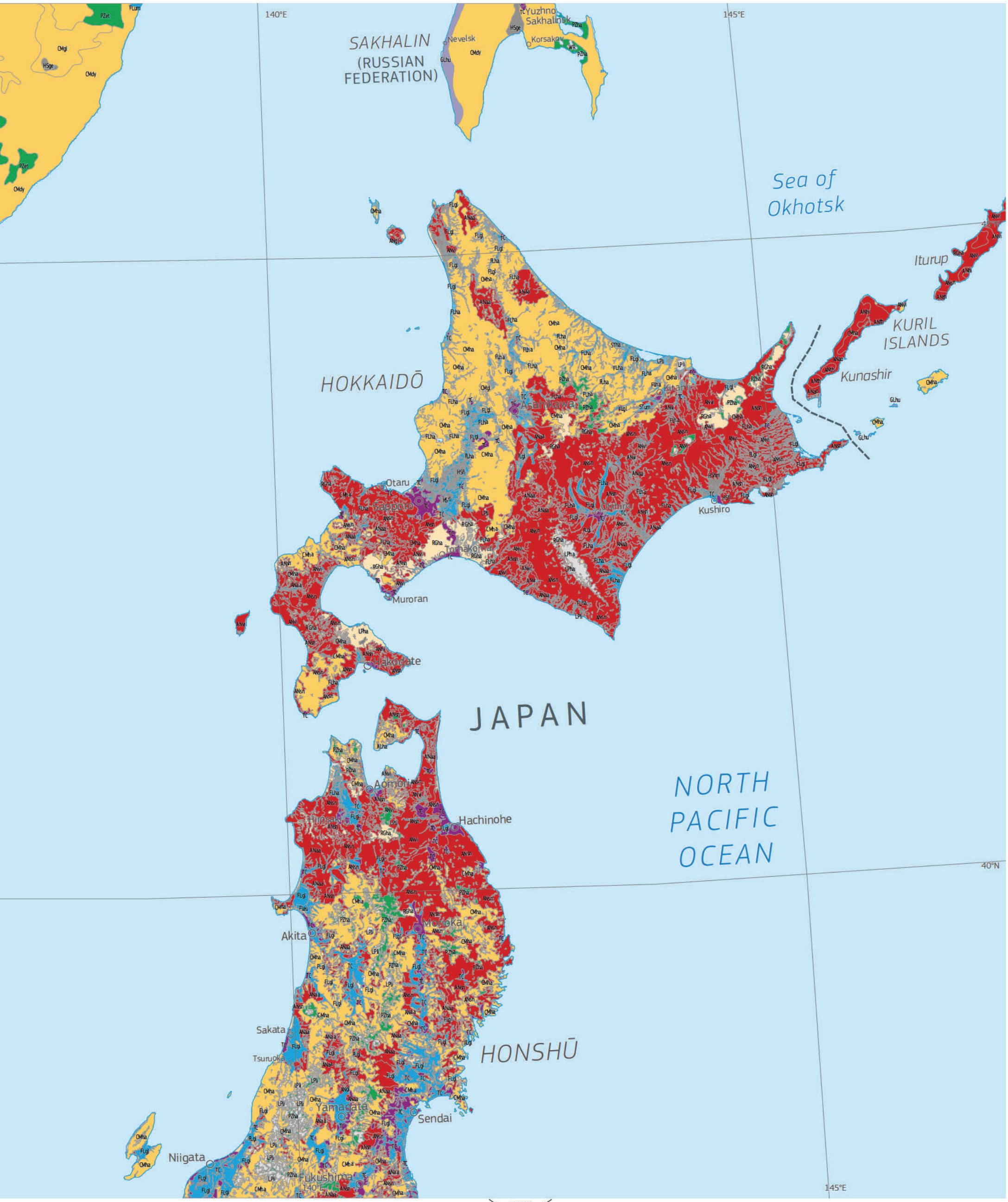
Much of the map reflects mountainous terrain. Several peaks of the Changbai Mountains, which run along the border with the Democratic People's Republic of Korea and China, exceed 2000m a.s.l. Towards the north, the densely forested Sikhote-Alin mountains follows the Russian coastline as a series of parallel ridges separated by narrow and deep valleys, before dropping to the lowlands of the Amur Valley. Towards the northwest, elevation drops to around 150m on the flat and low-lying Songnen Plain. The main national borders in the region are denoted by rivers - the Yalu and Tumen Rivers between China and the Democratic People's Republic of Korea while to the east, the Amur forms the border between the Russian Federation and northeastern China. With a length of more than 4 400km, the Amur is the tenth longest river in the world and drains much of the continental area covered by the map before emptying to the sea near the city of Vladivostok.

Both the islands of Hokkaidō and Honshu are mountainous with active volcanic peaks rising above a series of plateaus and ridges. With an elevation of 3776m a.s.l., the volcanic peak of Mount Fuji (just off the map) makes Honshu the world's 7th highest island. On both islands, extensive alluvial plains are cut by numerous short rivers and streams. The Kushiro Plain on Hokkaido is the largest wetland in Japan.

Much of the mainland tends to have a continental monsoon climate with long, cold winters and short, warm summers. Average January temperatures can be well below freezing, especially at higher elevations (Harbin is known as the Ice City, where temperatures around –15°C are the norm in winter). Summers along coasts are moderated by the sea to give higher temperatures. Precipitation is higher in the summer and autumn, with annual averages around 1500mm in the mountains of the Democratic People's Republic of Korea but decreasing eastwards to about one third. Over the Japanese Islands, the climate is generally humid continental with cool summers and cold winters. Hokkaido's annual mean temperature is around 10°C. With temperatures rising towards the south. Precipitation is constant throughout the year while heavy snow is common on the western side of Hokkaido in winter.

The soil patterns reflect a continuation of conditions on the east side of Plate 9. Increased precipitation on the Changbai Mountains gives rise to leached Cambisols while Luvisols are more widespread where the terrain is less steep. The high clay content surrounding Lake Khanka on the border between the Russian Federation and China gives rise to waterlogged conditions and the development of Planosols, Gleysols and Stagnosols under grasslands. The forested Sikhote-Alin mountains are characterised by Cambisols and Podzols under conifer and mixed forests where leaching is more pronounced. Phaeozems are the dominant soils of the lowland plains of the steppe region.

In contrast, the islands of Japan are characterised by large expanses of Andosols, reflecting the widespread volcanic activity that makes up the Pacific Ring of Fire. The mountainous cores of the islands are denoted by Andosols, which eventually grade to Cambisols on broad and gently sloping coastal plains. The large expanse of Gleysols on the western part of Hokkaidō denotes the wetlands and peat bogs of the Kushiro-Shitsugen National Park. Podzols are common locally, reflecting the high levels of precipitation that leads to the leaching of iron oxides and organic matter on sloping ground under conifer forests. Fluvisols denote the main river valleys and estuaries.


140°E
145°E
SAKHALIN
(RUSSIAN
FEDERATION)
Yuzhno
Sakhalinsk
Nevelsk
Korsakov
Sea of
Okhotsk
Iturup
KURIL
ISLANDS
Kunashir
HOKKAIDŌ
Asahikawa
Kitami
Otaru
Sapporo
Obihiro
Kushiro
Tomakomai
Muroran
Hakodate
JAPAN
NORTH
PACIFIC
OCEAN
40°N
Aomori
Hirosaki
Hachinohe
Akita
Morioka
Sakata
Tsuruoka
HONSHŪ
Yamagata
Sendai
Niigata
Fukushima
140°E
145°E

123

Sheet 11 | Eastern Mediterranean region of Western Asia, Iraq, Kuwait

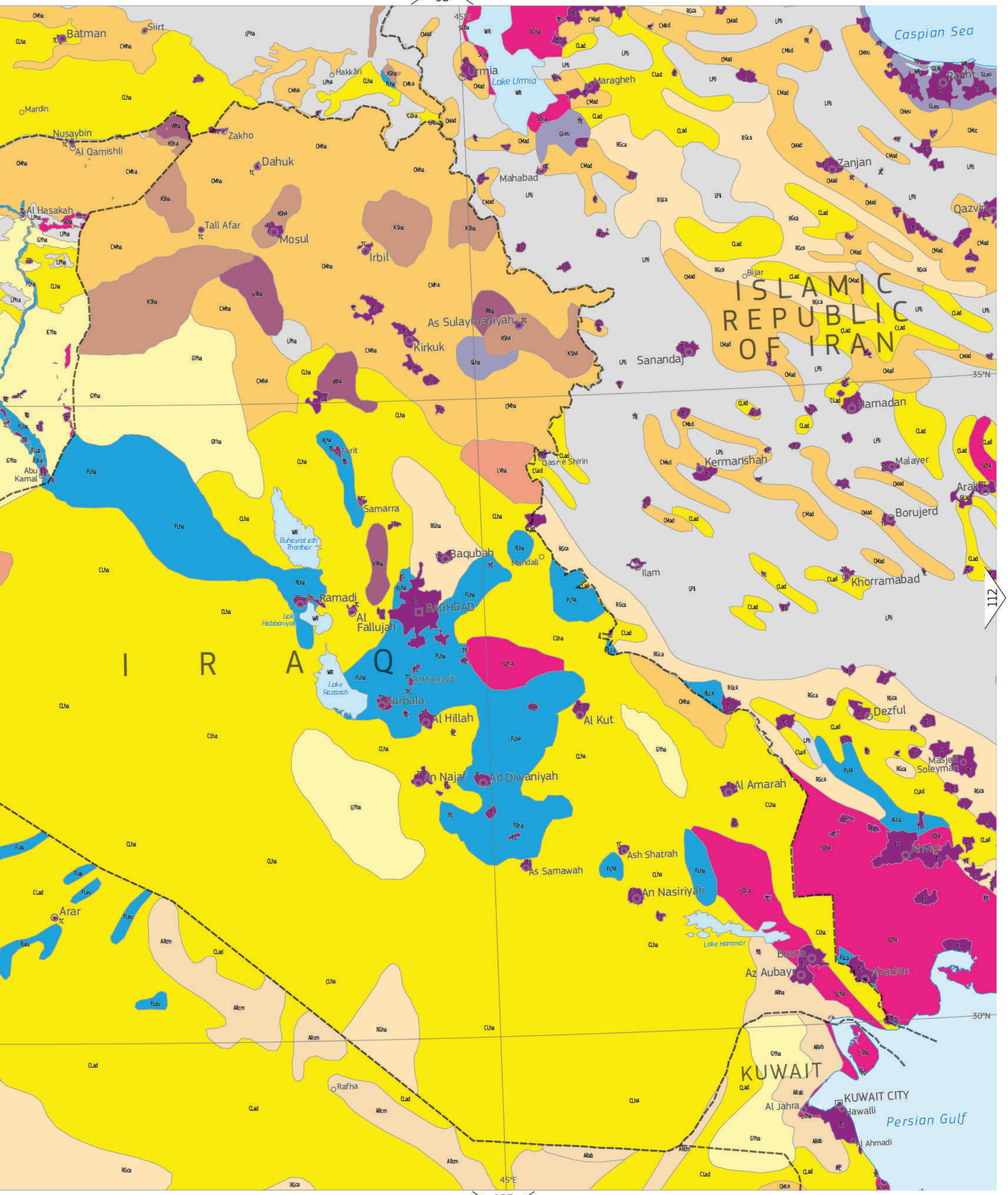


See explanatory text on page 89

98

112

125


Batman
Siirt
Mardin
Nusaybin
Al Qamishli
Zakho
Dahuk
Al Hasakah
Tall Afar
Mosul
Irbil
Kirkuk
As Sulaymaniyah
Hakkâri
Urmia
Lake Urmia
Caspian Sea
Maragheh
Rasht
Zanjan
Mahabad
Qazvin
Bijar
Sanandaj
ISLAMIC REPUBLIC OF IRAN
Hamadan
Kermanshah
Malayer
Arak
Borujerd
Qasr-e Shirin
Ilam
Khorramabad
Dezful
Masjed Soleyman
Ahvaz
Abu Kamal
Tikrit
Samarra
Buhayrat ath Tharthar
Baqubah
Mandali
Ramadi
Lake Habbaniyah
Al Fallujah
BAGHDAD
Al Musayyib
Karbala
Al Hillah
An Najaf
Ad Diwaniyah
Al Kut
Al Amarah
Ash Shatrah
As Samawah
An Nasiriyah
Lake Hammar
Basra
Az Aubayr
Abadan
Arar
Rafha
KUWAIT
KUWAIT CITY
Hawalli
Al Jahra
Al Ahmadi
Persian Gulf
I R A Q
45°E
35°N
30°N

Sheet 12 | Islamic Republic of Iran, W Afghanistan



99

111

126

See explanatory text on page 89

100

114

127

TURKMENISTAN

OF IRAN

AFGHANISTAN

PAKISTAN

ASHGABAT

Buzmeyin

Bojnurd

Quchan

Kaka

Tejen

Mary

Atamyrat

Andkhvoy

Meymaneh

Sabzewar

Neyshabur

Mashhad

Torbat-e Jam

Kashmar

Birjand

Qala i Naw

Chaghcharan

Karokh

Herat

Farah

Yazdan

Lashkar Gah

Zaranj

Zabol

Kerman

Zahedan

Bam

60°E

65°E

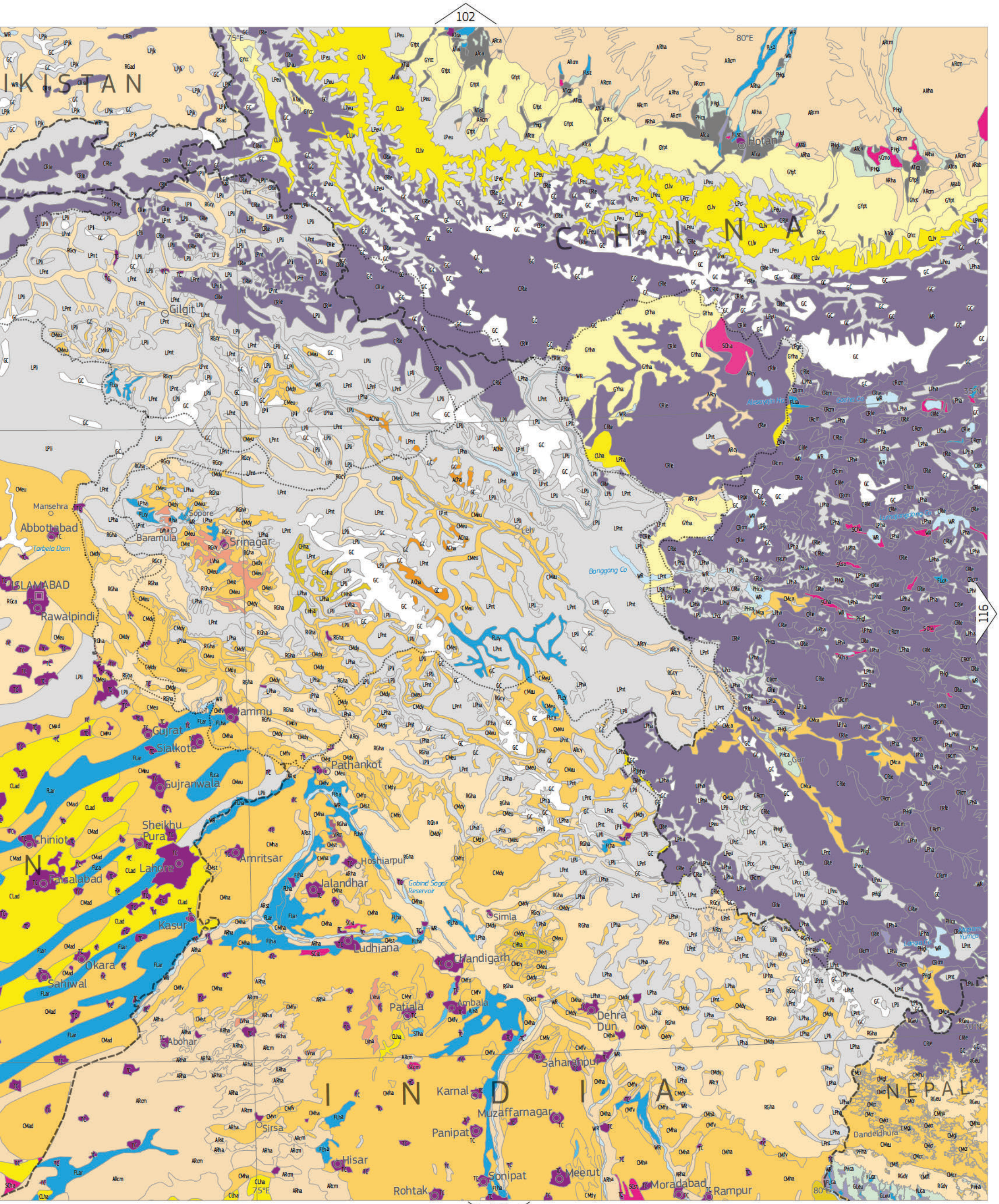
35°N

30°N

Sheet 13 | E Afghanistan, N Pakistan, S Tajikistan

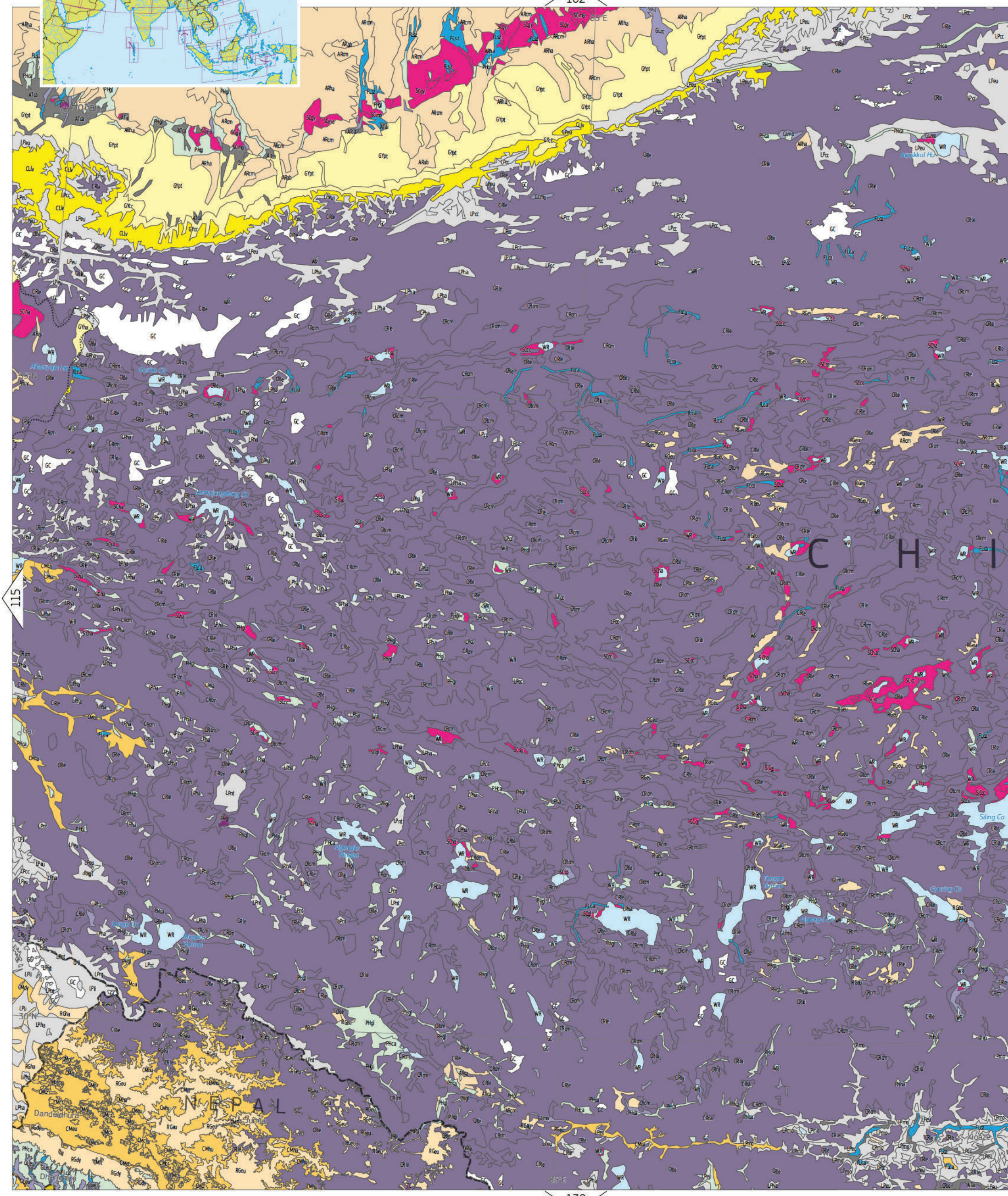


See explanatory text on page 89

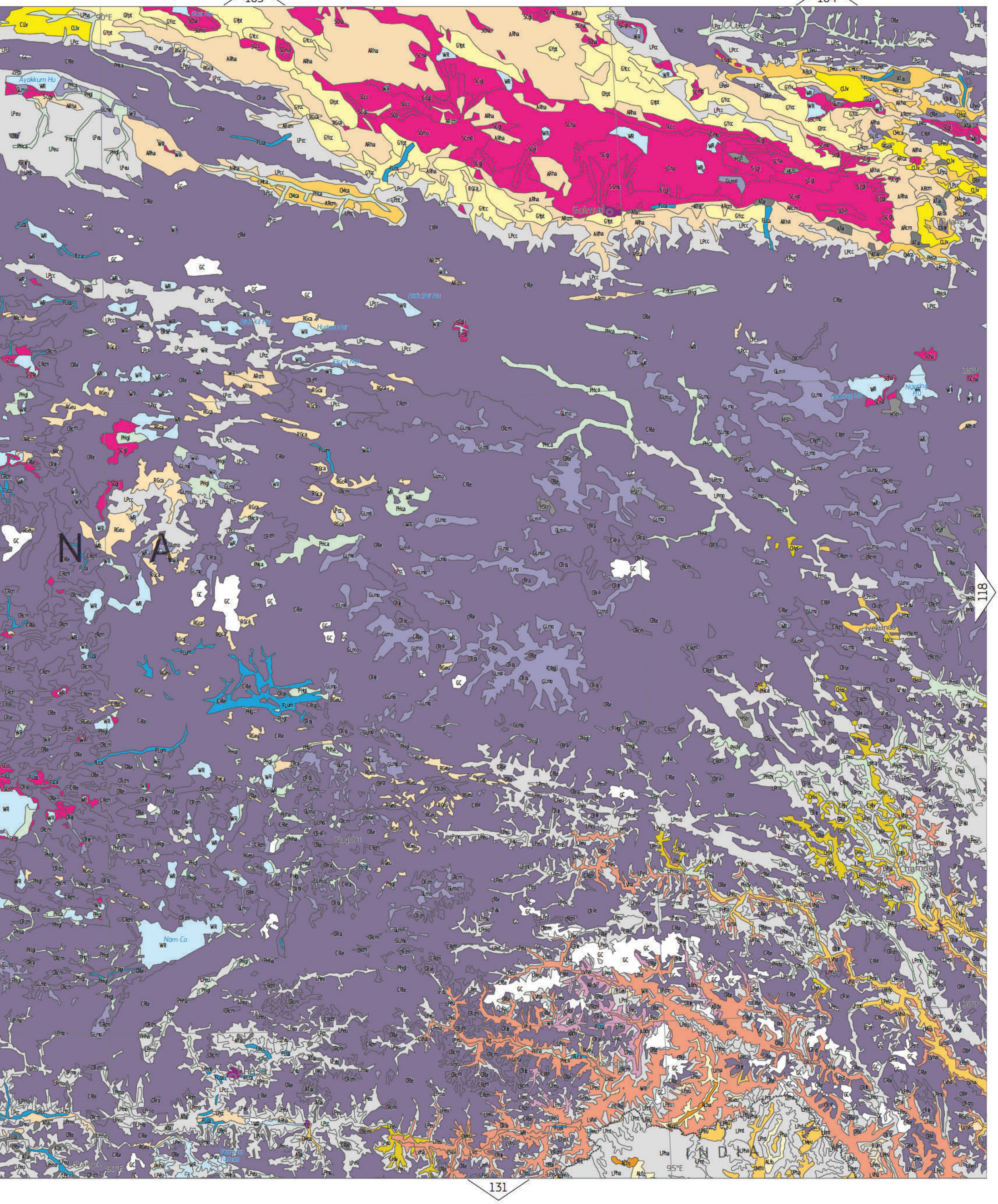

102
116
129
75°E
80°E
35°N
30°N
C H I N A
I N D I A
N E P A L
Gilgit
Hotan
Leh
Srinagar
Jammu
Mansehra
Abbottabad
Baramula
Tarbela Dam
ISLAMABAD
Rawalpindi
Sopore
Gujrat
Sialkot
Gujranwala
Chiniot
Sheikhu Pura
Amritsar
Lahore
Faisalabad
Kasur
Okara
Sahiwal
Hoshiarpur
Jalandhar
Ludhiana
Patiala
Abohar
Sirsa
Hisar
Rohtak
Karnal
Panipat
Sonipat
Pathankot
Gobind Sagar Reservoir
Chandigarh
Ambala
Simla
Saharanpur
Muzaffarnagar
Meerut
Dehra Dun
Moradabad
Rampur
Dandeldhura
Gar
Banggong Co
Alesaygin Hu
Gozha Co
Lumajangdong Co
Longmu Co
Zhuqen Yumco
Tarbela Dam

Sheet 14 | W China (Tibet)





See explanatory text on page 89


90°E
95°E
35°N
30°N
Ayakkum Hu
Gas Hu
Golmud
Hoh Sai Hu
Hoh Xil Hu
Hutent Nur
Eisen Nur
Nagchu
Nam Co
Lhasa
Qamdo
Yushu
Chamdo
Nyingchi
Yekundo
Qyangze
Yamdrok Tso
Ngoring Hu
Gyaring Hu
N E P A L
I N D I A
118
131

Sheet 15 | Central China

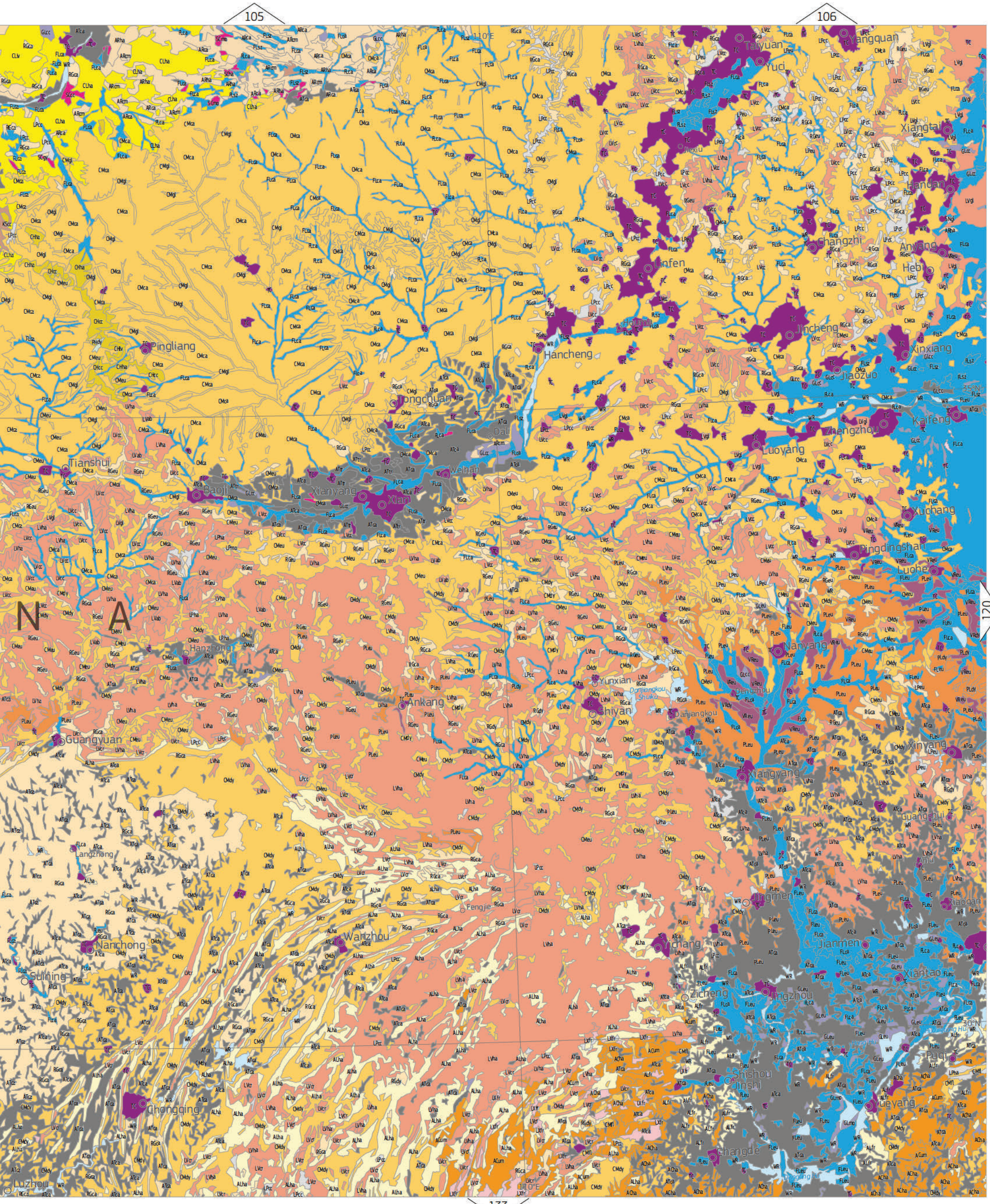


104

117

132

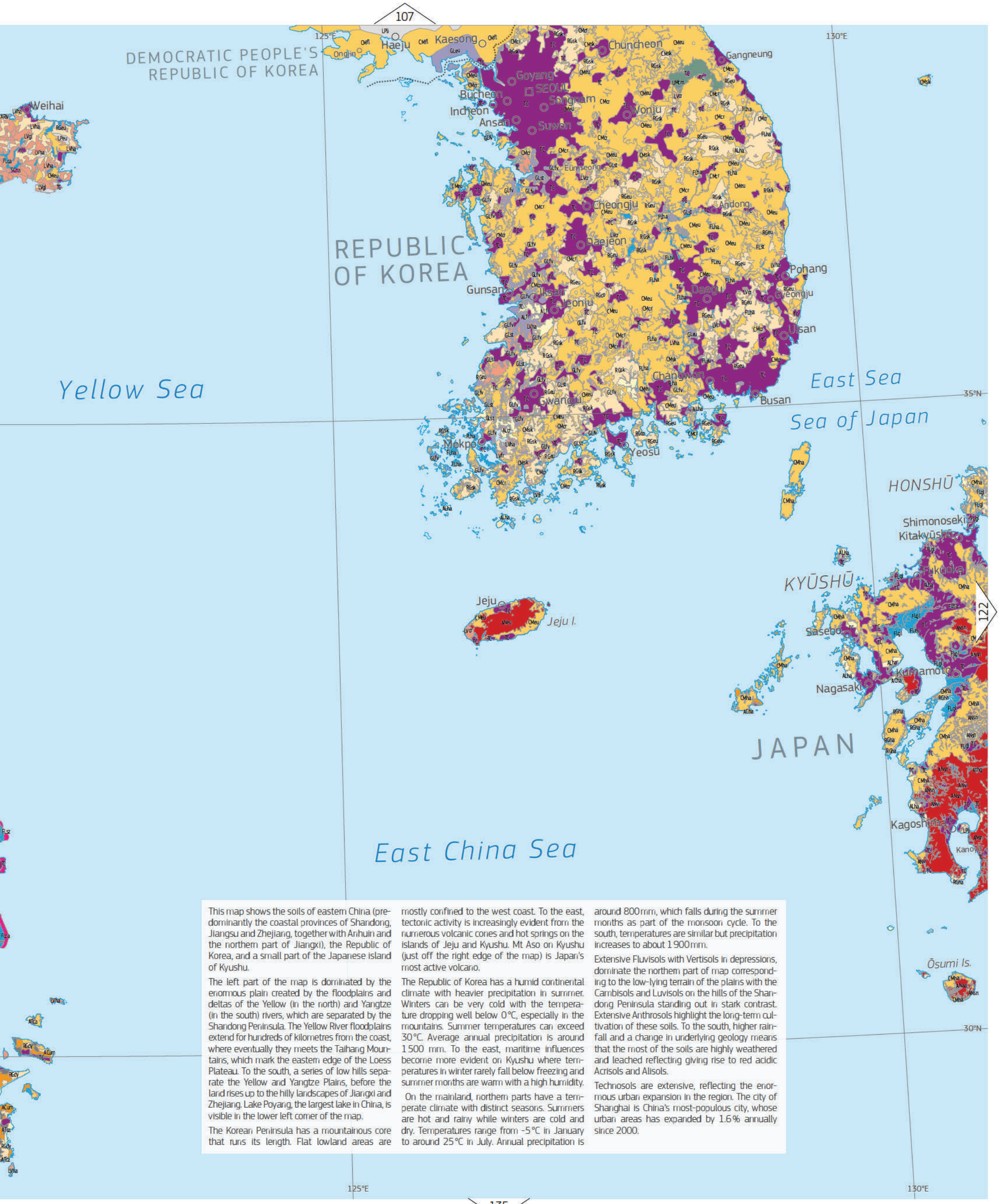
See explanatory text on page 89


105
106
110°E
35°N
30°N
120
133
N A
Taiyuan
Yuci
Jiexiu
Yangquan
Xiangtai
Handan
Changzhi
Anyang
Hebi
Linfen
Jincheng
Xinxiang
Jiaozuo
Hancheng
Houma
Kaifeng
Zhengzhou
Luoyang
Xuchang
Pingdingshan
Luohe
Nanyang
Xinyang
Xiangyang
Guangshui
Suizhou
Jingmen
Xiaogan
Jianmen
Xiantao
Jingzhou
Yueyang
Changde
Yichang
Zicheng
Shishou
Jinshi
Pingliang
Tianshui
Baoji
Xianyang
Xian
Tongchuan
Weinan
Dali
Hanzhong
Ankang
Yunxian
Shiyan
Danjiangkou
Dengzhou
Guangyuan
Nanchong
Suining
Chongqing
Luzhou
Langzhong
Wanzhou
Fengjie
Qijiang

Sheet 16 | E China, Republic of Korea



106
134
119
115°E
120°E
35°N
30°N
Bo Hai
CHINA
Hengshui
Dezhou
Binzhou
Yantai
Nangong
Xiangtai
Handan
Liaocheng
Jinan
Zibo
Weifang
Laiyang
Pingdu
Changzhi
Anyang
Hebi
Taian
Laiwu
Zhucheng
Qingdao
Jincheng
Puyang
Jining
Linyi
Rizhao
Jiaozuo
Xinxiang
Heze
Zaozhuang
Lianyungang
Zhengzhou
Kaifeng
Shangqiu
Xuzhou
Xinyi
Shuyang
Xuchang
Huaibei
Pingdingshan
Luohe
Zhoukou
Suzhou
Huaiyin
Yancheng
Jieshou
Fuyang
Bengbu
Huainan
Yangzhou
Taizhou
Xinyang
Guangshui
Hefei
Luan
Maanshan
Changzhou
Wuxi
Nantong
Yangtze River
Taihu
Suzhou
Shanghai
Macheng
Wuhu
Tongling
Xuanzhou
Huzhou
Jiaxing
Jianmen
Wuhan
Xiantao
Anqing
Huangshi
Hangzhou
Fuyang
Shaoxing
Ningbo
Puqi
Jiujiang
Yueyang
Jingdezhen
Jinhua
Quzhou



This map shows the soils of eastern China (predominantly the coastal provinces of Shandong, Jiangsu and Zhejiang, together with Anhuin and the northern part of Jiangxi), the Republic of Korea, and a small part of the Japanese island of Kyushu.

The left part of the map is dominated by the enormous plain created by the floodplains and deltas of the Yellow (in the north) and Yangtze (in the south) rivers, which are separated by the Shandong Peninsula. The Yellow River floodplains extend for hundreds of kilometres from the coast, where eventually they meets the Taihang Mountains, which mark the eastern edge of the Loess Plateau. To the south, a series of low hills separate the Yellow and Yangtze Plains, before the land rises up to the hilly landscapes of Jiangxi and Zhejiang. Lake Poyang, the largest lake in China, is visible in the lower left corner of the map.

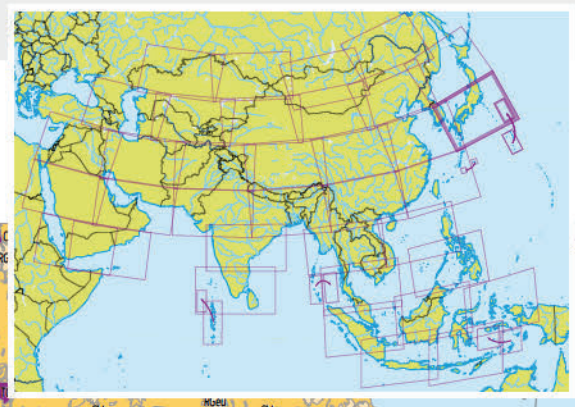
The Korean Peninsula has a mountainous core that runs its length. Flat lowland areas are mostly confined to the west coast. To the east, tectonic activity is increasingly evident from the numerous volcanic cones and hot springs on the islands of Jeju and Kyushu. Mt Aso on Kyushu (just off the right edge of the map) is Japan's most active volcano.

The Republic of Korea has a humid continental climate with heavier precipitation in summer. Winters can be very cold with the temperature dropping well below 0 °C, especially in the mountains. Summer temperatures can exceed 30 °C. Average annual precipitation is around 1 500 mm. To the east, maritime influences become more evident on Kyushu where temperatures in winter rarely fall below freezing and summer months are warm with a high humidity.

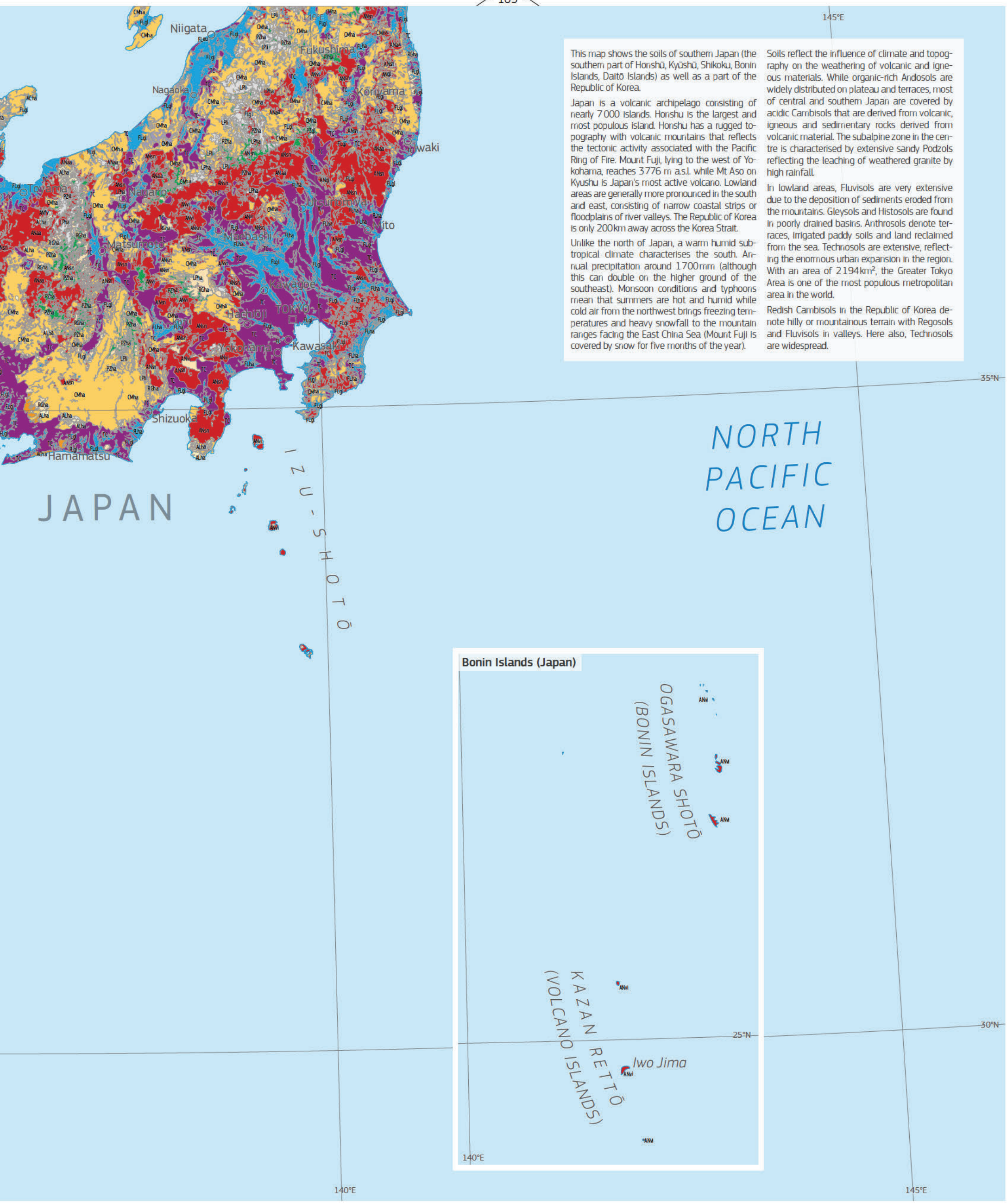
On the mainland, northern parts have a temperate climate with distinct seasons. Summers are hot and rainy while winters are cold and dry. Temperatures range from -5 °C in January to around 25 °C in July. Annual precipitation is around 800 mm, which falls during the summer months as part of the monsoon cycle. To the south, temperatures are similar but precipitation increases to about 1 900 mm.

Extensive Fluvisols with Vertisols in depressions, dominate the northern part of map corresponding to the low-lying terrain of the plains with the Cambisols and Luvisols on the hills of the Shandong Peninsula standing out in stark contrast. Extensive Anthrosols highlight the long-term cultivation of these soils. To the south, higher rainfall and a change in underlying geology means that the most of the soils are highly weathered and leached reflecting giving rise to red acidic Acrisols and Alisols.

Technosols are extensive, reflecting the enormous urban expansion in the region. The city of Shanghai is China's most-populous city, whose urban areas has expanded by 1.6 % annually since 2000.



108
135°E
East Sea
Sea of Japan
Oki Is.
HONSHŪ
Takaoka
Kanazawa
Fukui
Matsue
Tottori
Maizuru
Kyoto
Ōtsu
Nagoya
Gifu
Tsu
Ōsaka
Kōbe
Okayama
Takamatsu
Wakayama
Tokushima
Kochi
SHIKOKU
Hiroshima
Kure
Inner Sea
Matsuyama
Shimonoseki
Kitakyūshū
Fukuoka
Ōita
Sasebo
Nagasaki
Kumamoto
Miyazaki
Kagoshima
KYŪSHŪ
Korea Strait
East China Sea
Ōsumi Is.
Eumseong
Cheongju
Andong
Pohang
Daegu
Gyeongju
Ulsan
Changwon
Busan
Yeosu
35°N
30°N
121
130°E
135



This map shows the soils of southern Japan (the southern part of Honshū, Kyūshū, Shikoku, Bonin Islands, Daitō Islands) as well as a part of the Republic of Korea.

Japan is a volcanic archipelago consisting of nearly 7000 islands. Honshu is the largest and most populous island. Honshu has a rugged topography with volcanic mountains that reflects the tectonic activity associated with the Pacific Ring of Fire. Mount Fuji, lying to the west of Yokohama, reaches 3776 m a.s.l. while Mt Aso on Kyushu is Japan's most active volcano. Lowland areas are generally more pronounced in the south and east, consisting of narrow coastal strips or floodplains of river valleys. The Republic of Korea is only 200km away across the Korea Strait.

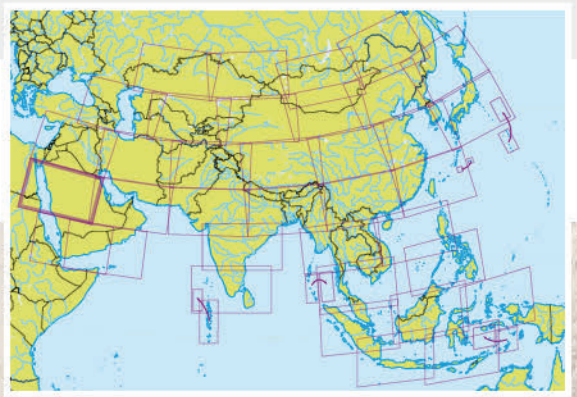
Unlike the north of Japan, a warm humid subtropical climate characterises the south. Annual precipitation around 1700mm (although this can double on the higher ground of the southeast). Monsoon conditions and typhoons mean that summers are hot and humid while cold air from the northwest brings freezing temperatures and heavy snowfall to the mountain ranges facing the East China Sea (Mount Fuji is covered by snow for five months of the year).

Soils reflect the influence of climate and topography on the weathering of volcanic and igneous materials. While organic-rich Andosols are widely distributed on plateau and terraces, most of central and southern Japan are covered by acidic Cambisols that are derived from volcanic, igneous and sedimentary rocks derived from volcanic material. The subalpine zone in the centre is characterised by extensive sandy Podzols reflecting the leaching of weathered granite by high rainfall.

In lowland areas, Fluvisols are very extensive due to the deposition of sediments eroded from the mountains. Gleysols and Histosols are found in poorly drained basins. Anthrosols denote terraces, irrigated paddy soils and land reclaimed from the sea. Technosols are extensive, reflecting the enormous urban expansion in the region. With an area of 2194km², the Greater Tokyo Area is one of the most populous metropolitan area in the world.

Redish Cambisols in the Republic of Korea denote hilly or mountainous terrain with Regosols and Fluvisols in valleys. Here also, Technosols are widespread.

Sheet 18 | Central Saudi Arabia



110

136

35°E

40°E

25°N

22°30'N

20°N

El Tur

Hurghada

Bur Safaga

Girga

Qena

Luxor

Isna

Kom Ombo

Aswan

Lake Nasser

Berenice

Tabuk

Al Wajh

Yanbu al Bahr

Madina

Jeddah

Makkah

At Taif

EGYPT

Red Sea

SAUDI ARABIA

ARcm

CLad

RGca

LPli

SCha

SCgl

TC

FLeu

CMad

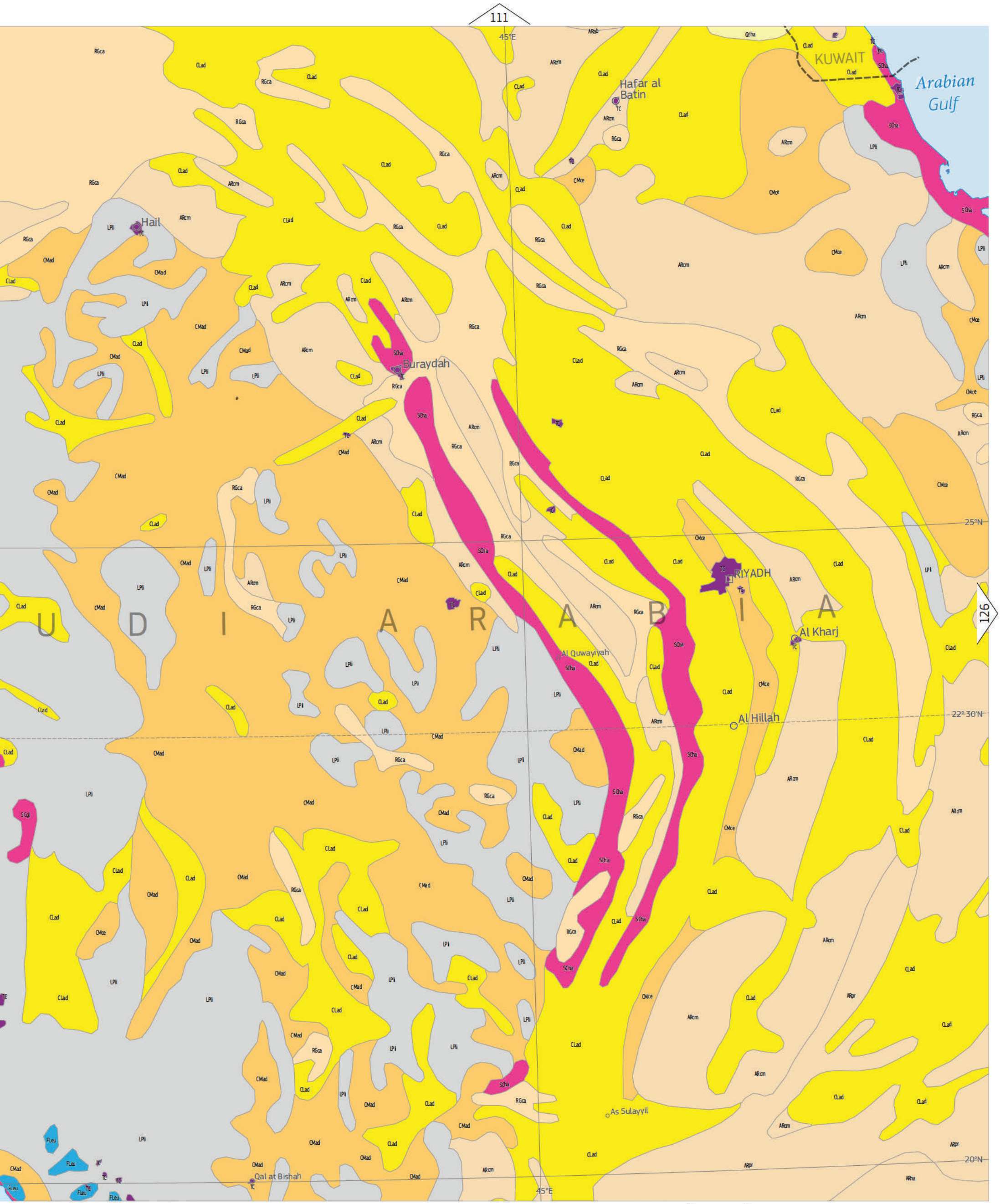
LPl

This map shows the soils of central part of the Arabian Peninsula. Lying between the Red Sea to the west and the Persian Gulf to the east. The Red Sea marks the splitting of the Arabian Peninsula from the Horn of Africa, which started some 40 million years ago and is still con-tinuing. The Gulf of Aqaba, to the east of the Sinai Peninsula, is the northward extent of this rifting process and marks the southern end of the Dead Sea Transform, which is the border of Asia.

Almost all of the area shown on the map is part of the Arabian Desert, the largest desert in Asia and the fifth largest in the world. In some respects, it is an extension of the Sahara Desert, which lies to the west in Egypt. While sand dunes are common, large tracts of the desert are gravelly and sand free. In the west, the Hejaz Mountains run parallel to the Red Sea Coast and contain more than 2000 dormant volcanoes with large basaltic lava fields. These volcanoes reflect tectonic activity at the edge of the Arabian Plate. The centre of the map is occupied by the Najd Plateau. Rising to over 1500m in height this rocky plateau with pockets of sand and bare hills, slopes from west to east to meet the Ad Dahna Desert that forms the sandy coast of the Persian Gulf. Rivers are dry (known in Arabic as wadis) and flow only after sporadic rainfall events, often as violent flash floods.

The region has a hot and arid desert climate. Summers are extremely hot and dry, ranging from 27°C to 43°C in the inland areas, slightly cooler in coastal areas. Winters, from December to February, are cool, with temperatures around 14°C in January. Precipitation is low, on average <100mm per year but with large annual variations. Humidity is low, except for coastal areas, where it can be high during the summer months (e.g. Kuwait City).

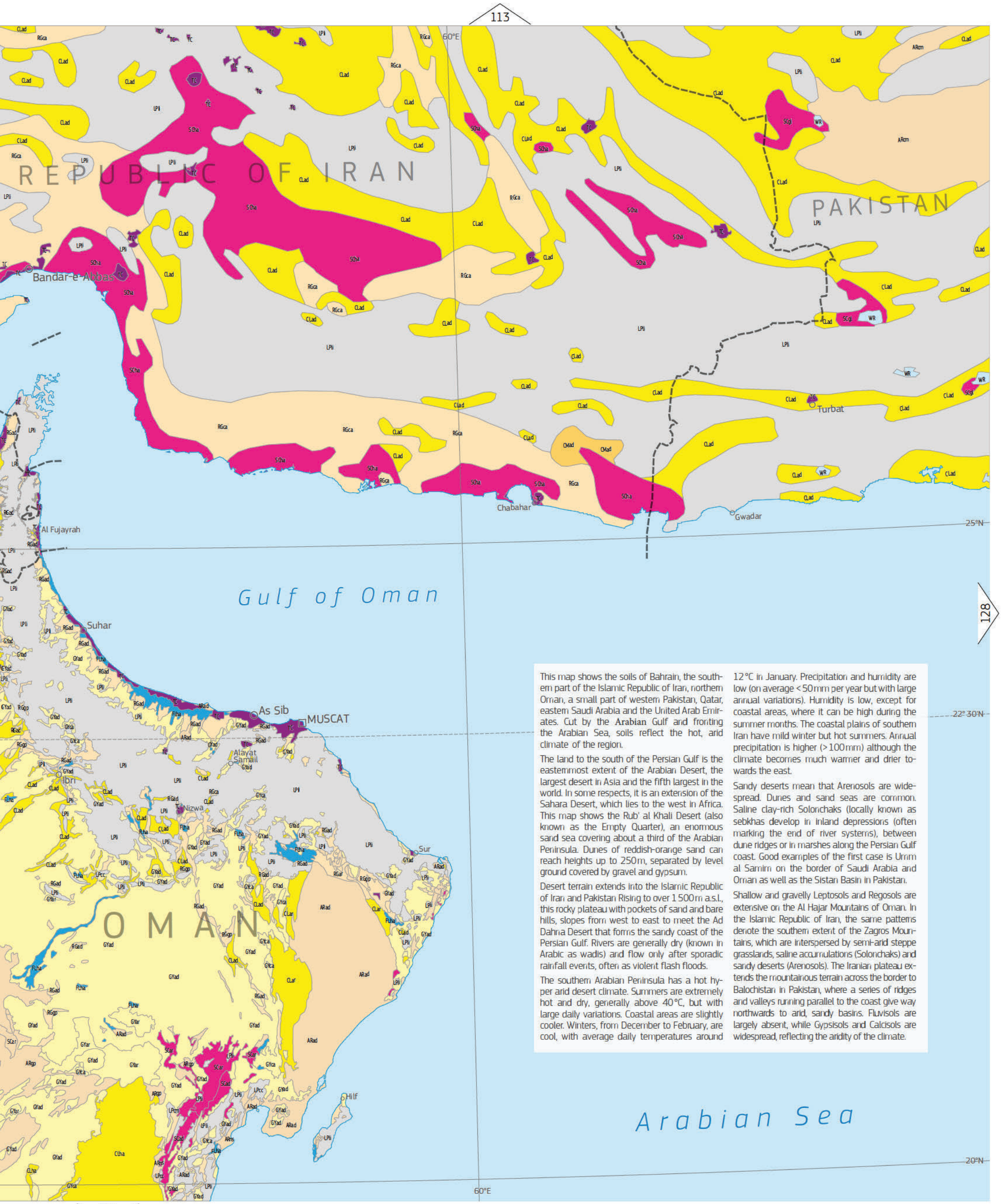
Sandy deserts mean that Arenosols are widespread. Dunes and sand seas are common. Saline clay-rich Solonchaks (locally known as sebkhas develop in inland depressions (often marking the end of river systems), between dune ridges or along the Red Sea coast. Shallow and gravelly Leptosols and Regosols are extensive on the central plateau and western mountains. Fluvisols, also gravelly in nature, are found along seasonal river channels (e.g. Wadi Al-Hamd). Volcanic soils (not visible on the scale of this map) can be observed in lava flows and cones in the western highlands (e.g. Harrat Khaybar). Anthrosols with higher organic matter levels can be found in oases.


111
45°E
KUWAIT
Arabian Gulf
Hafar al Batin
Hail
Buraydah
RIYADH
Al Kharj
Al Quwayiyah
Al Hillah
As Sulayyil
Qal at Bishah
25°N
22°30'N
20°N
45°E
126
137
U D I A R A B I A
RGca
CLad
ARcm
LPli
CMad
SCha
CMce
ARbb
Grha
TC

Sheet 19 | E Saudi Arabia, Gulf States, S Islamic Republic of Iran



112
125
137
138
139
50°E
55°E
25°N
22° 30'N
20°N
Persian Gulf
Bandar-e Bushehr
Fasa
Al Jubayl
Al-Qatif
Ad Dammam
Az Zahran
BAHRAIN
MANAMA
QATAR
DOHA
Al Mubarraz
Al Hufuf
Ras al Khaymah
Umm al Qaywayn
Sharjah
Dubai
Jabal Ali
ABU DHABI
Al Ayn
UNITED ARAB EMIRATES
SAUDI ARABIA
ISLAMIC



This map shows the soils of Bahrain, the southern part of the Islamic Republic of Iran, northern Oman, a small part of western Pakistan, Qatar, eastern Saudi Arabia and the United Arab Emirates. Cut by the **Arabian** Gulf and fronting the Arabian Sea, soils reflect the hot, arid climate of the region.

The land to the south of the Persian Gulf is the easternmost extent of the Arabian Desert, the largest desert in Asia and the fifth largest in the world. In some respects, it is an extension of the Sahara Desert, which lies to the west in Africa. This map shows the Rub' al Khali Desert (also known as the Empty Quarter), an enormous sand sea covering about a third of the Arabian Peninsula. Dunes of reddish-orange sand can reach heights up to 250m, separated by level ground covered by gravel and gypsum.

Desert terrain extends into the Islamic Republic of Iran and Pakistan Rising to over 1 500m a.s.l., this rocky plateau with pockets of sand and bare hills, slopes from west to east to meet the Ad Dahna Desert that forms the sandy coast of the Persian Gulf. Rivers are generally dry (known in Arabic as wadis) and flow only after sporadic rainfall events, often as violent flash floods.

The southern Arabian Peninsula has a hot hyper arid desert climate. Summers are extremely hot and dry, generally above 40°C, but with large daily variations. Coastal areas are slightly cooler. Winters, from December to February, are cool, with average daily temperatures around 12°C in January. Precipitation and humidity are low (on average < 50mm per year but with large annual variations). Humidity is low, except for coastal areas, where it can be high during the summer months. The coastal plains of southern Iran have mild winter but hot summers. Annual precipitation is higher (> 100mm) although the climate becomes much warmer and drier towards the east.

Sandy deserts mean that Arenosols are widespread. Dunes and sand seas are common. Saline clay-rich Solonchaks (locally known as sebkhas develop in inland depressions (often marking the end of river systems), between dune ridges or in marshes along the Persian Gulf coast. Good examples of the first case is Umm al Samim on the border of Saudi Arabia and Oman as well as the Sistan Basin in Pakistan.

Shallow and gravelly Leptosols and Regosols are extensive on the Al Hajar Mountains of Oman. In the Islamic Republic of Iran, the same patterns denote the southern extent of the Zagros Mountains, which are interspersed by semi-arid steppe grasslands, saline accumulations (Solonchaks) and sandy deserts (Arenosols). The Iranian plateau extends the mountainous terrain across the border to Balochistan in Pakistan, where a series of ridges and valleys running parallel to the coast give way northwards to arid, sandy basins. Fluvisols are largely absent, while Gypsisols and Calcisols are widespread, reflecting the aridity of the climate.



This map shows the soils of southeastern Pakistan and northwestern India (Rajasthan, Gujarat, Madhya Pradesh). The map shows a dramatic contrast, with soil types reflecting the arid conditions on the one side and the clay-rich soils on the other.

The border between India and Pakistan runs through the Thar Desert, most of which is covered by mobile sand dunes. Terrain is mostly flat with occasional rocky outcrops. The desert in bounded to the west by the fertile, lower floodplain of the Indus River (one of the major rivers of Asia and the 19th longest river in the world), which discharges to the sea through a large delta to the south of the city of Karachi. Both the delta and the extensive Gujarat Plains reflect the transportation of a vast volume of sediments that have been eroded in the mountainous catchments of the Indus in the Himalayas and Hindu Kush.

To the southeast of the Gujarat, the Aravalli Range, thought to be one of the oldest geological formations on the planet, denotes the beginning of more undulating terrain with narrow steep ridges and plateaus.

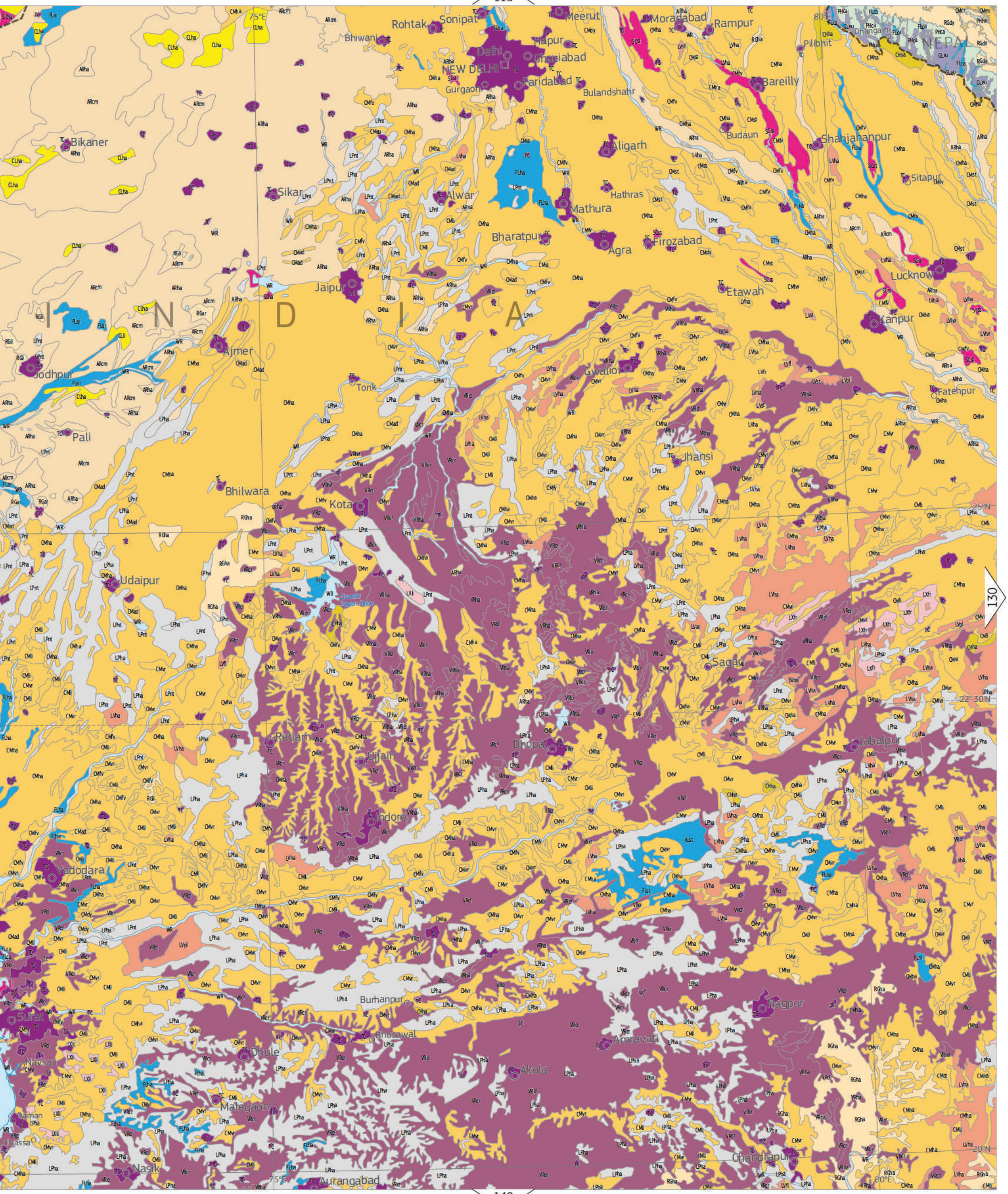
In the lower right corner of the map, the Narmada and the Tapti Rivers are among the few rivers in India that flow from east to west, discharge into the Gulf of Khambhat. The river systems in the upper right corner of the map form the headwaters of the Ganges and Yamuna Rivers that flow to the Bay of Bengal in the east.

Like the soils, the area covered by the map shows a range of climates. Southeastern Pakistan and Rajasthan have a hot arid climate. Precipitation levels are low and irregular. Summers are extremely hot and dry, ranging from 27 °C to 43 °C in the inland areas, slightly cooler in coastal areas. Towards the southeast, temperatures are lower, with cooler winters and a distinct monsoonal rainy season, with most rain falling between June and September. Precipitation levels generally increase to the south but the higher ground of the Deccan Plateau is drier than the coast.

Where the Thar Desert meets the Arabian Sea, extensive areas of flat and saline mudflats (Solonchaks) are seasonally flooded to form the ecologically important nature reserves of the Great and Little Rann of Kutch. Mangroves are common along the coast (Fluvisols).

The western part of the Gujurat Plains are dominated by dark, clay-rich Vertisols, that crack when dry but swell and become very sticky when wet. These soils, reflecting the weathering of basalt, extend southeastwards into central India. To the east, coarser alluvial deposits and sandy loam are more common (also shown by the Fluvisols of the Indus floodplain). Luvisols and Lixisols denote higher ground and slopes with reworked deposits (such as the Aravalli Range that runs to the east from the Gulf of Khambhat).

The Leptosols to the west of the Indus denote the Kirthar Mountains, a series of parallel steep, rocky ridges that are run north–south and are separated by calcareous alluvial plains (shown as elongated polygons of Calcisols on the left of the map). Leptosols also denote higher ground on the Deccan Plateau.


75°E
80°E
25°N
22°30'N
20°N
INDIA
NEPAL
Rohtak
Sonipat
Meerut
Moradabad
Rampur
Bhiwani
Hapur
Dhangarhi
Pilibhit
Delhi
NEW DELHI
Ghaziabad
Gurgaon
Faridabad
Bareilly
Bulandshahr
Budaun
Bikaner
Aligarh
Shahjahanpur
Sitapur
Sikar
Alwar
Hathras
Mathura
Bharatpur
Agra
Firozabad
Jaipur
Etawah
Lucknow
Kanpur
Ajmer
Jodhpur
Tonk
Gwalior
Fatehpur
Pali
Jhansi
Bhilwara
Kota
Udaipur
Sagar
Ratlam
Ujjain
Bhopal
Jabalpur
Indore
Vadodara
Burhanpur
Nagpur
Surat
Bhusawal
Amravati
Dhule
Navsari
Akola
Malegaon
Daman
Silvassa
Nasik
Chandrapur
Aurangabad
Gandhi Sagar Dam
130
140

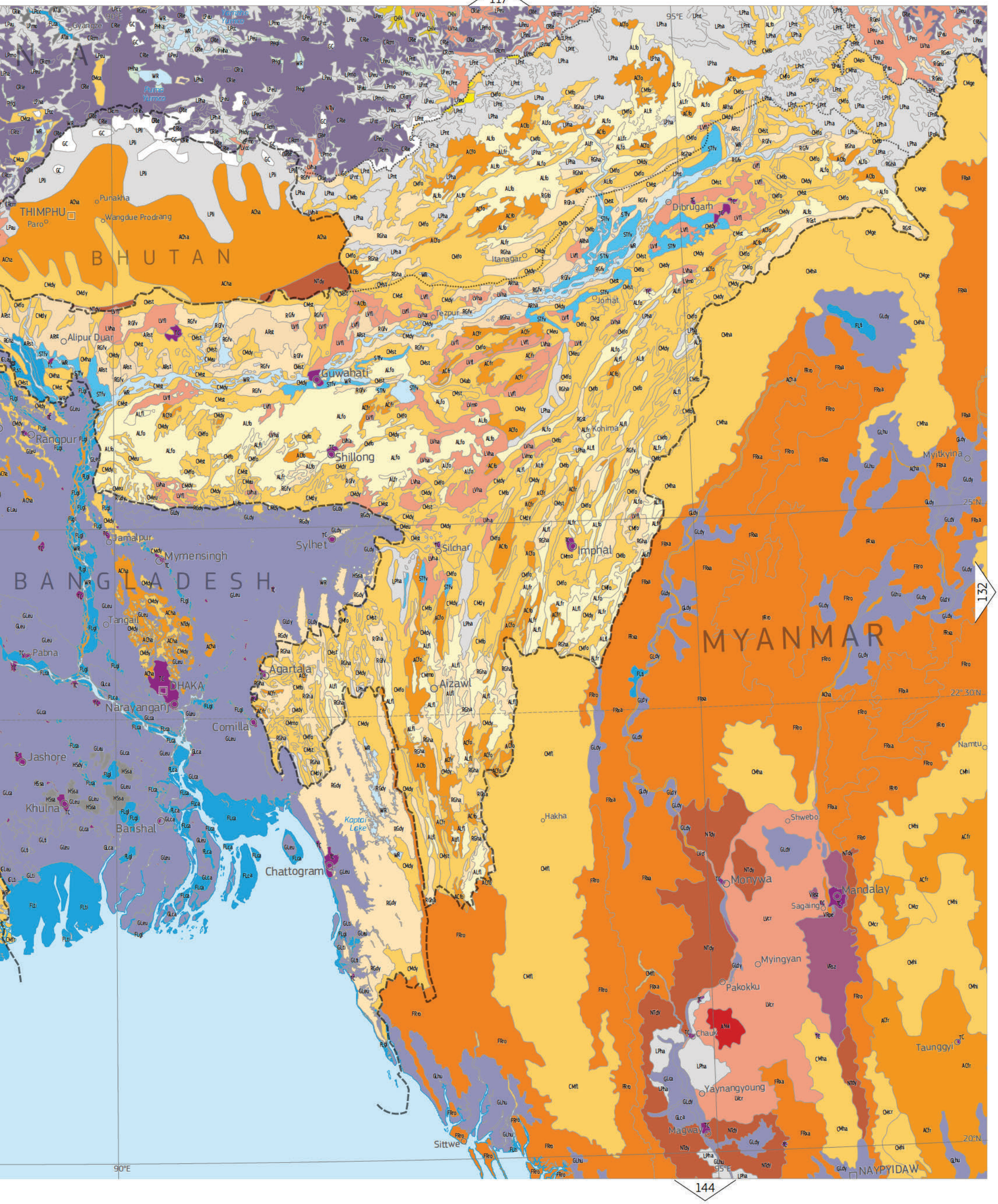


116

129

141

See explanatory text on page 89

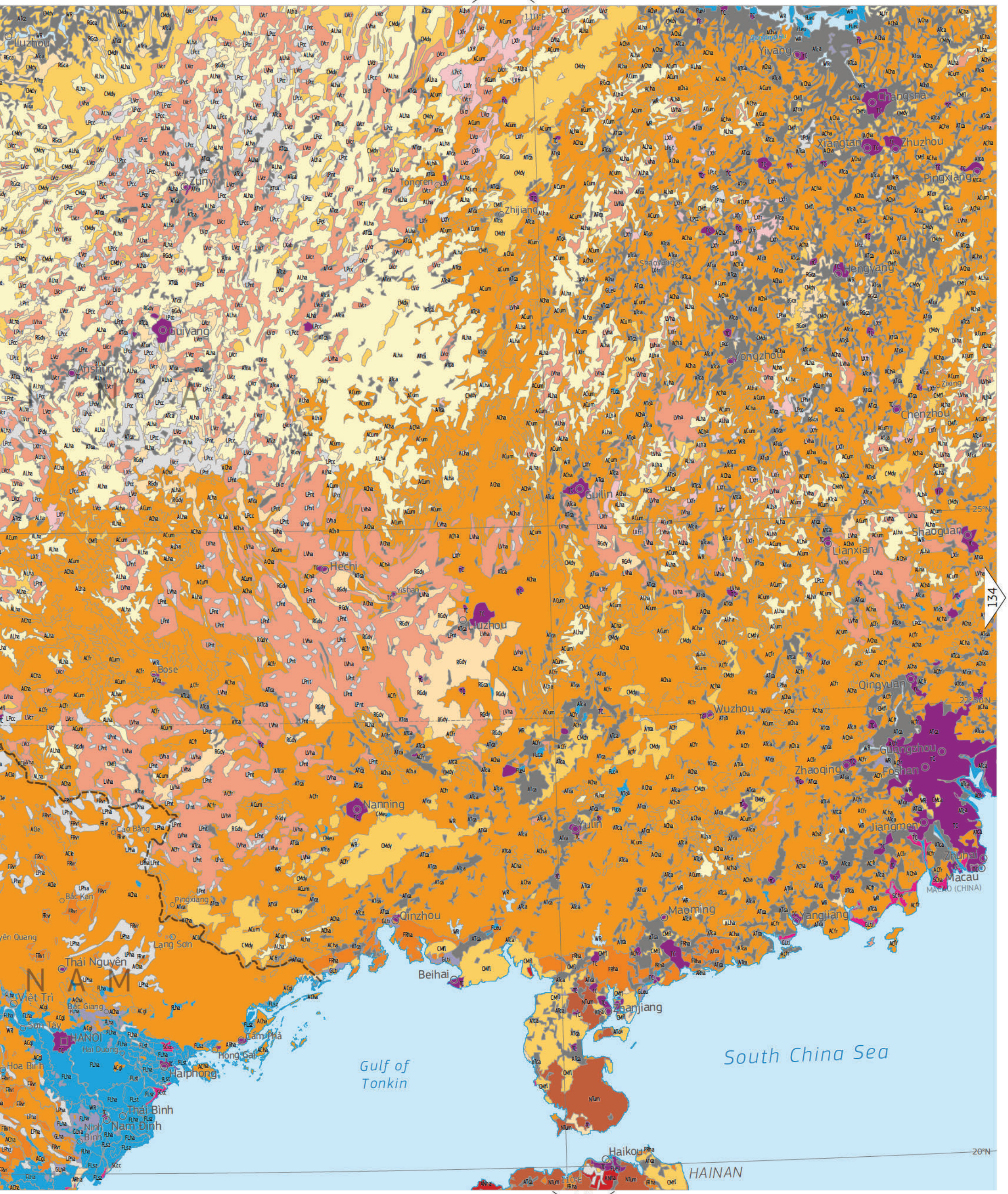

90°E
95°E
25°N
22°30'N
20°N
THIMPHU
Paro
Punakha
Wangdue Prodrang
BHUTAN
Gyangze
Yamdrok Yumco
Puma Yumco
Dibrugarh
Itanagar
Tezpur
Jorhat
Alipur Duar
Guwahati
Shillong
Kohima
Myitkyina
Rangpur
Jamalpur
Mymensingh
Sylhet
Silchar
Imphal
BANGLADESH
Tangail
Pabna
Agartala
Aizawl
DHAKA
Narayanganj
Comilla
Jashore
Khulna
Barishal
Chattogram
Kaptai Lake
MYANMAR
Hakha
Shwebo
Monywa
Mandalay
Sagaing
Myingyan
Pakokku
Chauk
Taunggyi
Yaynangyoung
Magway
Sittwe
NAYPYIDAW
Namtu
132
144

Sheet 22 | SE China (Guangxi), N Viet Nam, N Lao People's Democratic Republic



118
131
144
145

See explanatory text on page 89


110°E
Luzhou
Zunyi
Tongren
Zhijiang
Dongting Hu
Yiyang
Changsha
Xiangtan
Zhuzhou
Pingxiang
Shaoyang
Hengyang
Yongzhou
Zixing
Chenzhou
Guiyang
Anshun
Guilin
Liuzhou
Hechi
Yishan
Shaoguan
Lianxian
25°N
Bose
Qingyuan
22°30'N
Wuzhou
Guangzhou
Foshan
Zhaoqing
Nanning
Cao Bằng
Yulin
Jiangmen
Zhuhai
Macau
MACAO (CHINA)
Bắc Kạn
Pingxiang
Qinzhou
Maoming
Yangjiang
Lạng Sơn
Thái Nguyên
Beihai
Zhanjiang
N A M
Việt Trì
Bắc Giang
Sơn Tây
HANOI
Hải Dương
Cẩm Phả
Hòn Gai
Haiphong
Hoa Bình
Thái Bình
Nam Định
Ninh Bình
Gulf of Tonkin
South China Sea
Haikou
HAINAN
20°N
110°E
134
146

Sheet 23 | SE China, Japan Islands (Okinawa)



120

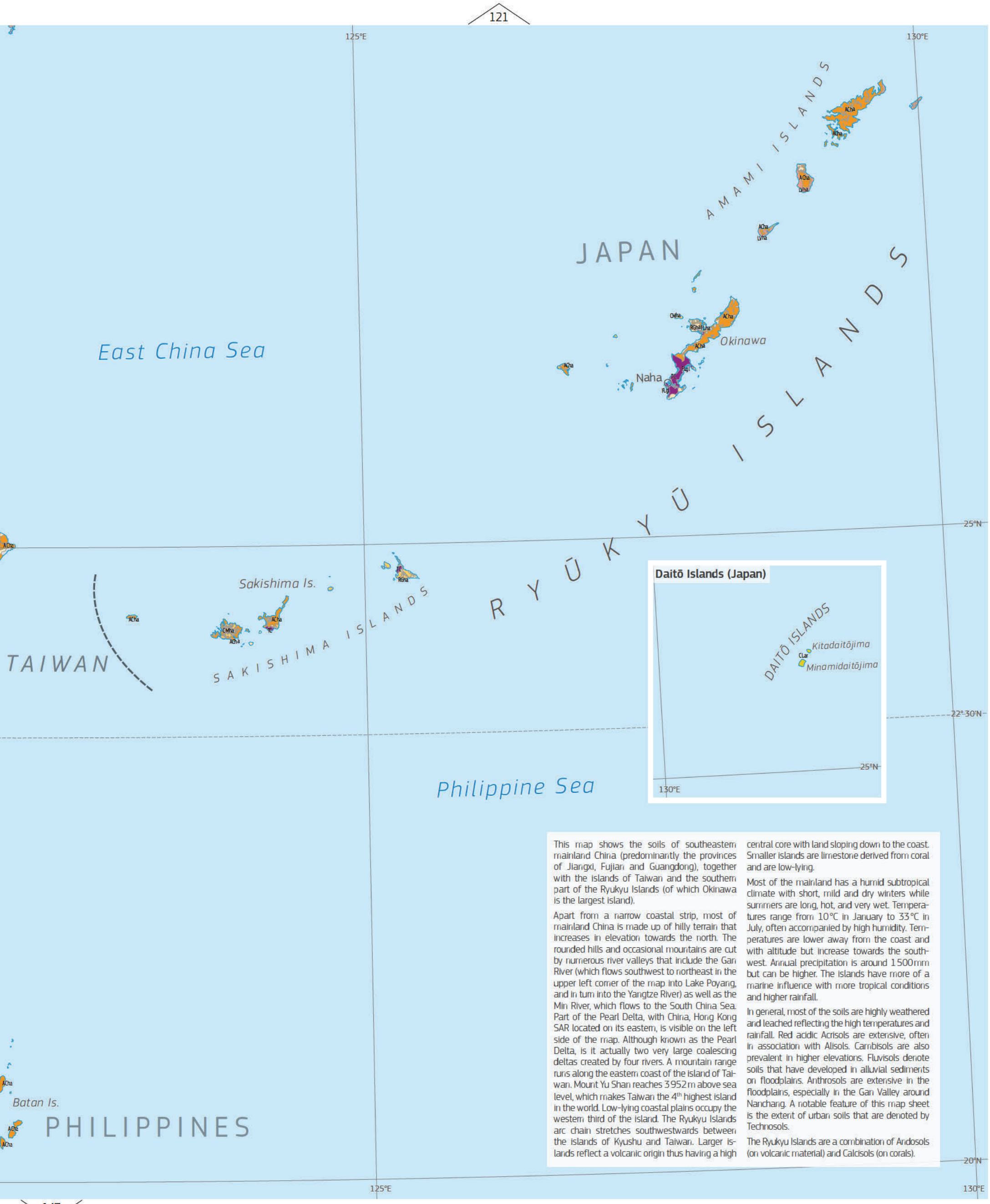
120°E

Nanchang
Shangrao
Quzhou
Linhai
Jiaojing
Huangyan
Lishui
Wenzhou
Linchuan
Fengcheng
Zhuzhou
Yichun
Xinyu
Pingxiang
Jian
Shaowu
Nanping
Ninde
Sanming
Fuzhou
Ganzhou
Changting
Putian
Longyan
Quanzhou
Zhangzhou
Xiamen
Meizhou
Shaoguan
Heyuan
Chaozhou
Shantou
Huizhou
Dongguan
Shenzhen
Hong Kong
CHINA, HONG KONG SAR
Zhuhai
Macau
CHINA, MACAO SAR
Zixing
Ganzhou
Xinfengjiang Shuiku
Keelung
TAIPEI
Taoyuan
Yangmei
Zhubei
Hsinchu
Pingzhen
Yilan
Miaoli
Taichung
Changhua
Nantou
Hualien
Douliou
Chiayi
Peizi
Taibao
Tainan
Pingtung
Kaohsiung
Taitung
Penghu Is.
Magong
Taiwan Strait
South China Sea
Bashi Channel
Luzon Strait
MALAY ARCHIPELAGO
CHINA

133

146

25°N
22°30'N
20°N
115°E
120°E



This map shows the soils of southeastern mainland China (predominantly the provinces of Jiangxi, Fujian and Guangdong), together with the islands of Taiwan and the southern part of the Ryukyu Islands (of which Okinawa is the largest island).

Apart from a narrow coastal strip, most of mainland China is made up of hilly terrain that increases in elevation towards the north. The rounded hills and occasional mountains are cut by numerous river valleys that include the Gan River (which flows southwest to northeast in the upper left corner of the map into Lake Poyang, and in turn into the Yangtze River) as well as the Min River, which flows to the South China Sea. Part of the Pearl Delta, with China, Hong Kong SAR located on its eastern, is visible on the left side of the map. Although known as the Pearl Delta, is it actually two very large coalescing deltas created by four rivers. A mountain range runs along the eastern coast of the island of Taiwan. Mount Yu Shan reaches 3952 m above sea level, which makes Taiwan the 4th highest island in the world. Low-lying coastal plains occupy the western third of the island. The Ryukyu Islands arc chain stretches southwestwards between the islands of Kyushu and Taiwan. Larger islands reflect a volcanic origin thus having a high central core with land sloping down to the coast. Smaller islands are limestone derived from coral and are low-lying.

Most of the mainland has a humid subtropical climate with short, mild and dry winters while summers are long, hot, and very wet. Temperatures range from 10°C in January to 33°C in July, often accompanied by high humidity. Temperatures are lower away from the coast and with altitude but increase towards the southwest. Annual precipitation is around 1500 mm but can be higher. The islands have more of a marine influence with more tropical conditions and higher rainfall.

In general, most of the soils are highly weathered and leached reflecting the high temperatures and rainfall. Red acidic Acrisols are extensive, often in association with Alisols. Cambisols are also prevalent in higher elevations. Fluvisols denote soils that have developed in alluvial sediments on floodplains. Anthrosols are extensive in the floodplains, especially in the Gan Valley around Nancharg. A notable feature of this map sheet is the extent of urban soils that are denoted by Technosols.

The Ryukyu Islands are a combination of Andosols (on volcanic material) and Calcisols (on corals).

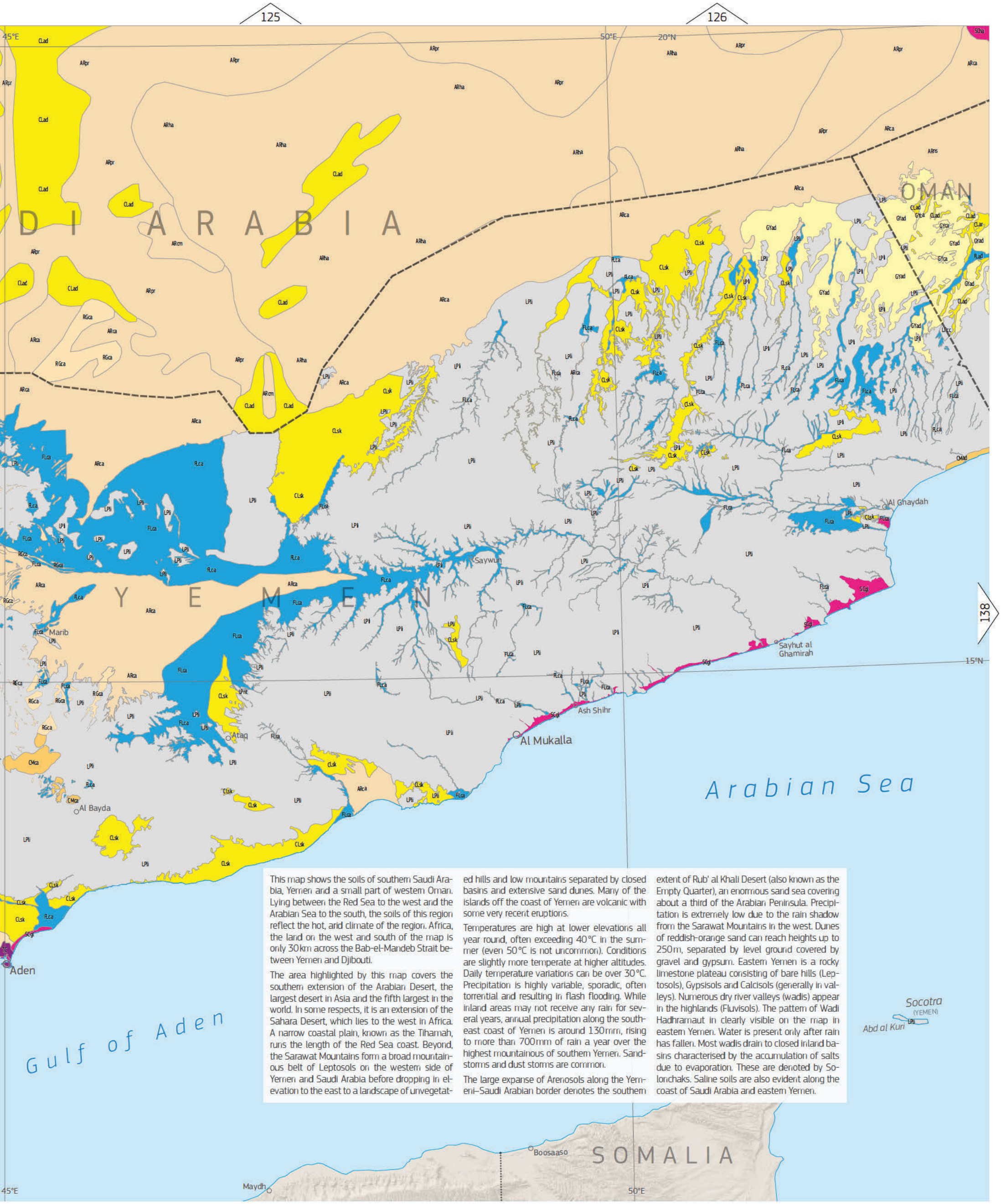


124

20°N
40°E
15°N
40°E

Qal at Bishah
Al Qunfudhah
Abha
Najran
Jizan
Sadah
Hajjah
SANAA
Al Hudaydah
Dhamar
Rida
Zabīd
Ibb
Taizz
Lahij
Assab
Obock
Tadjoura
DJIBOUTI
Farasān Islands
Dahlak Arch.
Bab-el-Mandeb Strait
Red Sea
Tokar
Agordat
Keren
Massawa
ASMARA
Mendefera
Adigrat
Aksum
Mekele
Gondar
Bahir Dar
Lake Tana
Dese
Bati
Lake Gemeri
Lake Adobed
Lake Abbe
Lake Assal
Dikhil
Ali Sabih

SUDAN
ERITREA
ETHIOPIA
DJIBOUTI
S A U



This map shows the soils of southern Saudi Arabia, Yemen and a small part of western Oman. Lying between the Red Sea to the west and the Arabian Sea to the south, the soils of this region reflect the hot, arid climate of the region. Africa, the land on the west and south of the map is only 30 km across the Bab-el-Mandeb Strait between Yemen and Djibouti.

The area highlighted by this map covers the southern extension of the Arabian Desert, the largest desert in Asia and the fifth largest in the world. In some respects, it is an extension of the Sahara Desert, which lies to the west in Africa. A narrow coastal plain, known as the Tihamah, runs the length of the Red Sea coast. Beyond, the Sarawat Mountains form a broad mountainous belt of Leptosols on the western side of Yemen and Saudi Arabia before dropping in elevation to the east to a landscape of unvegetated hills and low mountains separated by closed basins and extensive sand dunes. Many of the islands off the coast of Yemen are volcanic with some very recent eruptions.

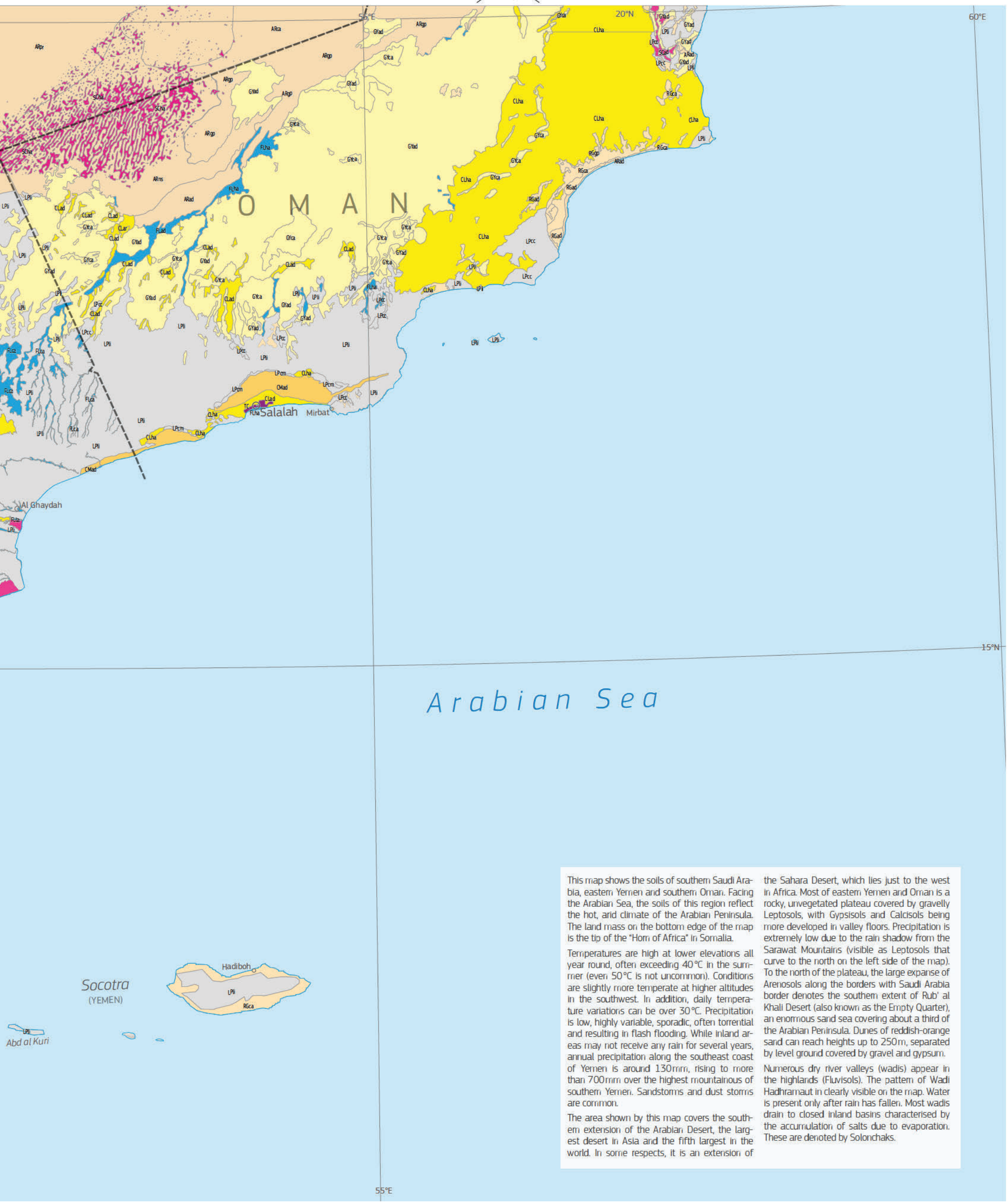
Temperatures are high at lower elevations all year round, often exceeding 40 °C in the summer (even 50 °C is not uncommon). Conditions are slightly more temperate at higher altitudes. Daily temperature variations can be over 30 °C. Precipitation is highly variable, sporadic, often torrential and resulting in flash flooding. While inland areas may not receive any rain for several years, annual precipitation along the southeast coast of Yemen is around 130 mm, rising to more than 700 mm of rain a year over the highest mountainous of southern Yemen. Sandstorms and dust storms are common.

The large expanse of Areniosols along the Yemeni–Saudi Arabian border denotes the southern extent of Rub' al Khali Desert (also known as the Empty Quarter), an enormous sand sea covering about a third of the Arabian Peninsula. Precipitation is extremely low due to the rain shadow from the Sarawat Mountains in the west. Dunes of reddish-orange sand can reach heights up to 250 m, separated by level ground covered by gravel and gypsum. Eastern Yemen is a rocky limestone plateau consisting of bare hills (Leptosols), Gypsisols and Calcisols (generally in valleys). Numerous dry river valleys (wadis) appear in the highlands (Fluvisols). The pattern of Wadi Hadhramaut in clearly visible on the map in eastern Yemen. Water is present only after rain has fallen. Most wadis drain to closed inland basins characterised by the accumulation of salts due to evaporation. These are denoted by Solonchaks. Saline soils are also evident along the coast of Saudi Arabia and eastern Yemen.

Sheet 25 | S Saudi Arabia, S Oman



125
126
20°N
50°E
137
15°N
45°E
S A U D I A R A B I A
Y E M E N
S O M A L I A
Gulf of Aden
Najran
SANAA
Marib
Dhamar
Rida
Ibb
Al Bayda
'Ataq
Lahij
Aden
Saywun
Ash Shihr
Al Mukalla
Sayhut al Ghamirah
Maydh
Boosaaso
Caluula
CMad
ARcm
CLad
LPll
ARpr
ARha
ARca
RGca
FLca
CLsk
OMca
SCgl
GYad
LPhl
LPli



This map shows the soils of southern Saudi Arabia, eastern Yemen and southern Oman. Facing the Arabian Sea, the soils of this region reflect the hot, arid climate of the Arabian Peninsula. The land mass on the bottom edge of the map is the tip of the "Horn of Africa" in Somalia.

Temperatures are high at lower elevations all year round, often exceeding 40 °C in the summer (even 50 °C is not uncommon). Conditions are slightly more temperate at higher altitudes in the southwest. In addition, daily temperature variations can be over 30 °C. Precipitation is low, highly variable, sporadic, often torrential and resulting in flash flooding. While inland areas may not receive any rain for several years, annual precipitation along the southeast coast of Yemen is around 130 mm, rising to more than 700 mm over the highest mountainous of southern Yemen. Sandstorms and dust storms are common.

The area shown by this map covers the southern extension of the Arabian Desert, the largest desert in Asia and the fifth largest in the world. In some respects, it is an extension of the Sahara Desert, which lies just to the west in Africa. Most of eastern Yemen and Oman is a rocky, unvegetated plateau covered by gravelly Leptosols, with Gypsisols and Calcisols being more developed in valley floors. Precipitation is extremely low due to the rain shadow from the Sarawat Mountains (visible as Leptosols that curve to the north on the left side of the map). To the north of the plateau, the large expanse of Arenosols along the borders with Saudi Arabia border denotes the southern extent of Rub' al Khali Desert (also known as the Empty Quarter), an enormous sand sea covering about a third of the Arabian Peninsula. Dunes of reddish-orange sand can reach heights up to 250 m, separated by level ground covered by gravel and gypsum.

Numerous dry river valleys (wadis) appear in the highlands (Fluvisols). The pattern of Wadi Hadhramaut is clearly visible on the map. Water is present only after rain has fallen. Most wadis drain to closed inland basins characterised by the accumulation of salts due to evaporation. These are denoted by Solonchaks.

Sheet 26 | Central India



129

75°E

20°N

15°N

142

Surat
Navsari
Daman
Silvassa
Nasik
Bhiwandi
Kalyan
Mumbai
Pune
Aurangabad
Ahmednagar
Malegaon
Dhule
Burhanpur
Bhusawal
Parbhani
Nanded
Latur
Sholapur
Sangli
Kolhapur
Vijayapura
Belagavi
Hubballi
Parjaji
Davangere
Shivamogga
Tumakuru
Kalaburagi
Bidar
Hyderabad
Akola
Amravati
Nagpur
Chandrapur
Nizamabad
Karimnagar
Warangal
Raichur
Kurnool
Nandyal
Proddatur
Hindupur
Tirupati
Ballari
Hosapete
Tungabhadra
Nagarjuna Sagar Dam
Bhadra Reservoir

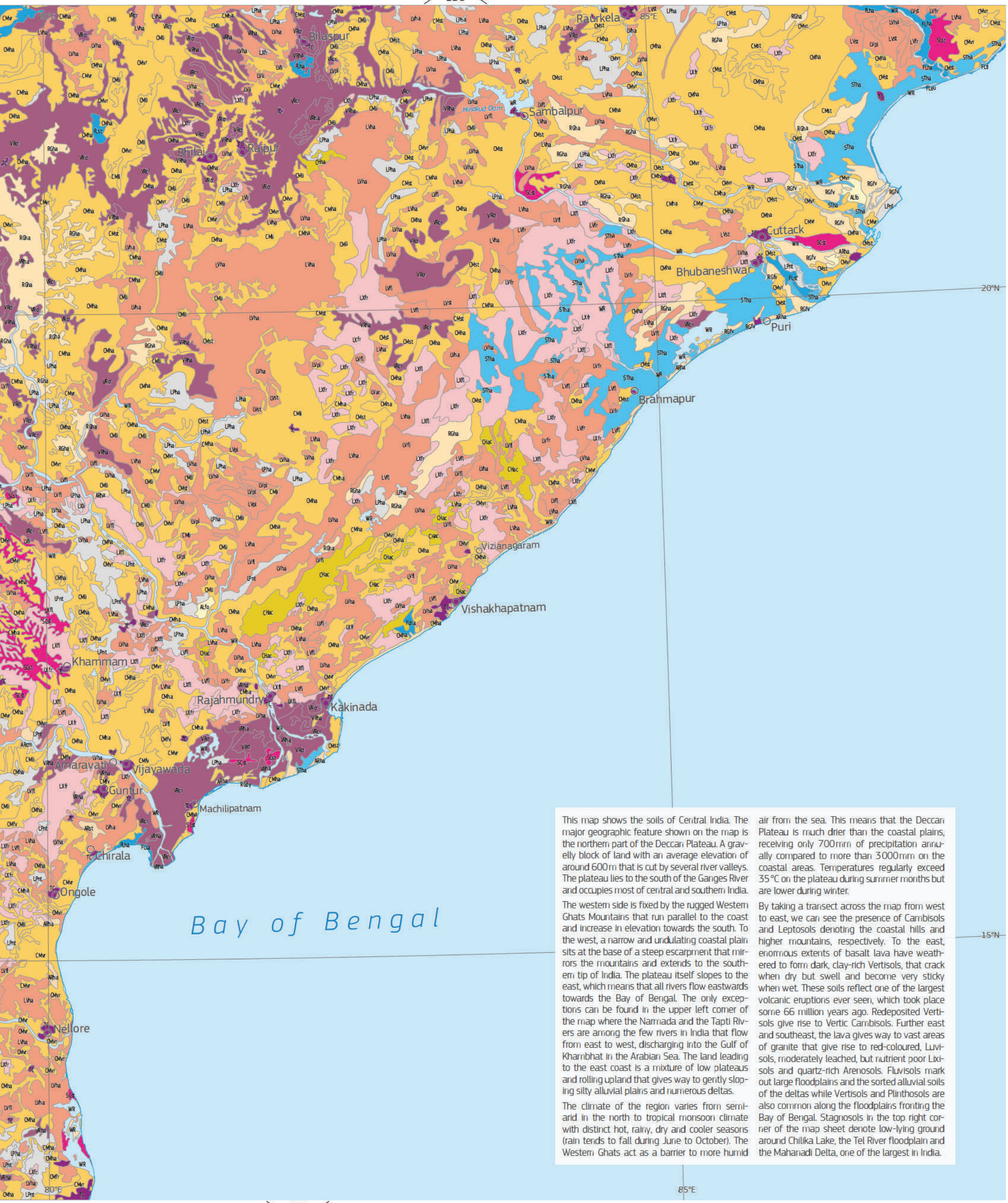
DECCAN PLATEAU

INDIA

Arabian Sea

Laccadive Sea

130



This map shows the soils of Central India. The major geographic feature shown on the map is the northern part of the Deccan Plateau. A gravelly block of land with an average elevation of around 600 m that is cut by several river valleys. The plateau lies to the south of the Ganges River and occupies most of central and southern India.

The western side is fixed by the rugged Western Ghats Mountains that run parallel to the coast and increase in elevation towards the south. To the west, a narrow and undulating coastal plain sits at the base of a steep escarpment that mirrors the mountains and extends to the southern tip of India. The plateau itself slopes to the east, which means that all rivers flow eastwards towards the Bay of Bengal. The only exceptions can be found in the upper left corner of the map where the Narmada and the Tapti Rivers are among the few rivers in India that flow from east to west, discharging into the Gulf of Khambhat in the Arabian Sea. The land leading to the east coast is a mixture of low plateaus and rolling upland that gives way to gently sloping silty alluvial plains and numerous deltas.

The climate of the region varies from semi-arid in the north to tropical monsoon climate with distinct hot, rainy, dry and cooler seasons (rain tends to fall during June to October). The Western Ghats act as a barrier to more humid air from the sea. This means that the Deccan Plateau is much drier than the coastal plains, receiving only 700 mm of precipitation annually compared to more than 3000 mm on the coastal areas. Temperatures regularly exceed 35 °C on the plateau during summer months but are lower during winter.

By taking a transect across the map from west to east, we can see the presence of Cambisols and Leptosols denoting the coastal hills and higher mountains, respectively. To the east, enormous extents of basalt lava have weathered to form dark, clay-rich Vertisols, that crack when dry but swell and become very sticky when wet. These soils reflect one of the largest volcanic eruptions ever seen, which took place some 66 million years ago. Redeposited Vertisols give rise to Vertic Cambisols. Further east and southeast, the lava gives way to vast areas of granite that give rise to red-coloured, Luvisols, moderately leached, but nutrient poor Lixisols and quartz-rich Arenosols. Fluvisols mark out large floodplains and the sorted alluvial soils of the deltas while Vertisols and Plinthosols are also common along the floodplains fronting the Bay of Bengal. Stagnosols in the top right corner of the map sheet denote low-lying ground around Chilika Lake, the Tel River floodplain and the Mahanadi Delta, one of the largest in India.

143



140

75°E

8°N

10°N

5°N

Arabian Sea

Lakshadweep
(Laccadive Islands)
(INDIA)

Kavaratti

Nine Degree Channel

Laccadive Sea

Eight Degree Channel

Shivamogga

Bhadra Reservoir

Tumakuru

Mangaluru

Mandya

Krishna Raja Sagar

Mysuru

Kozhikode

Tiruppur

Coimbatore

Valparai

Kochi

Alappuzha

Kollam

Thiruvananthapuram

Nagercoil

Maldives

Thiladhunmathi Atoll

Northern Maalhosmadulu Atoll

Southern Maalhosmadulu Atoll

North Malé Atoll

MALÉ

Ari Atoll

South Malé Atoll

Haddhunmathi Atoll

Huvadhu Atoll

Addu Atoll

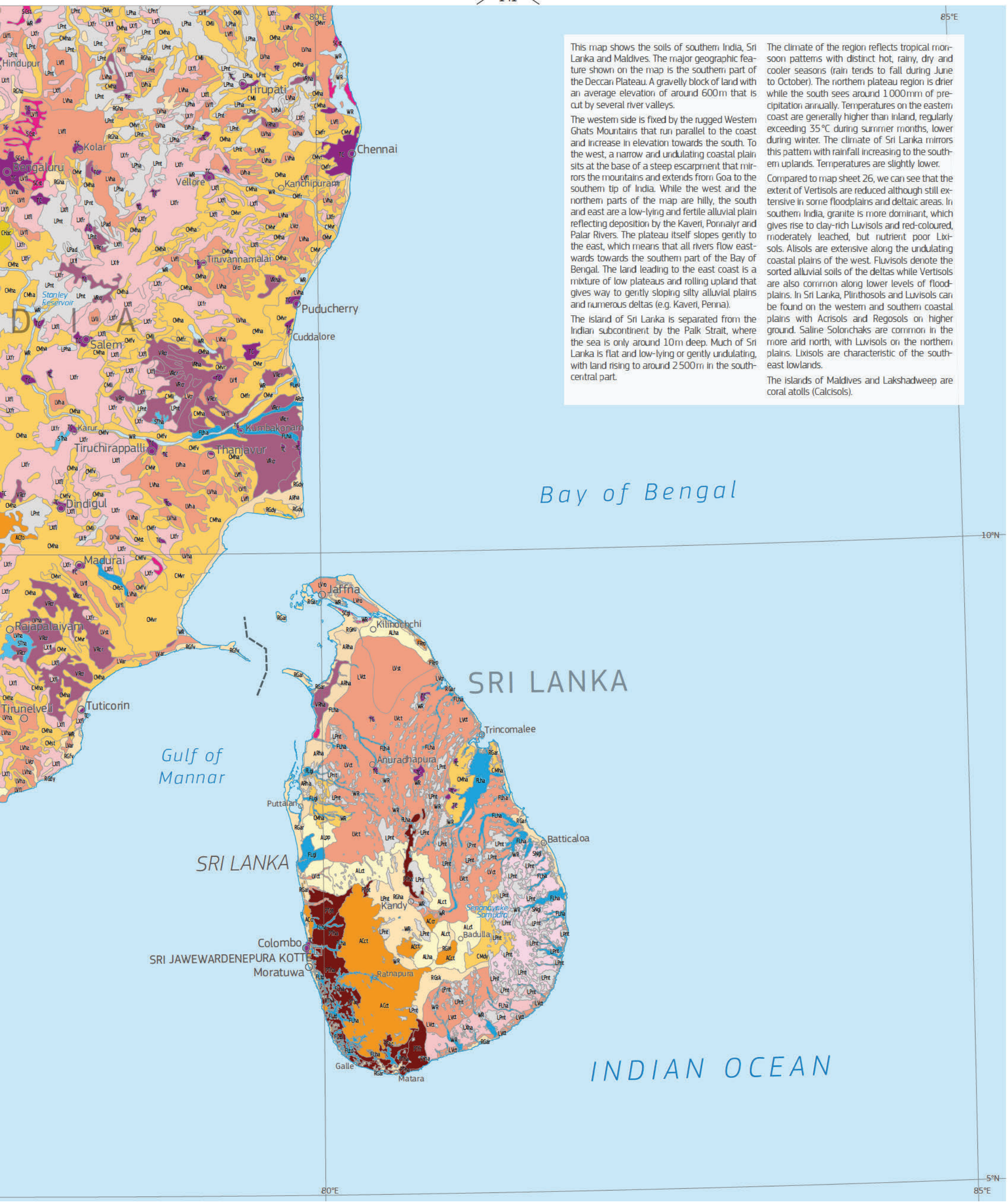
Equator

MALDIVES

MALDIVES

70°E

75°E



This map shows the soils of southern India, Sri Lanka and Maldives. The major geographic feature shown on the map is the southern part of the Deccan Plateau. A gravelly block of land with an average elevation of around 600 m that is cut by several river valleys.

The western side is fixed by the rugged Western Ghats Mountains that run parallel to the coast and increase in elevation towards the south. To the west, a narrow and undulating coastal plain sits at the base of a steep escarpment that mirrors the mountains and extends from Goa to the southern tip of India. While the west and the northern parts of the map are hilly, the south and east are a low-lying and fertile alluvial plain reflecting deposition by the Kaveri, Ponnaiyr and Palar Rivers. The plateau itself slopes gently to the east, which means that all rivers flow eastwards towards the southern part of the Bay of Bengal. The land leading to the east coast is a mixture of low plateaus and rolling upland that gives way to gently sloping silty alluvial plains and numerous deltas (e.g. Kaveri, Penna).

The island of Sri Lanka is separated from the Indian subcontinent by the Palk Strait, where the sea is only around 10 m deep. Much of Sri Lanka is flat and low-lying or gently undulating, with land rising to around 2 500 m in the south-central part.

The climate of the region reflects tropical monsoon patterns with distinct hot, rainy, dry and cooler seasons (rain tends to fall during June to October). The northern plateau region is drier while the south sees around 1 000 mm of precipitation annually. Temperatures on the eastern coast are generally higher than inland, regularly exceeding 35 °C during summer months, lower during winter. The climate of Sri Lanka mirrors this pattern with rainfall increasing to the southern uplands. Temperatures are slightly lower.

Compared to map sheet 26, we can see that the extent of Vertisols are reduced although still extensive in some floodplains and deltaic areas. In southern India, granite is more dominant, which gives rise to clay-rich Luvisols and red-coloured, moderately leached, but nutrient poor Lixisols. Alisols are extensive along the undulating coastal plains of the west. Fluvisols denote the sorted alluvial soils of the deltas while Vertisols are also common along lower levels of floodplains. In Sri Lanka, Plinthosols and Luvisols can be found on the western and southern coastal plains with Acrisols and Regosols on higher ground. Saline Solonchaks are common in the more arid north, with Luvisols on the northern plains. Lixisols are characteristic of the south-east lowlands.

The islands of Maldives and Lakshadweep are coral atolls (Calcisols).



131

95°E

20°N

15°N

148

MYANMAR

Bay of Bengal

Sittwe

Kyaukphyu

Chauk

Yaynangyoung

Magway

Allanmyo

Pyay

Taungoo

Pyu

Taunggyi

NAYPYIDAW

Loikaw

Letpadan

Hinthada

Pathein

Wakema

Phyarpon

Labutta

Bago

Yandoon

Rangoon

Thongwa

Pa-an

Mawlamyine

Mudon

Ye

Dawei

Myeik

Myeik Arch.

Thayetmyo

Mae Hong Son

Chiang Mai

Lamphun

Lampang

Phrae

Nan

Bhumphol K. K. Nam

Tak

Mae Sot

Kamphaeng Phet

Chao Nen Dam

Kanchanaburi

ANDAMAN ISLANDS
INDIA

N. Andaman

Middle Andaman

S. Andaman

Port Blair

This map shows the soils of southern Myanmar, central Thailand, the Lao People's Democratic Republic, central Viet Nam, northern Cambodia and the northern part of the Andaman Islands (India).

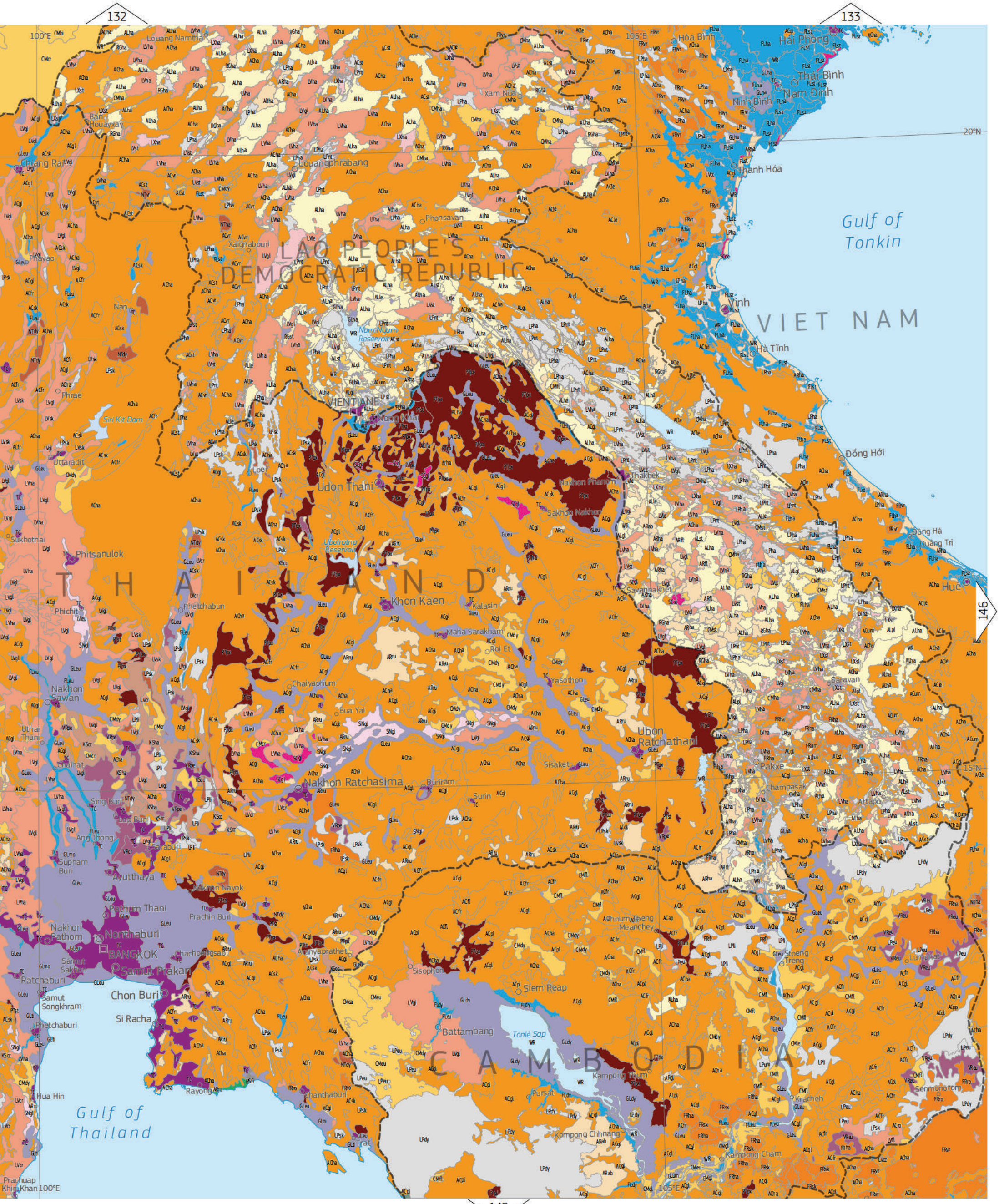
Northern Thailand and the Lao People's Democratic Republic are mountains, resulting in a rugged forested landscape of plains and plateaus that are crossed by numerous rivers. High ground extends southwards along the Myanmar border to the Malay Peninsula and also along the eastern side of the Irrawaddy Valley. Central Thailand is a mostly a lowland plain that is drained by the tributaries of the Chao Phraya River, which discharges into the Bay of Bangkok through a large delta (evident in the centre of the map). Northeastern Thailand is characterised by a series of low hills and shallow lakes that eventually drain into the Mekong River (visible in the lower right part of the map). The distinctive blue triangular area on the left-hand side of the sheet denotes the large delta of the Irrawaddy River, which empties into the Andaman Sea. To complete the picture, part of the Red River delta in Viet Nam is also visible in the upper right corner of the map. All these delta areas are low-lying (just a few metres above sea-level), densely populated and intensively used for rice cultivation. Flooding due to tropical storms and sea-level rise are major concerns.

Most of the area shown on the map has a tropical savanna climate with a distinct dry winter. Towards the south, the climate becomes more tropical monsoon with precipitation levels increasing. Annual rainfall is around 1 500mm, falling from May to October. Temperatures during the dry season can reach 40 °C but drop to around 25 °C during the monsoon rains. Northeastern Cambodia has a more temperate climate.

The dominant soil type of this region is yellow or red Acrisols, reflecting intense chemical weathering under a hot and humid climate. Despite their inherent low fertility and elevated levels of aluminium that are often toxic to most crops, Acrisols can support tea plants, rubber trees, oil palm and coffee. Higher elevations are denoted by areas of Cambisols and Leptosols. Ferralsols are more prevalent to the west while Alisols are common on the steep slopes of western Laos. Plinthosols are found around the edges of the Khorat Plateau in eastern Thailand.

The floodplains of the major rivers and delta regions are characterised by a distinctive pattern of Fluvisols, with Gleysols and Histosols in depressions and lower elevations. The large expanse of Gleysols in central Cambodia denotes the highly diverse wetlands of the Tonlé Sap (or Great Lake). An interesting phenomenon is that for most of the year, the Tonlé Sap is fed by the Mekong River. However, at the end of the rainy season (September/October), heavy rains raise the level of the lake so that the direction of flow is reversed, with the water moving from the lake into the Mekong! Low-lying areas, predominantly along the coast, are often waterlogged giving rise to Solonchaks, Gleysols, Stagnosols and Histosols. Mangrove forests widespread.

Andaman Island (in the lower left corner of the map) is the tip of a typical volcanic island arc system reflecting tectonic activity along the edge of the Eurasian Plate. Intensely leached Cambisols (with Ferralsols) are found under forested uplands while valley floors consist of Fluvisols and Gleysols. Many of the lowland soils have medium to high organic matter content. However, severe erosion due to extensive deforestation is a widespread issue.


132
133
146
149
100°E
105°E
20°N
15°N
Louang Namtha
Ban Houayxay
Chiang Rai
Phayao
Nan
Phrae
Uttaradit
Sukhothai
Phitsanulok
Phichit
Nakhon Sawan
Uthai Thani
Chainat
Sing Buri
Lop Buri
Ang Thong
Saraburi
Supham Buri
Ayutthaya
Pathum Thani
Nakhon Pathom
Nonthaburi
BANGKOK
Samut Prakan
Samut Sakhon
Ratchaburi
Samut Songkhram
Phetchaburi
Hua Hin
Prachuap Khiri Khan
Chon Buri
Si Racha
Rayong
Chanthaburi
Trat
Chachoengsao
Prachin Buri
Nakhon Nayok
Nakhon Ratchasima
Chaiyaphum
Phetchabun
Loei
Siri Kit Dam
Nam Ngum Reservoir
VIENTIANE
Xaignabouri
Louangphrabang
Phonsavan
Xam Nua
Udon Thani
Nong Khai
Ubolratna Reservoir
Khon Kaen
Kalasin
Maha Sarakham
Roi Et
Yasothon
Bua Yai
Sisaket
Buriram
Surin
Ubon Ratchathani
Hòa Bình
Hải Phòng
Thái Bình
Nam Định
Ninh Bình
Thanh Hóa
Vinh
Hà Tĩnh
Đồng Hới
Thakhek
Nakhon Phanom
Sakhon Nakhon
Đông Hà
Quảng Trị
Hue
Savannakhet
Pakxe
Champasak
Attapu
Saravan
Gulf of Tonkin
VIET NAM
THAILAND
LAO PEOPLE'S DEMOCRATIC REPUBLIC
CAMBODIA
Gulf of Thailand
Phnum Doeng Meanchey
Sisophon
Siem Reap
Battambang
Tonlé Sap
Pursat
Kampong Thum
Kampong Chhnang
Kampong Cham
Stoeng Treng
Lumphat
Senmonorom
Kracheh

Sheet 29 | Central Viet Nam, S China (Hainan Island), N Philippines (Luzon)



133

145

149

110°E

115°E

20°N

15°N

CHINA

VIET NAM

LAOS

CAMBODIA

Gulf of Tonkin

HAINAN

Paracel Islands

Haikou

Sanya

Đông Hà

Quảng Trị

Huế

Da Nang

Quảng Ngãi

Kon Tum

Play Ku

Qui Nhon

Tuy Hòa

Buôn Ma Thuột

Nha Trang

Đà Lạt

Cam Ranh

This map is centred on the South China Sea and shows the soils of central Viet Nam, Hainan Island (southern China) and the northern Philippine islands of Luzon and Mindoro. Most of the region has a tropical monsoon climate with constantly warm temperatures and abundant rainfall that occurs in a distinct wet season. Tropical storms are frequent. The climate becomes more temperate with altitude.

The Annamite Mountains rise steeply from a narrow coastal plain and run parallel to the Vietnamese coast along the border with the Lao People's Democratic Republic. The western part of Hainan Island is mountainous while to the east, topography drops in a series of tablelands to a low lying coastal plain. A similar landscape pattern characterises the archipelago centred around the Philippine island of Luzon where flat terrain extends from the coastline toward various mountain ranges. The central section of Luzon is characterised by a flat alluvial plain. Evidence of volcanic activity (i.e. craters, cones, lava flows) are common on Luzon and Hainan.

Intense chemical weathering as a result of the hot and humid climate gives rise to extensive acidic Acrisols and Ferralsols, predominantly on undulating terrain and plains. Low-lying areas are often waterlogged giving rise to Gleysols, Stagnosols and Histosols. Mangrove forests are widespread along the coast.

The fertile Luzon plain is characterised by extensive Vertisols and Lixisols, that reflect the chemical weathering of basaltic rocks and their deposition in the floodplains of the Cagayan and Pampanga Rivers. Vertisols are also common in the valley floors of the eastern part of the Lao People's Democratic Republic and central Vietnam (e.g. the Song Ba). Andosols to the west of Manila reflect the volcanic Zambales mountain chain, which includes Mount Pinatubo, famous for its devastating eruption in 1991. To the south of Manila, the Andosols are associated with the Taal Volcano complex. Andosols are also widespread in the eastern part of Hainan Island.

Nitisols are found in weathered basalt on gently sloping land in northern Hainan and at the southern end of the Leizhou Peninsula on mainland China.


120°E
20°N
15°N
Luzon Strait
Batan Is.
Babuyan Is.
PHILIPPINES
South China Sea
Philippine Sea
LUZON
Laoag
Vigan
Tuguegarao
Baguio City
Dagupan
Tarlac
Cabanatuan
Angeles
Olongapo
MANILA
Pasay City
Quezon City
Laguna de Bay
Lake Taal
San Pablo
Batangas
Mindoro
Calamian Group
Sulu Sea
MALAY ARCHIPELAGO
Panay



144

100°E

Andaman Sea

Myeik

MYANMAR

Myeik Arch.

Phetchaburi

Hua Hin

Si Racha

Rayong

Chanthaburi

Prachuap Khiri Khan

Gulf of Thailand

Ranong

Ko Samui

Surat Thani

THAILAND

Nakhon Si Thammarat

Phangnga

Krabi

Thung Song

Phuket I.

Phuket

Trang

Phatthalung

Songkhla

Hat Yai

Pattani

Satun

Yala

Narathiwat

Kangar

Langkawi

Alor Setar

Sungai Petani

George Town

Butterworth

Penang

Taiping

Ipoh

Kuala Lipis

Strait of Malacca

MALAY ARCHIPELAGO

Banda Aceh

Lhokseumawe

Langsa

SUMATRA

INDONESIA

GREATER SUNDA ISLANDS

MALA

95°E

5°N

10°N

10°N

92°30'E

ANDAMAN ISLANDS (INDIA)

S. Andaman

Port Blair

Andaman Sea

Little Andaman

Ten Degree Channel

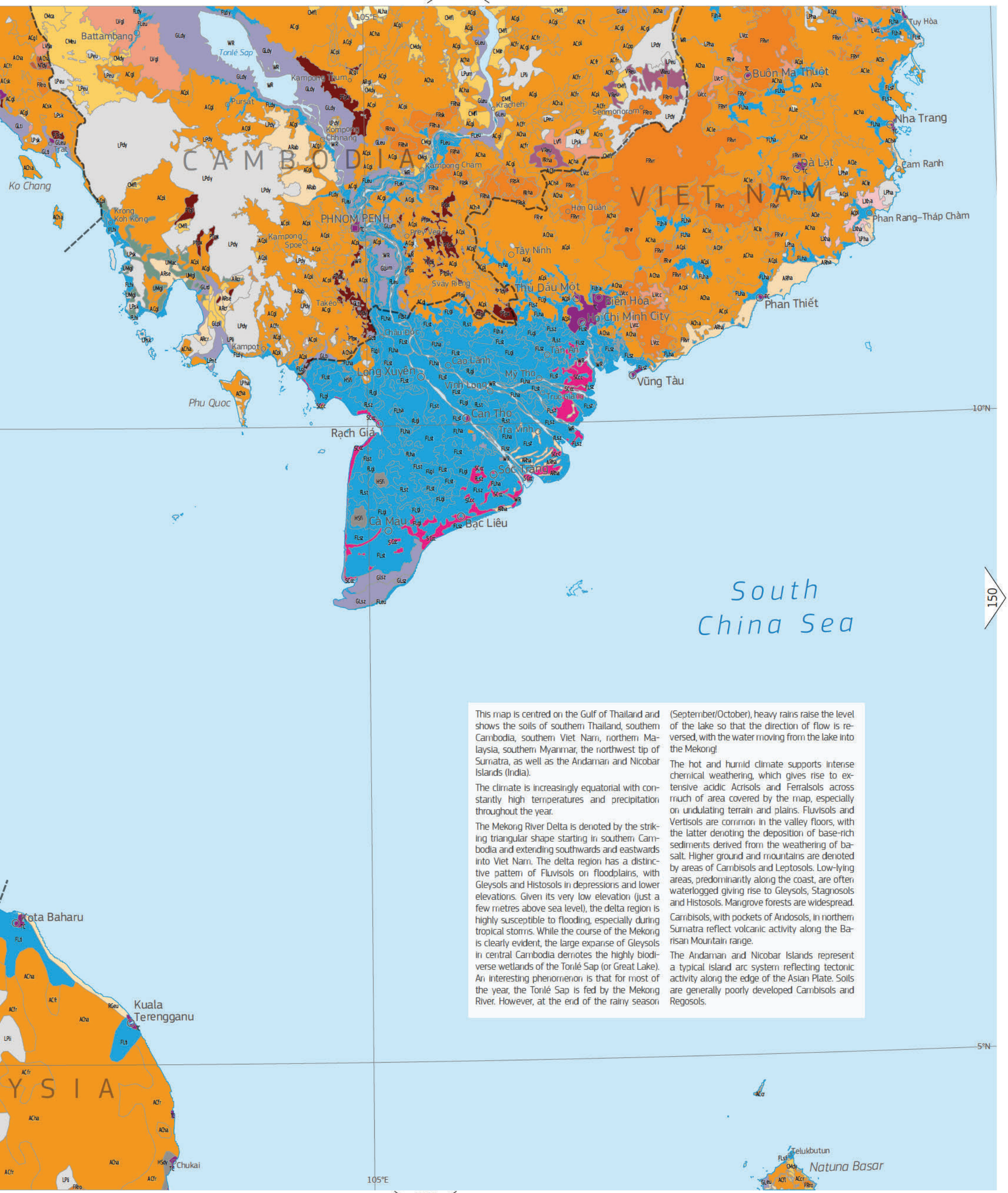
Car Nicobar

NICOBAR ISLANDS (INDIA)

Great Nicobar

Nicobar Islands (and South Andaman), India

152



This map is centred on the Gulf of Thailand and shows the soils of southern Thailand, southern Cambodia, southern Viet Nam, northern Malaysia, southern Myanmar, the northwest tip of Sumatra, as well as the Andaman and Nicobar Islands (India).

The climate is increasingly equatorial with constantly high temperatures and precipitation throughout the year.

The Mekong River Delta is denoted by the striking triangular shape starting in southern Cambodia and extending southwards and eastwards into Viet Nam. The delta region has a distinctive pattern of Fluvisols on floodplains, with Gleysols and Histosols in depressions and lower elevations. Given its very low elevation (just a few metres above sea level), the delta region is highly susceptible to flooding, especially during tropical storms. While the course of the Mekong is clearly evident, the large expanse of Gleysols in central Cambodia denotes the highly biodiverse wetlands of the Tonlé Sap (or Great Lake). An interesting phenomenon is that for most of the year, the Tonlé Sap is fed by the Mekong River. However, at the end of the rainy season (September/October), heavy rains raise the level of the lake so that the direction of flow is reversed, with the water moving from the lake into the Mekong!

The hot and humid climate supports intense chemical weathering, which gives rise to extensive acidic Acrisols and Ferralsols across much of area covered by the map, especially on undulating terrain and plains. Fluvisols and Vertisols are common in the valley floors, with the latter denoting the deposition of base-rich sediments derived from the weathering of basalt. Higher ground and mountains are denoted by areas of Cambisols and Leptosols. Low-lying areas, predominantly along the coast, are often waterlogged giving rise to Gleysols, Stagnosols and Histosols. Mangrove forests are widespread.

Cambisols, with pockets of Andosols, in northern Sumatra reflect volcanic activity along the Barisan Mountain range.

The Andaman and Nicobar Islands represent a typical island arc system reflecting tectonic activity along the edge of the Asian Plate. Soils are generally poorly developed Cambisols and Regosols.

Sheet 31 | S Philippines (Visayas, Mindanao, Palawan), Malaysia (N Sabah)



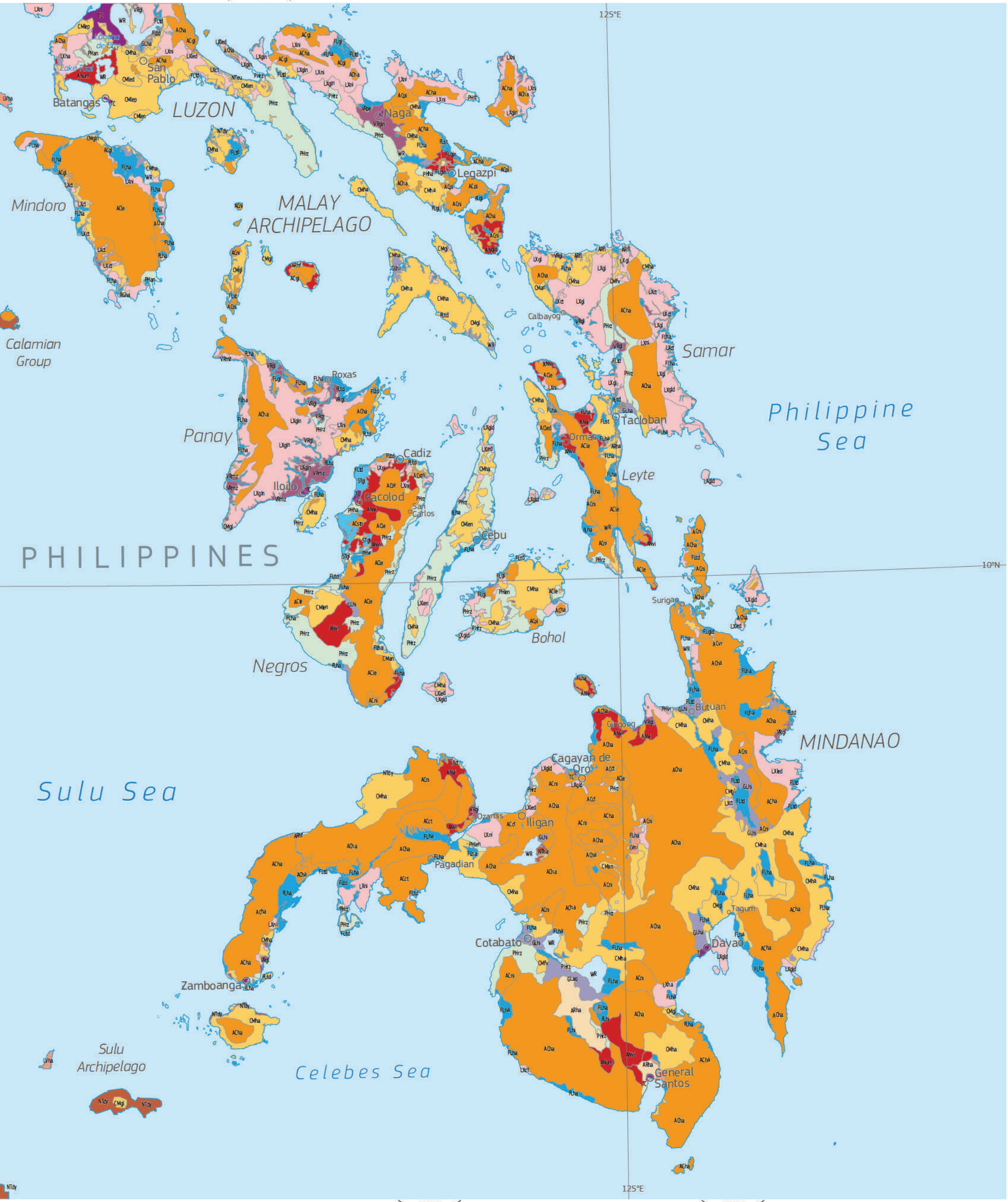
This map is centred on the Sulu Sea and shows the soils of the southern Philippine islands of Visayas, Mindanao and Palawan, together with the northern tip of Sabah on the island of Kalimantan (also known as Borneo). The area covered by the map has a tropical monsoon climate, which means that the temperature is relatively constant all year (around 27 °C) with high precipitation and humidity reflecting maritime influences (although the climate becomes more temperate with altitude).

The topography of the Philippines is varied with volcanic mountains, many still active, forming the core of the larger islands (e.g. the stratovolcano of Mount Apo on the island of Mindanao). Lowland areas are generally either narrow coastal strips or the floodplains of river valleys. Northeast Sabah is characterised by a series of low mountain ranges and plains with occasional hills.

Cambisols and Acrisols are the most common soil types in the Philippines. Vertisols are widespread, particularly in the level ground of the paddy rice fields and alluvial plains. Poorly drained, medium textured Cambisols are found on the level ground of the broad alluvial plains. Deep and well-drained, acidic Acrisols have formed in the weathering of basalt and andesite on undulating terraces and steep foot slopes of hills and mountains while Lixisols are found on upland areas. Very fertile Phaeozems with organic-rich topsoils can be found on stable limestone uplands in Luzon, Bohol, Cebu and other islands.

On the island of Kalimantan, consistently high temperatures and precipitation has caused intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols and Cambisols (all with low pH, nutrients and organic matter levels). Accumulations of peat (Histosols), with Gleysols, are widespread in waterlogged lowland basins of the Klagan, Sapi and Danum Rivers, which grade to saline Fluvisols under coastal mangroves that are subject to daily tidal flooding or river flows.

147


125°E
10°N
LUZON
MALAY ARCHIPELAGO
PHILIPPINES
Philippine Sea
Sulu Sea
Celebes Sea
MINDANAO
Mindoro
Calamian Group
Panay
Negros
Bohol
Leyte
Samar
Sulu Archipelago
Batangas
San Pablo
Laguna de Bay
Lake Taal
Naga
Legazpi
Roxas
Iloilo
Cadiz
Bacolod
San Carlos
Cebu
Tacloban
Ormoc
Calbayog
Surigao
Butuan
Gingoog
Cagayan de Oro
Iligan
Ozamis
Pagadian
Zamboanga
Cotabato
Davao
Tagum
General Santos

155 156



148

5°N

Equator

95°E

100°E

Lhokseumawe
Langsa
Simeulue
Nias
Sibolga
Padangsidempuan
Binjai
Medan
Tebingtinggi
Pematangsiantar
Danau Toba
Tarutung
Batu Is.
Siberut
Sipura
Padang
Bukittinggi
Padangpanjang
Sawahlunto
Pekanbaru
Pagai Utara
Pagai Selatan
Sungaipenuh
Taiping
Ipoh
Teluk Intan
Kuala Lipis
Raub
KUALA LUMPUR
Shah Alam
Kelang
Putrajaya
Seremban
Strait of Malacca
INDIAN OCEAN
MALAY ARCHIPELAGO
MAL
I N D O

Straddling the equator, this map shows the soils on the island of Sumatera (Indonesia) and the southern portion of the Malay Peninsula (southern Malaysia and Singapore), which are separated by the Straits of Malacca. The map also covers a small part of western Kalimantan island.

A pronounced equatorial climate means that most areas have constant temperatures all year (on average, 28 °C in the coastal plains, dropping with higher elevations). Annual precipitation and humidity are both high (around 2000 mm and between 70 and 90%, respectively).

A line of volcanoes runs along the western coast of Sumatra, which makes up the Barisan Mountain range (in Indonesian "Bukit Barisan"). Indonesia has more active volcanoes than any other country in the world reflecting tectonic process at the boundary between the Asian and Australian Plates. On the eastern part of Sumatra island, elevation drops rapidly to a series of large lowland plains with extensive swamps and mangrove forests. The plains are cut by several rivers that flow eastwards to the South China Sea.

Peninsular Malaysia is divided between by the Titiwangsa Mountains, which form a series of heavily forested mountain ranges running down the centre of the peninsula. They become lower in elevation towards the south and grade into flat and low-lying coastal plains. Several rivers flow off the western and eastern sides of the mountains. A similar topographic arrangement can be seen on the island of Kalimantan.

Differences in soil types generally reflect local geological conditions. Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols, Cambisols and Acrisols (predominantly on granite and rhyolite lava) with low pH, nutrients and organic matter levels). More fertile Andosols are found in intermediate lava flows and ash associated with the volcanic activity along the Barisan Mountains in Sumatra. Low lying areas are characterised by extensive accumulations of peat (Histosols), while Gleysols, are widespread in waterlogged lowland basins, which grade to saline Fluvisols under coastal mangroves. Fluvisols also denote the main river valleys and tidal flats. The dominant soils on the islands of Singapore, Bangka and Belitung are Acrisols and Cambisols with some light-coloured, deep, acidic Podzols.

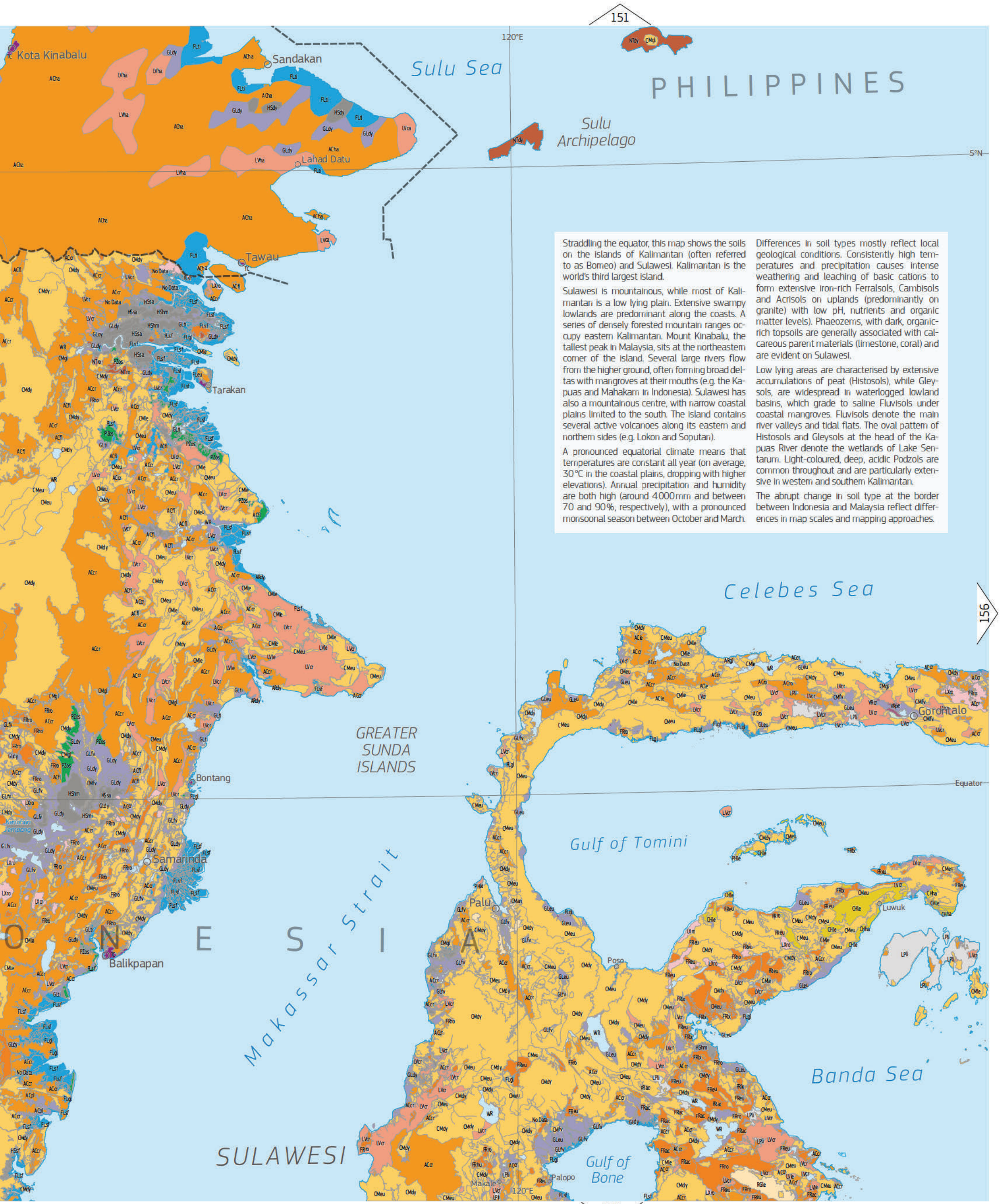
Lake Toba in northern Sumatra, which on the map is surrounded by Andosols, sits in the collapsed crater of a supervolcano that erupted 74000 years ago. Experts believe that this was the largest volcanic eruption on Earth in the past 25 million years and caused a drop in global temperatures.

158


149
105°E
5°N
Chukai
Kuantan
Malacca
Muar
Keluang
Batu Pahat
Johor Bahru
SINGAPORE
Strait of Singapore
Tanjungpinang
Pulau Tioman
Air Pasir
Telukbutun
Natuna Basar
Subi Besar
South China Sea
Riau Arch.
GREATER SUNDA ISLANDS
BORNEO
KALIMANTAN
Singkawang
Pontianak
Equator
154
Jambi
Palembang
Perabumulih
Lahat
Bengkulu
Pangkalpinang
Bangka
Belitung
Tanjungpandan
Java Sea
159



150
115°E
5°N
BRUNEI DARUSSALAM
BANDAR SERI BEGAWAN
Miri
Natuna Basar
South China Sea
Bintulu
MALAYSIA
Sibu
BORNEO
Kuching
153
Singkawang
Equator
Pontianak
KALIMANTAN
No Data
MALAY ARCHIPELAGO
Java Sea
Palangkaraya
Sampit
Kualakapuas
110°E
115°E
159



Straddling the equator, this map shows the soils on the islands of Kalimantan (often referred to as Borneo) and Sulawesi. Kalimantan is the world's third largest island.

Sulawesi is mountainous, while most of Kalimantan is a low lying plain. Extensive swampy lowlands are predominant along the coasts. A series of densely forested mountain ranges occupy eastern Kalimantan. Mount Kinabalu, the tallest peak in Malaysia, sits at the northeastern corner of the island. Several large rivers flow from the higher ground, often forming broad deltas with mangroves at their mouths (e.g. the Kapuas and Mahakam in Indonesia). Sulawesi has also a mountainous centre, with narrow coastal plains limited to the south. The island contains several active volcanoes along its eastern and northern sides (e.g. Lokon and Soputan).

A pronounced equatorial climate means that temperatures are constant all year (on average, 30°C in the coastal plains, dropping with higher elevations). Annual precipitation and humidity are both high (around 4000mm and between 70 and 90%, respectively), with a pronounced monsoonal season between October and March.

Differences in soil types mostly reflect local geological conditions. Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols, Cambisols and Acrisols on uplands (predominantly on granite) with low pH, nutrients and organic matter levels). Phaeozems, with dark, organic-rich topsoils are generally associated with calcareous parent materials (limestone, coral) and are evident on Sulawesi.

Low lying areas are characterised by extensive accumulations of peat (Histosols), while Gleysols, are widespread in waterlogged lowland basins, which grade to saline Fluvisols under coastal mangroves. Fluvisols denote the main river valleys and tidal flats. The oval pattern of Histosols and Gleysols at the head of the Kapuas River denote the wetlands of Lake Sentarum. Light-coloured, deep, acidic Podzols are common throughout and are particularly extensive in western and southern Kalimantan.

The abrupt change in soil type at the border between Indonesia and Malaysia reflect differences in map scales and mapping approaches.

Sheet 34 | Indonesia (Halmahera, Seram, Buru, W Western New Guinea)



151

125°E

Celebes Sea

Philippine Sea

Talaud Islands

Sangihe Islands

Manado

Gorontalo

Sulawesi

155

Equator

Molucca Sea

Morotai

Ternate

Tidore

Halmahera

Greater Sunda Islands

Luwuk

Peleng

Taliabu

Mangole

Sulabesi

Obi

Banda Sea

Buru

Amahai

Seram

Ambon

Kendari

161

This map is centered on the Maluku Islands (Indonesia) of Halmahera, Seram and Buru, together with the island chains of Bacan, Sulu Obi and Lease. The region of Papua (the western part of the island of New Guinea) occupies the right side of the map while the easternmost peninsulas of the island of Sulawesi can be seen extending into the Molucca Sea on the left of the map. While the precise boundary between the Asian and Pacific Plates is uncertain due to the complex pattern of tectonic plates in this area, the islands of Misool and New Guinea sit on the Australian Plate, and therefore, from a geological perspective, are not in Asia.

Most of the islands are the result of uplifted land due to the actions of the four tectonic plates that meet in this area. This is reflected by widespread seismic and volcanic activity. Most islands have a steep mountainous core, covered in dense rainforest. Mount Binaiya on the island of Seram is one of the most topographically prominent peaks on Earth, reaching an elevation of just over 3000 m from its base at sea level.

The climate is equatorial monsoonal. Annual average temperatures are about 26 °C with negligible variations throughout the year. Precipitation levels are high and increase southwards (mostly falling during October to April). While the mountains can cause temperatures to drop, they also increase precipitation so that over rainfall of over 3000 m per year is common.

Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols, Cambisols and Acrisols (resulting in soils with low pH, nutrients and organic matter levels). Lixisols, with higher pH, can be found on deeply weathered limestone. Calcisols on the islands of Buru and Seram reflect a well-developed karst landscape with some of the deepest caves in the world. Andosols on the northeastern peninsula of Sulawesi and the north of Halmahera reflect soil development on the volcanic ejecta of Mount Tarigkoko and Dukono, respectively. Flat areas are located in narrow strips near the coast and along the banks of rivers and are denoted by the presence of Fluvisols.

Although not geologically in Asia, the Papua Region exhibits a diverse range of soil types. Low lying areas, particularly along the coast, are characterised by extensive accumulations of peat (Histosols). These are evident along the southern coastline. The tectonic activity described above has resulted in the uplift of the Maoke Mountains, which occupy much of inland. The highest areas are depicted by the pattern of Leptosols that run parallel to the south coast. The highest peaks are covered in ice and snow all year. Gleysols, are widespread in lowland waterlogged basins, which grade to saline Fluvisols under coastal mangroves. Fluvisols denote the main river valleys and tidal flats. The large area of Histosols and Gleysols on the north coast of the region denote the floodplain and mouth of the Mamberamo River, which is known as the Lakes Plains region.

The grey line to the west of the island denotes the boundary between the Asian, Australian and Pacific Plates.



Sheet 35 | Indonesia (S Sumatera, Jawa, Bali, Lombok, S Kalimantan)



153

105°E

5°S

10°S

Jambi
Sungaipenuh
Pangkalpinang
Bangka
Belitung
Tanjungpandan
Palembang
Perabumulih
Bengkulu
Lahat
Kotabumi
Bandar Lampung
Enggano
Serang
JAKARTA
Bekasi
Indramayu
Bogor
Cirebon
Sukabumi
Bandung
Tasikmalaya

South China Sea

Greater

Sumatra

I N D I A N

Lying south of the equator, this map is centred on the shallow Java Sea, and shows the soils of southwestern Kalimantan (also known as Borneo) in the north of the map, southern Sumatra (to the left), Jawa, Bali, and a part of Lombok.

As evidenced by the soil patterns, this is a mountainous region, flanked by extensive swampy lowlands along the coasts. The Greater and Lesser Sunda Islands are dominated by a chain of volcanoes that runs along their southern coastlines. These volcanoes are known as the Banda Arc and reflect eruptions due to the subduction of the Australian Plate northeastwards under the Eurasian Plate. There are more than 40 active volcanoes on Jawa alone. From the mountains, forested terrain drops to a series of coalescing lowland plains, that are extensively cultivated for wet-rice and coffee.

The southwestern corner of Kalimantan consists of a series of low hills that increase in elevation towards the northeast. To the southeast, extensive low-lying swampy plains are crossed by rivers, such as the Katingan, Sebangau and Kahayan. Unlike the islands to the south, there is no active volcanism in this region.

A pronounced equatorial climate means that temperatures are constant all year (on average, 30 °C in the coastal plains, dropping with higher elevations). Annual precipitation and humidity are both high (around 3000 mm and between 70 and 90 %, respectively), with a pronounced monsoonal season between October and March/April.

On Sumatra, Jawa, Bali and Lombok, extensive Andosols have developed on lava flows and ash deposits adjacent to volcanic cones and vents. These are often associated with Cambisols where soil profiles are less developed. Erosion and subsequent transport of volcanic material by rivers has resulted in thick, fertile alluvial plains along river valleys. These are denoted by Fluvisols, together with Vertisols (especially on Jawa). Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols and Acrisols on hilly terrain in Sumatra, western Jawa and on Kalimantan. In these areas, pH, nutrients and organic matter levels are all low.

Low lying areas throughout the map are characterised by extensive accumulations of peat (Histosols). In the swamps of Kalimantan (around the Kahayan River) and southeastern Sumatra (the delta of the Musi River), Histosols vary from 0.5 m to more than 10 m thick. Fluvisols denote the main river valleys and tidal flats, often occurring with Gleysols that are widespread in waterlogged lowland basins. Under coastal mangroves, Fluvisols exhibit elevated saline levels. The dominant soils on the islands of Singapore, Bangka and Billiton are Acrisol and Cambisols, with some light-coloured, deep, acidic Podzols. Histosols are not found on Jawa, Bali or Lombok islands.


110°E
115°E
5°S
10°S
B O R N E O
K A L I M A N T A N
Palangkaraya
Sampit
Kualakapuas
Bandjarmasin
Martapura
S u n d a I s l a n d s
O N E S I A
J a v a S e a
Bawean
L e s s e r S u n d a I s l a n d s
Madura I.
Tegal
Pakalongan
Semarang
Pati
Tuban
Sumenep
Surabaya
Salatiga
Magelang
Surakarta
Yogyakarta
Cilacap
Madiun
Kediri
Mojokerto
Pasuruan
Probolinggo
Blitar
Malang
Jember
Banyuwangi
Bali
Singaraja
Denpasar
Kuta
Lombok
Mataram
Praya
Java
O C E A N



This map is centered in the Flores Sea which is bounded by the Lesser Sunda Islands of Sulawesi, Lombok, Sumbawa, Flores and Buru. Further south are the islands of Sumba and the Timor archipelago. The inset show the Tanimbar and Kai Islands that lie just to the east of the map sheet. The coastline of Australia lies only 500 km to the southeast. The boundary between the Asian and Australian Plates runs along the Timor Trough (parallel to the Timor-Leste coast), which is more than 3000 m deep in places.

An equatorial climate means that temperatures are constant all year. On average, western islands are warmer and more humid with annual temperatures of around 30 °C and annual precipitation around 2000 mm. Towards the east, both annual temperatures and precipitation drop to around 25 °C and 1500 mm in Timor-Leste. All areas experience a strong monsoonal season with most of the rain falling between November/December and March/April.

The dominant physical feature is the chain of volcanoes that runs from east to west through the centre of the map. These volcanoes reflect the subduction of the Australian Plate northeastwards under the Eurasian Plate (a continuation of the feature shown on Sheet 35). Almost all islands have a mountainous volcanic centre, with land dropping steeply towards narrow coastal plains. On the larger islands, the peaks are separated by river valleys (e.g. Flores). Souther Halmahera, Sumba and Timor-Leste are the result of uplifted land due to the intense tectonic activity in this area, with volcanic activity lacking on the latter two islands.

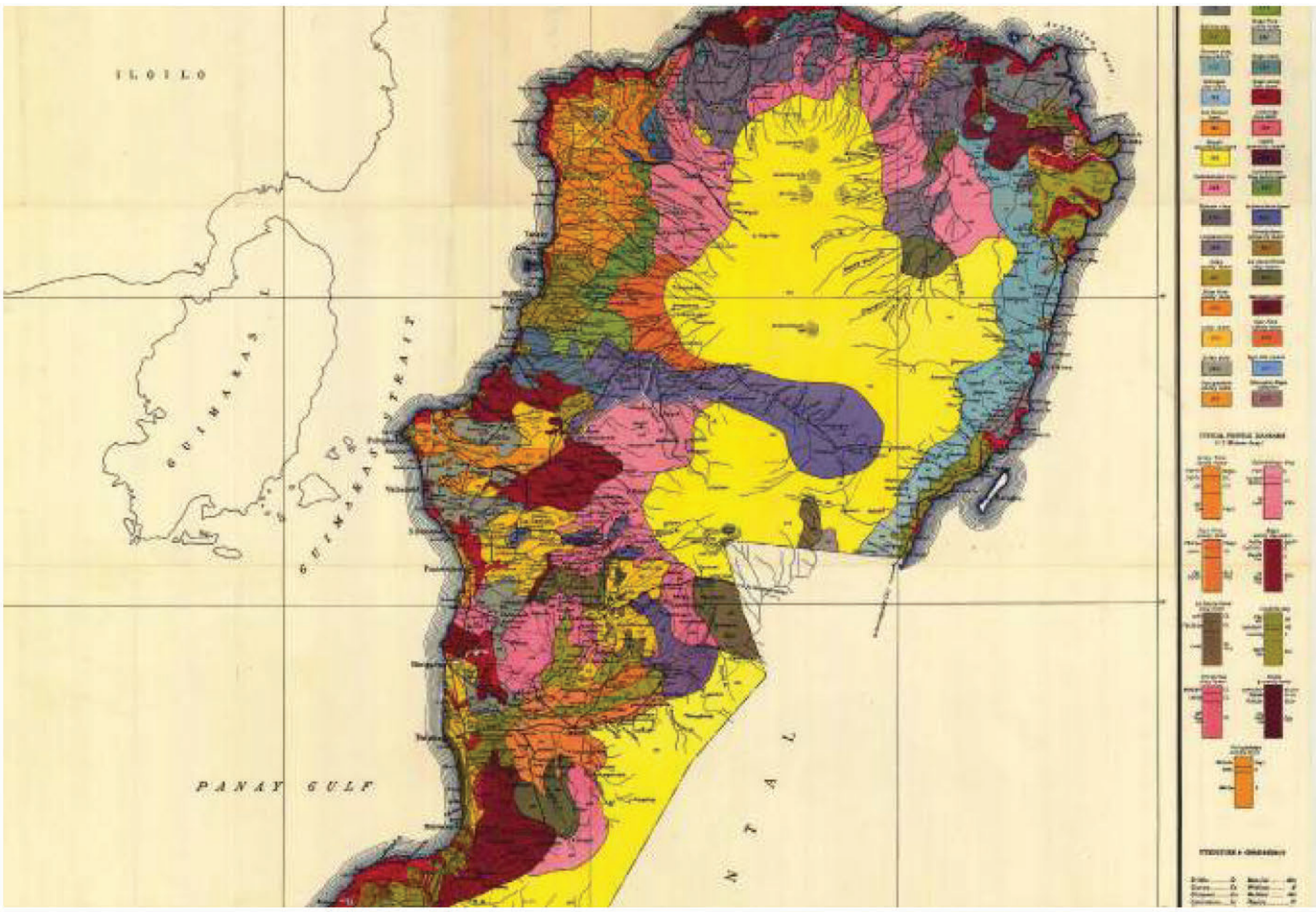
Most of the Lesser Sunda Islands are characterised by extensive Andosols that have developed on lava flows and ash deposits adjacent to volcanic cones and vents. Erosion and subsequent transport of volcanic material by rivers has resulted in fertile Vertisols and Fluvisols on alluvial plains along river valleys. Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols and Acrisols on hilly terrain in Halmahera and northern Timor. In these areas, pH, nutrients and organic matter levels are all low. Phaeozems, with dark, organic-rich topsoils are generally associated with calcareous parent materials (limestone, coral) and are evident on the islands of Flores, Timor and Sulawesi.

Unlike most of the islands shown on this map, the soils of Sunda are calcareous while on the island of Timor, a highly diverse collection of soil types reflects a range of parent materials. These include leached acidic Acrisols and Ferralsols on sloping ground, Lixisols with high pH on calcareous deposits, Kastanozems under savannah landscapes, Fluvisols and Vertisols in river valleys and floodplains, with Histosols (Sulawesi only) along the coast and in depressions. Mountainous regions are characterised by Leptosols and Cambisols.


Tanimbar Islands, Kai Islands (and Aru Islands)
156
125°E
130°E
5°S
10°S
Seram Sea
Sulawesi
Kendari
Baubau
Watubela Archipelago
INDONESIA
Banda Sea
Kei Kecil
Kai Besar
Kai Islands
Adi Island
Aru Islands
Arafura Sea
Babar
Babar Islands
Yamdena
Tanimbar Islands
MOLUCCAS
Damar
Romang
Wetar
Alor
Leti Islands
Sermata Islands
Babar
Maumere
DILI
TIMOR-LESTE
Timor
Kupang
Timor Sea

Examples of medium-scale soil maps





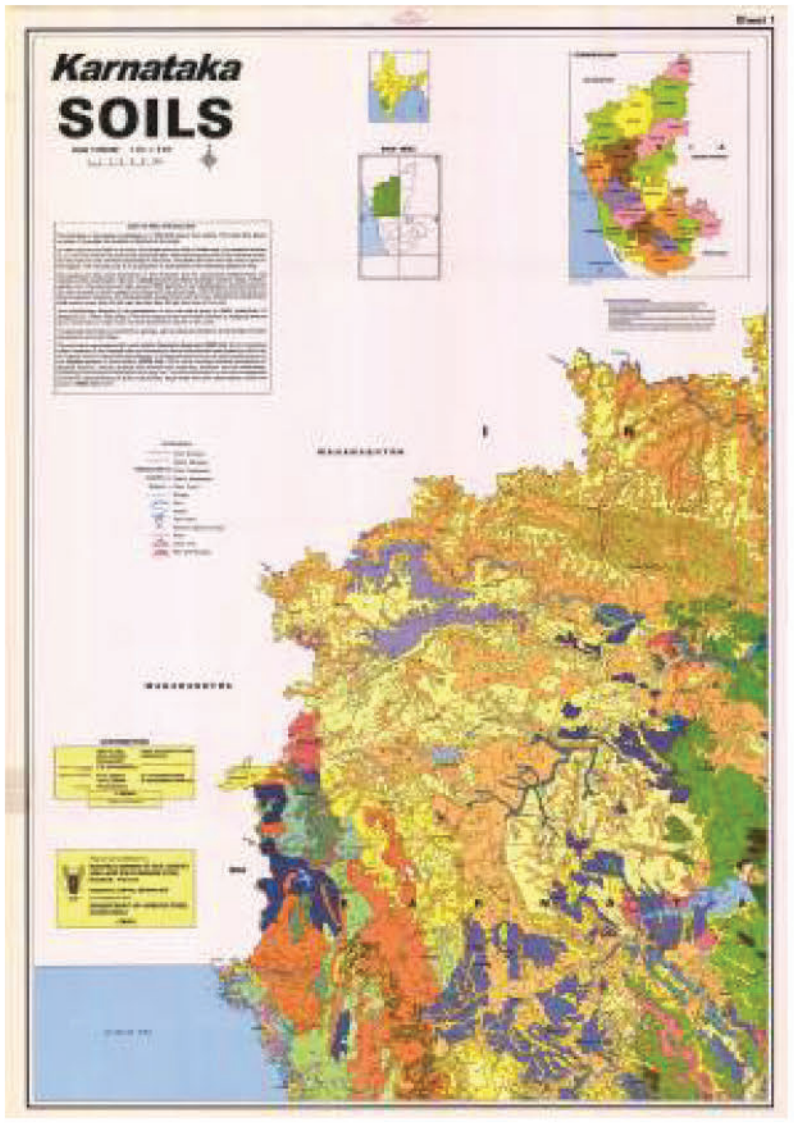
Medium-scale maps

As explained on page 69, maps can be prepared at a variety of scales. The preceding pages show soil patterns across Asia at a scale of 1:3 million (i.e. where 1 cm on the map corresponds to 30 km on the ground). Such maps are referred to as small-scale and provide an overview of general soil patterns over large regions. Conversely, large scale maps (e.g. 1:50 000–1:5 000) cover much smaller areas, such as a region or a town, but in much greater detail.

The use of 'large' or 'small' to describe maps arose from the traditional practice of writing map scales as numerical fractions where a scale of 1:20 000 is larger than 1:20 000 000. There is no exact definition of the boundary between large and small scale maps but those with scales of 1:500 000–100 000 are generally considered as being of a medium-scale. In this context, medium-scale maps show more detail for a given area than small–scale maps but may still be too coarse for specific applications (e.g. assessing pH or salinity levels for a field).

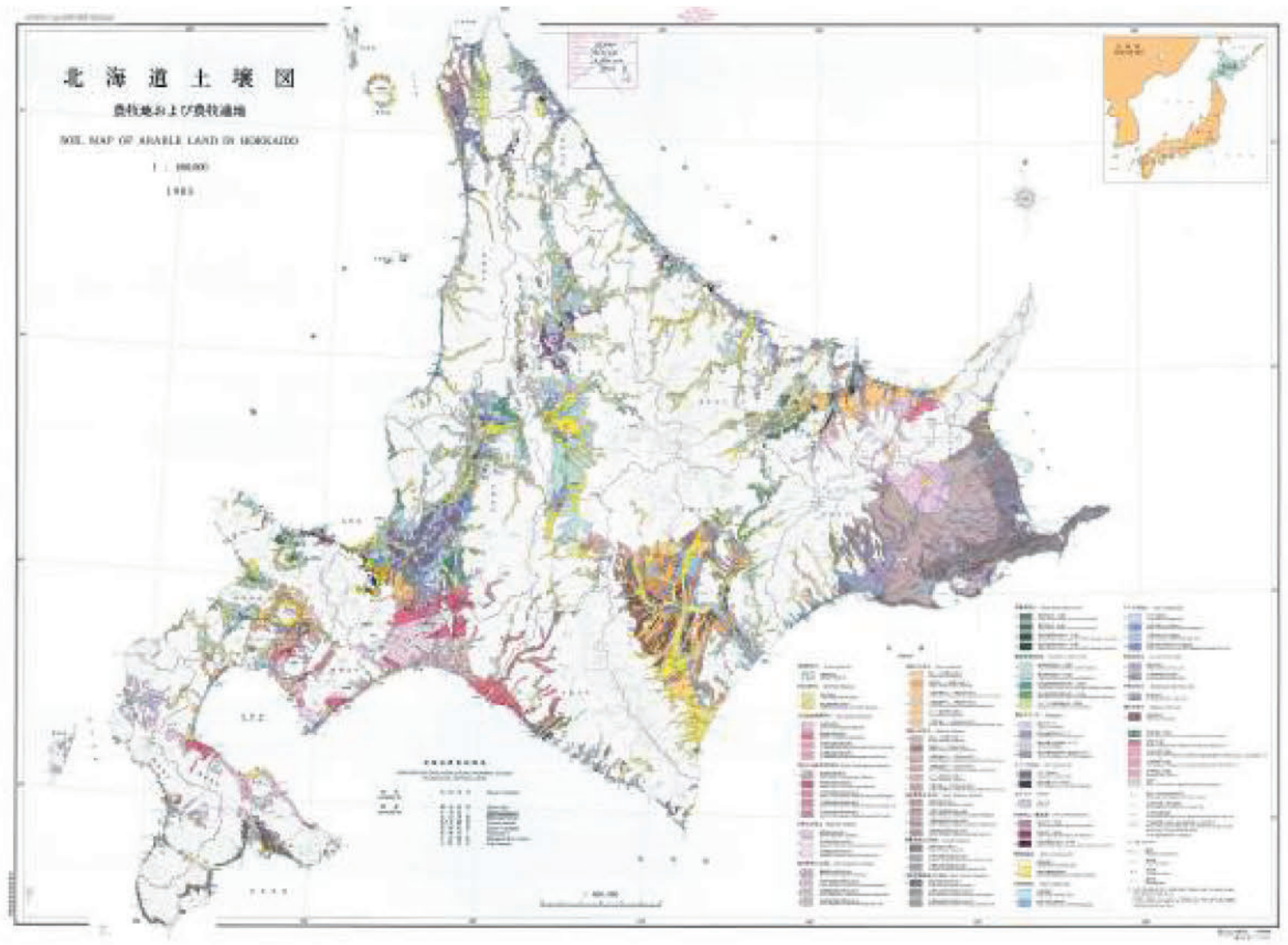
The images on these two pages are examples of medium-scale soil maps from different parts of Asia. While some are a little dated, they clearly show a substantially higher level of detail than the maps of the same area in the preceding pages. Please note that the colours and legends shown on these four examples reflect national soil mapping and classification schemes and may not necessarily match the patterns shown on the smaller scale equivalents shown in this atlas.

The maps on this page (and many others) can be downloaded from the EuDASM and similar map archives (see page 173).



Clockwise, from top of opposite page:

- reconnaissance soil map of the floodplain of the Kabadak River, a distributary of the Ganges in southwestern Bangladesh. Distributary channels flow away from a main stream channel (as opposed to tributaries) and are a common feature of deltas. The blue colours in the lower part of the map denote soils that have developed in tidal deposits (1:126 720 - 1959; EuDASM);
- one of four sheets that makes up the soil map of Karnataka in western India. The legend provides a description of the dominant soil type and highlights the soil depth, drainage, texture, slope, erosion and salinity. (1:500 000 - 1996: National Bureau of Soil Survey and Land Use Planning Nagpur);
- soil map of cultivated land on Hokkaido Island in Japan. The volcanic origin of these soils is highly evident in the legend as are soils that have been buried by volcanic ejecta. (1:600 000 - 1985: Hokkaido National Agricultural Experiment Station);
- soil map of the western part of Negros Island, the 4th largest of the Philippine islands. The map legend is based on soil texture apart from the yellow region, which is described as 'rough mountainous land'. (1:200 000 - 1996: Division of Soil Survey and Conservation).



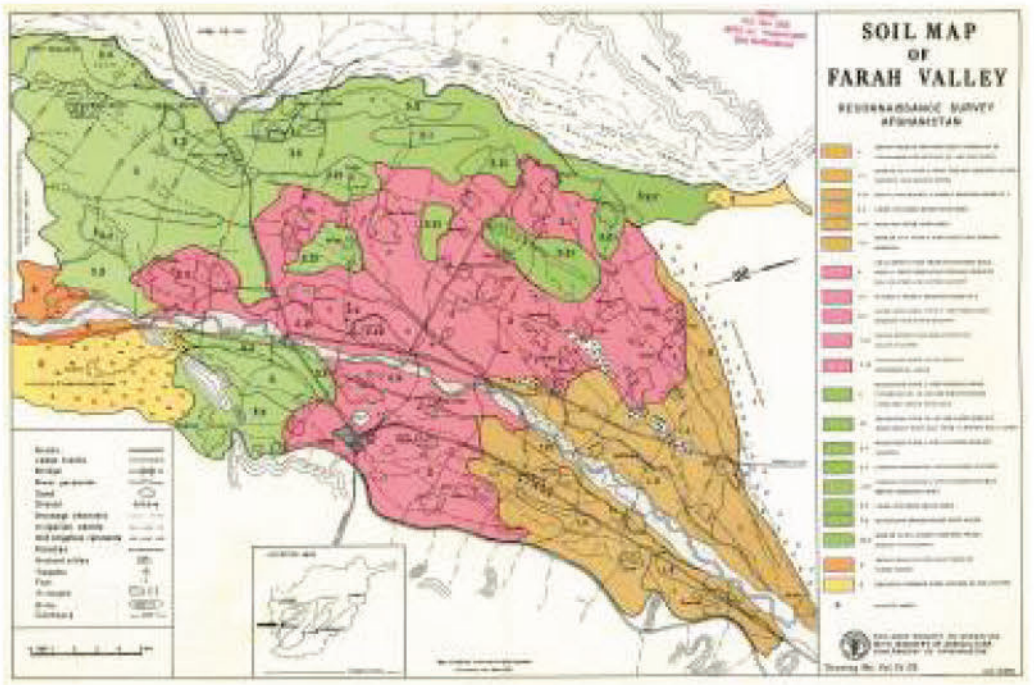
Examples of large-scale soil maps

Large-scale maps

Large-scale maps generally have a scale of 1:50 000 or greater (e.g. 1:24 000; 1:10 000; 1:5 000). A large-scale map shows greater detail for a relatively small area (e.g. 100 × 100 km, 10 × 10 km, individual farms). As the scale increases, the detail of the soil patterns becomes more and more evident. For example, on a 1:10 000 scale, 1 cm on the map corresponds to 100 m on the ground.

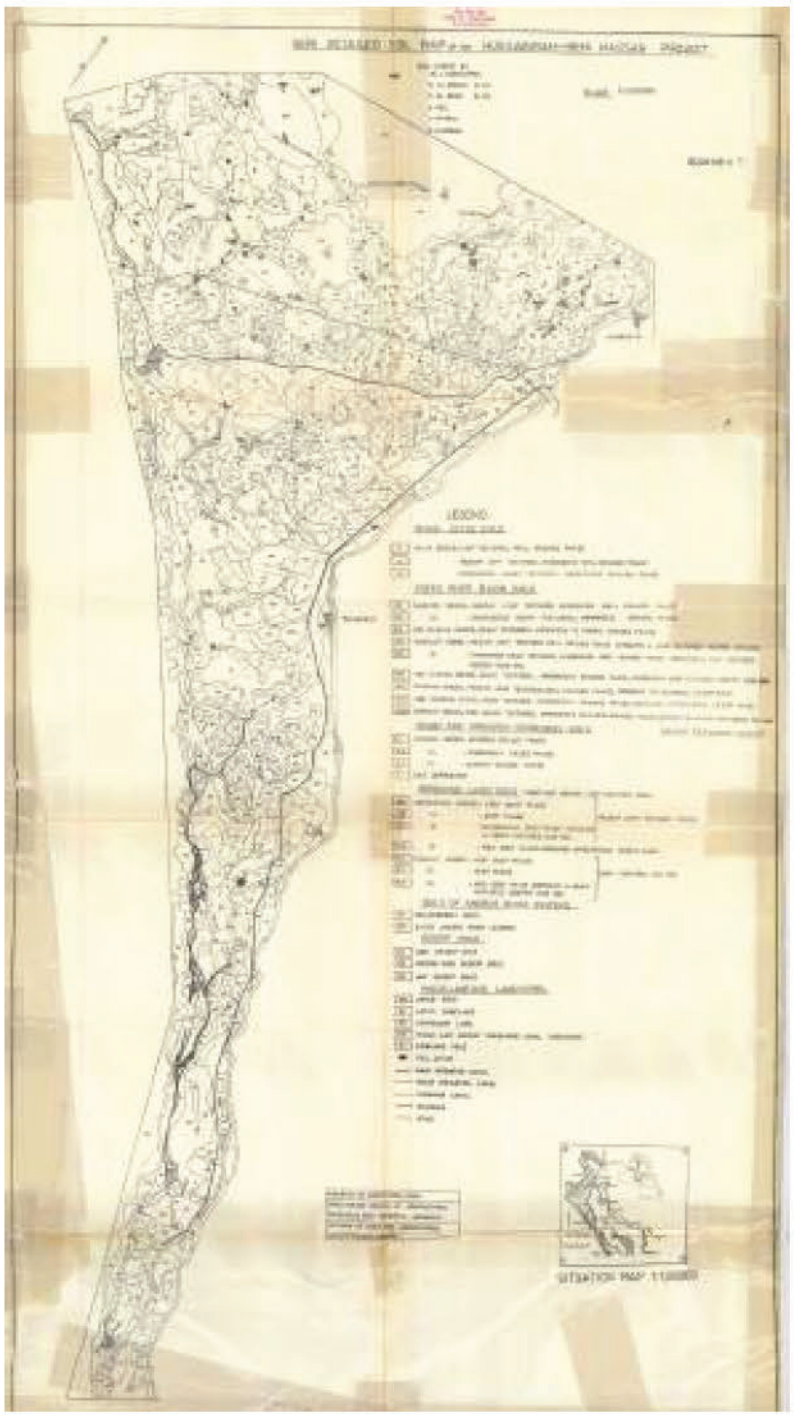
By definition, the creation of these maps entails a significant amount of effort to acquire the necessary source data. As a consequence, they tended to be produced only where the principal land use was agriculture. Large-scale maps are used to support land evaluation or the implementation of land use planning policies.

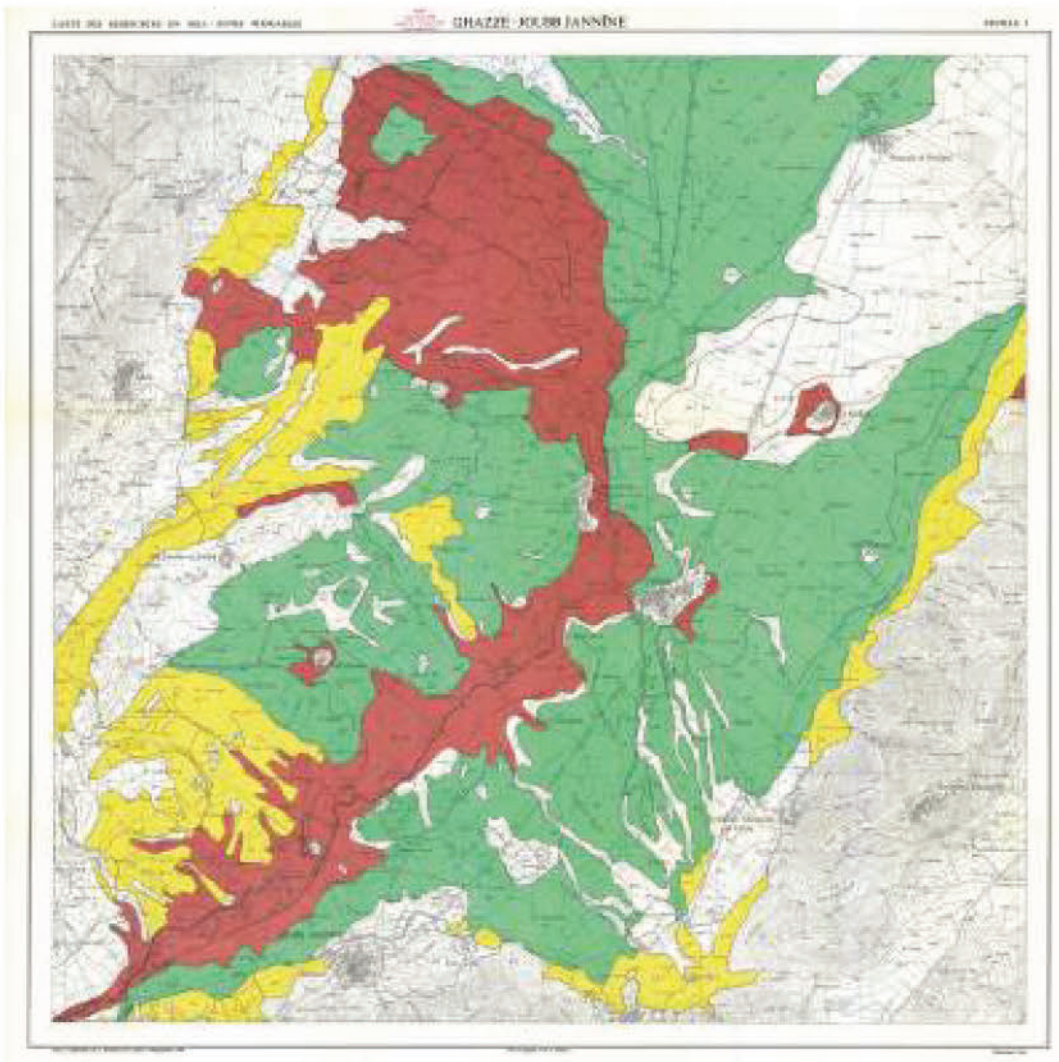
However, earth observation technologies (e.g. satellites, drones) and precision agriculture systems on tractors can generate highly detailed field-level maps relatively quickly.



Clockwise, from top-right:

- detailed soil map of part of the Farah Valley in Afghanistan. The map differentiates soils on the basis of texture, depth and drainage class. The identification of alluvial soils is important as nutrient levels in this area are generally low. The locations of sites that have been sampled for salinity are indicated as crosses. The green areas on the map are mostly Solonchaks and other saline soils, which are problematic for most crops. (1:10 000 – 1961: FAO);
- a very detailed soil map of an area close to Al Hussainiyah in central Iraq. The map was produced to support an agricultural suitability project that was investigating drainage and soil salinity issues. (1:10 000 – 1958; EuDASM);
- an example of a drone image of a rice field. Such detailed images can be used to create very large-scale maps that show the variation of soil characteristics in a single field. (MN);
- map showing soil types and irrigation class around the town of Joub Jannine in the Western Beqaa Valley in Lebanon. The brown coloured zone running through the centre of the map denotes silty alluvial soils with class 1 irrigation flanked on either side by red clay-rich red soils in green. (1:20 000 – 1968: Lebanese Republic Institute for Agronomic Research).







Soil mapping in the Republic of Korea: a model for Asia?



This atlas has shown the importance of understanding the spatial distribution of soils and their properties. This is especially true for agricultural development and a more rational management of land resources, particularly in response to issues such as ongoing land degradation, decreasing yields and climate change mitigation. To be effective for such purposes, soil data should be available at large-scales (preferably >1:50000). However, this level of detail is lacking for most of Asia. The situation is compounded by the fact that the detailed data that do exist are often more than 50 years old and systematic soil survey is not being carried out to collect more up to date data.

A country which stands out in this respect is the Republic of Korea. Not only is there a complete and detailed soil inventory of the country, the data have been digitised and can be viewed and queried over the internet. In this respect, the Republic of Korea could be a model for other Asian countries to follow in the establishment of a soil information system.

Between 1964 and 1999, extensive national soil survey projects were carried out as part of the United Nations Special Fund. Reconnaissance soil surveys were carried out from 1964 to 1969 over relatively wide areas. The printed soil map resulting from these surveys was produced at a scale of 1:50000 with a minimum mapping unit of 6.25 ha. This map has supported various policies, such as comprehensive land development plans.

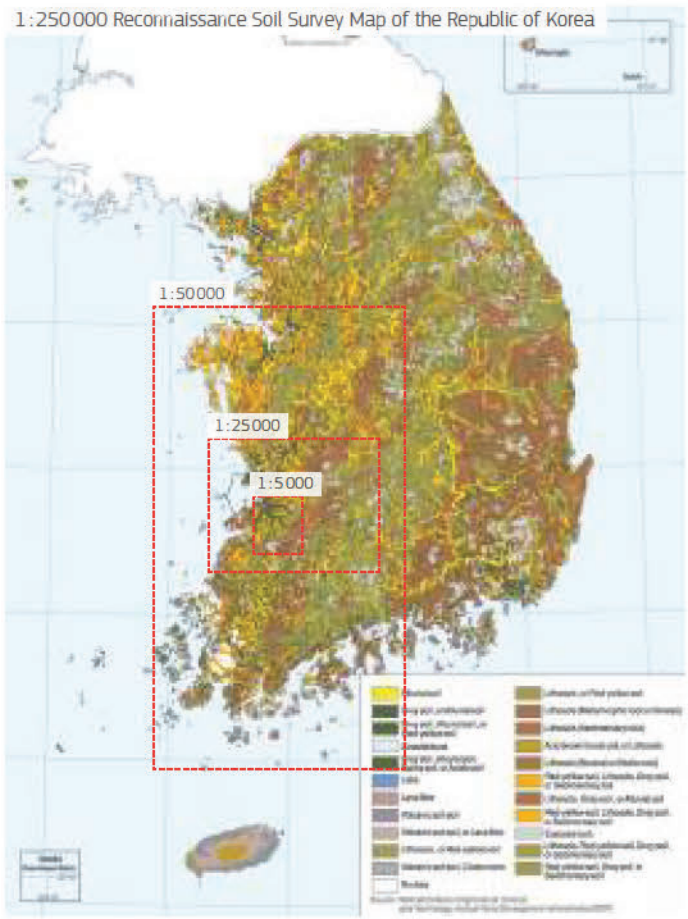
Between 1968 and 1990, soil mapping at a scale of 1:25000 was undertaken across the country. Even more detailed surveys at a scale of 1:5000 also began in 1980. By now, a total of 9586407 ha, or 96.6% of the Republic of Korea's total area has been surveyed. Only the areas surrounding the Military Demarcation Line and newly reclaimed lands are still to be mapped.

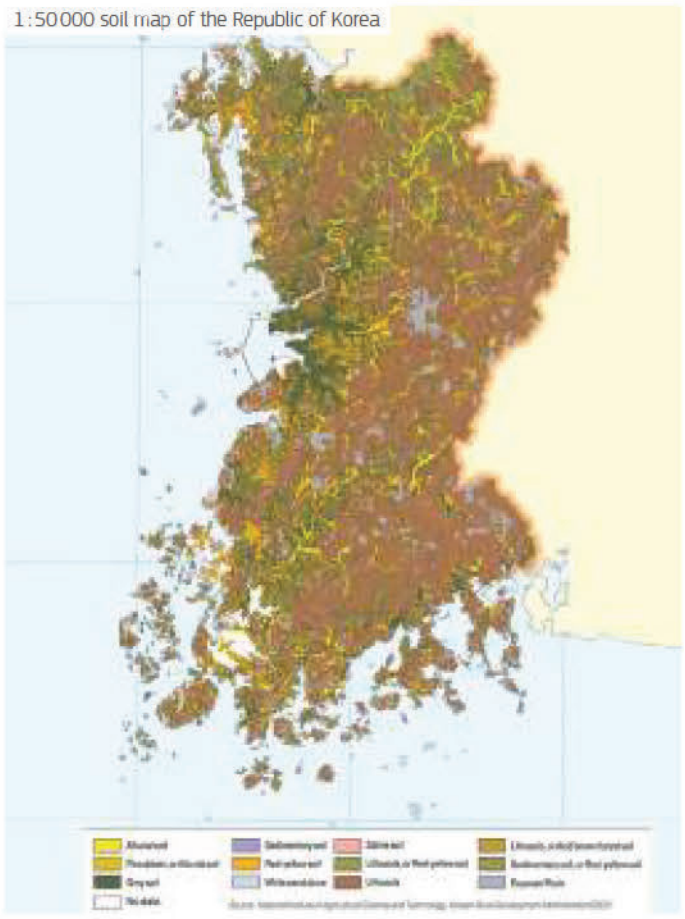
More than 405 soil series have been identified and over 17000 maps have been produced since the process began almost 60 years ago. The base maps for the highly detailed 1:5000 soil map were produced by the National Geographic Information Institute and include a digital topographical model at the same scale with contour lines at an interval of 1 m. Continuous cadastral maps were produced by combining the individual cadastral maps managed by the local government offices and reedited after correcting them to fit the landform of the topographic map. The detailed soil map and the edited cadastral maps are jointly used to check the characteristics of soils by parcel. Data from farmland ledgers, which is managed by local governments, are used to check farmer information and the area of parcels. These data are then supplemented by chemical data obtained by analysing soil samples. These include pH, organic matter content, effective phosphoric acid levels, calcium, magnesium, potassium, electrical conductivity, effective silicic acid, and the demand for lime.

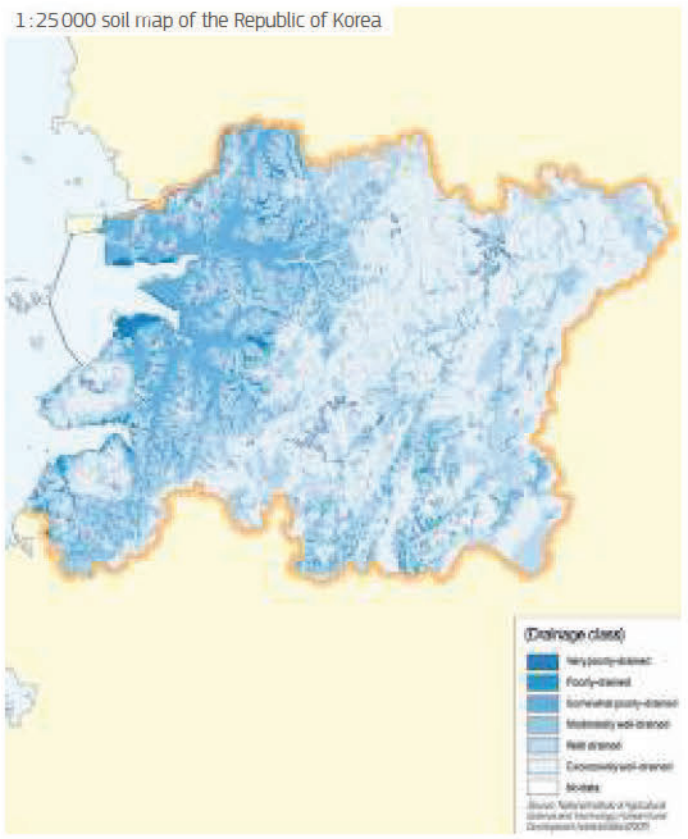
The resulting database has become the key instrument for the description of the physical environment that farmers face in the different agricultural regions of the country and for the evaluation of the agricultural potential.

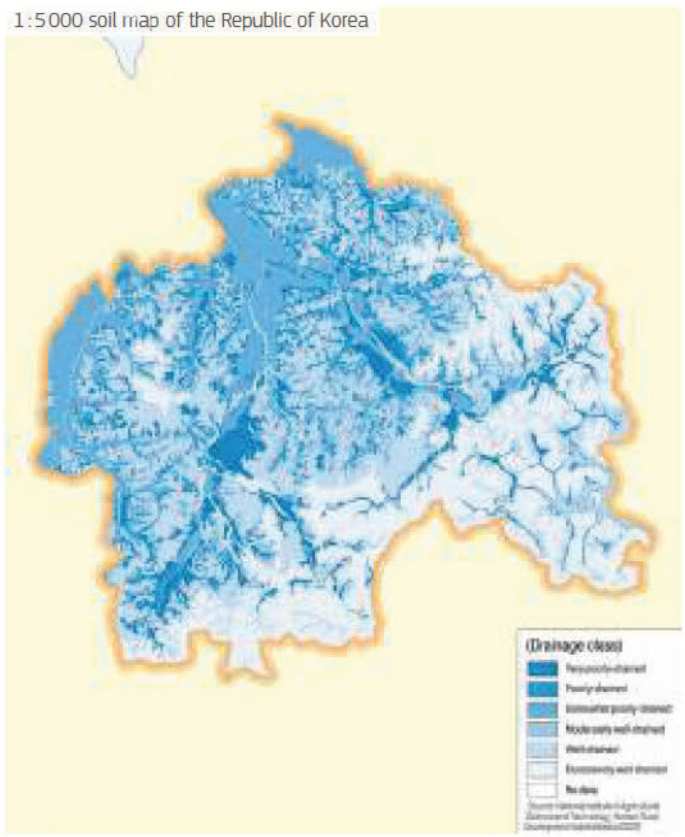
Such information is also important for urban planning, hazard assessment and the development of high-input agriculture schemes. The system allows for easy updating, modification or reorientation depending on the requirements of the different policy sectors.

For more information, please visit [98].



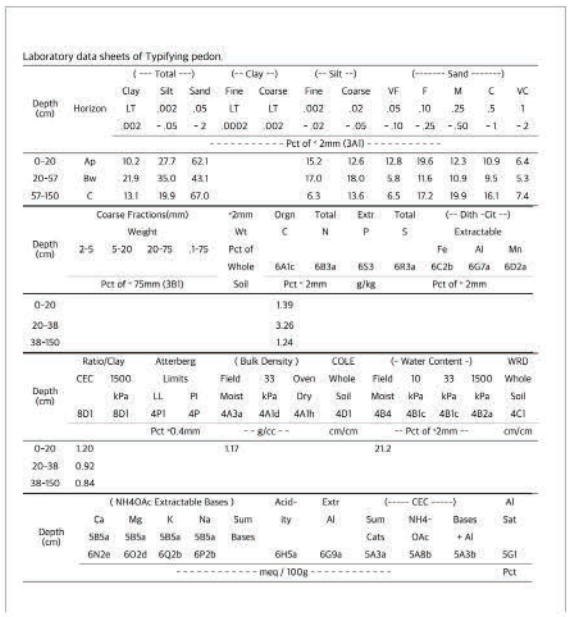






Examples of the multi-scale mapping exercises that underpin the Korean Soil Information System. A Reconnaissance Soil Survey Map at a scale of 1:250000 is supplemented by maps at 1:50000, 1:25000 and 1:5000 scales. (RDA)

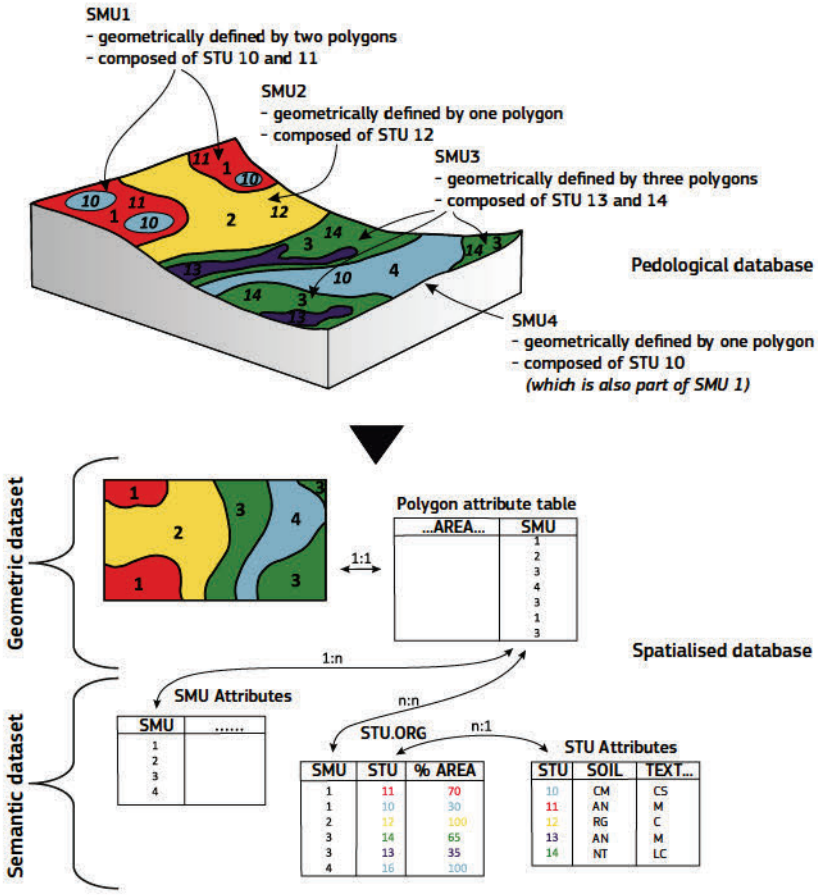




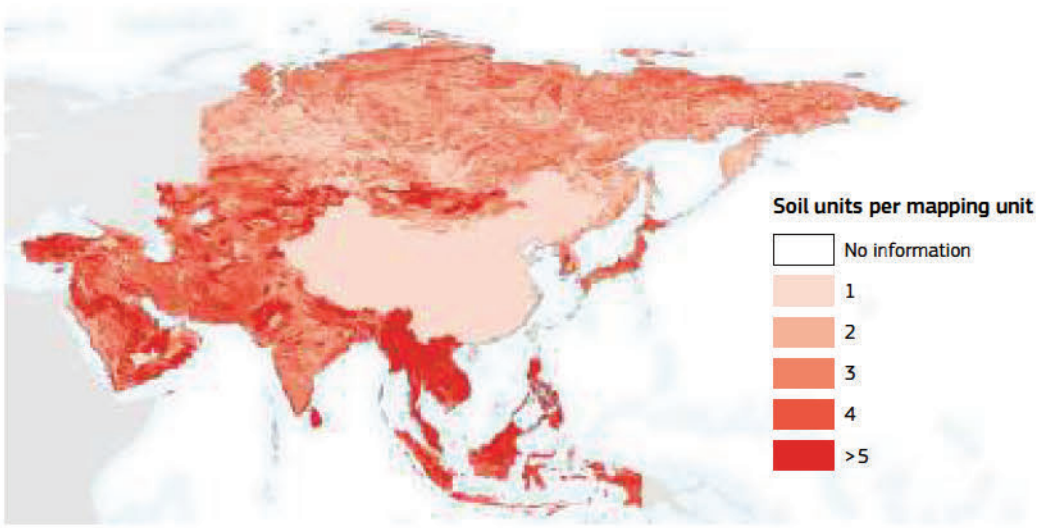
Expanded detail of the Abgog Soil Series from the online query system, which also produced results on soil characteristics from the underlying database. (RDA)

Maps of key soil properties

The following pages present a series of overview maps describing how soil properties vary across Asia. The maps are based on the Harmonised World Soil Database (see page 170). The very small scale used for these maps will inevitably mask specific local conditions. However, the broad patterns are representative of regional soil-forming factors and processes.



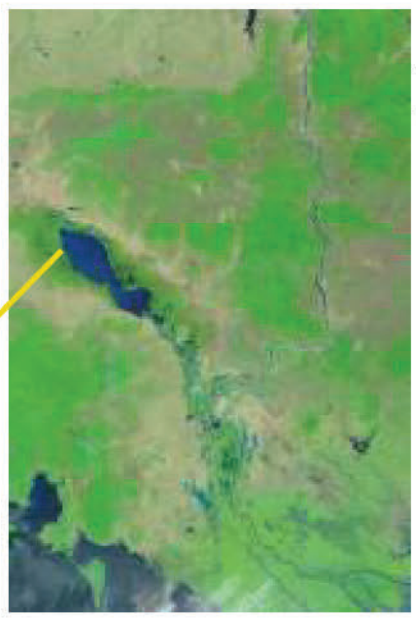
The Harmonised Soil World Database uses a simple relationship model to link a geometrical dataset (grid cells) and a semantic dataset (information on soil properties). The diagram illustrates how a geographical representation of soil and landscape patterns (known as Soil Mapping Units or SMUs) are linked to specific data on soil types (referred to as Soil Typological Units or STUs in this figure). Try and follow the diagram to understand that polygon 1 from the digital map (the red area), corresponds to SMU 1, which consists of two soil types (STU 10 and STU 11), which occupy 30% and 70% of area of SMU 1 respectively. In this example, analysis of the relationship table (STU.ORG) and the STU attribute table would show that the dominant soil of SMU 1 (i.e. STU 11) is an Andosol (AN). (JRC)



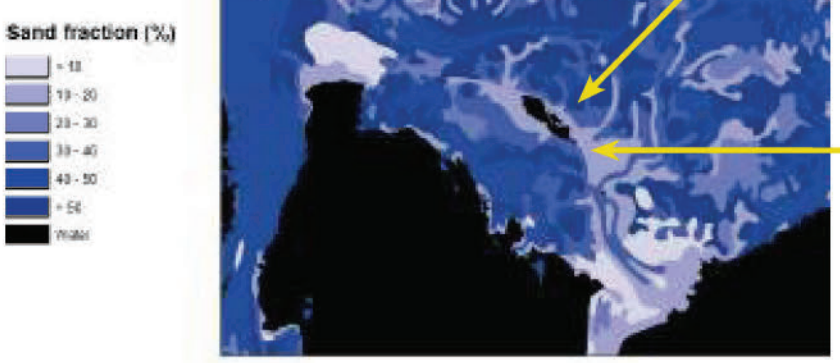
The map shows the variability of soil information in the database for Asia. As shown by the adjacent figure, each cell in the Harmonized World Soil Database can contain up to nine soil types. While the geographic locations of the component soil types within each cell are not defined, the database stores the typical proportion that each one occupies. When the mapping unit is composed of only one soil type, this percentage is equal to 100 (e.g. China). When there are several soil types, then the sum of the percentages is equal to 100% (e.g. one soil type may occupy 70% of the area of the polygon while a second soil type will occupy the remaining 30%). It should be noted that these areas are not necessarily contiguous - in this manner, a value of 30% could represent a soil that is found in many small patches across the area of interest.

Areas with lighter tones (e.g. Siberia) signify a lower number of soil types per mapping unit while darker areas (e.g. southeast Asian parts of the Arabian Peninsula) have more. It should be stressed that this variability is usually a reflection of the level of soil survey in a region as much as than the actual diversity of soil types.

In the case of the following property maps, data are presented for the dominant soil type within each cell (i.e. the soil having the highest percentage of area). However, it should be noted that only a proportion of the grid cell will have the assigned characteristic (unless there is only one type of soil!). (MM/YY)



A satellite image of the Tonlé Sap lake with the floodplain extending to the southeast. (NASA)





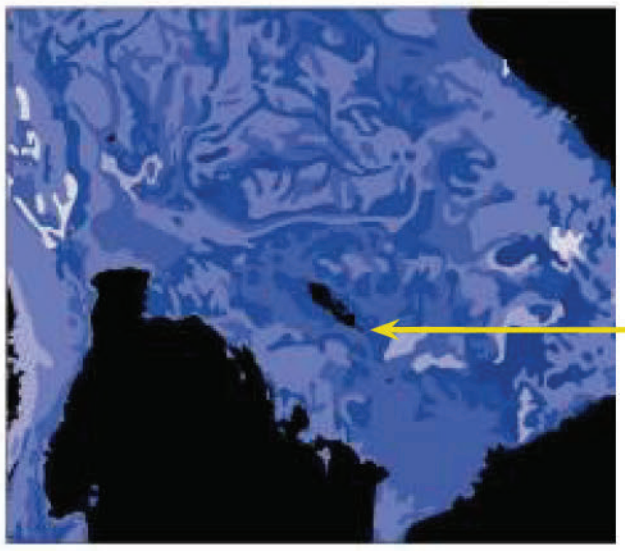
The dominant soil for the polygon indicated by the arrow is a relatively fine Gleysol that has formed on the floodplain of the Tonlé Sap River. (AC)

This pair of maps show how the depiction of soil properties can vary according to the selection of the dominant soil type. Both maps show the proportion of sand particles in the topsoils around the Gulf of Thailand. The darker shades denote increasing levels of sand-sized particles in the soil (and thus a coarser soil texture). Lighter toned areas have low levels of sand. Black areas denote the sea and lakes (e.g. the Tonlé Sap in Cambodia is just to the left of the arrow). Note the differences in the patterns of the two maps.

The upper map shows the proportion of sand particles for the dominant soil type (see facing page for full map for Asia). This is based on the soil type that occupies the largest area of each polygon. Darker areas have a high sand content (e.g. Thailand, Cardamom Mountains in Cambodia) while in other areas (e.g. parts of Mekong and Chao Phraya deltas), the sand content is much lower, indicating very different soil characteristics.

The lower map shows the same information for the second dominant soil type. In this example, the dominant soil type for the polygon indicated by the arrow has 70% sand fraction in the topsoil, while the second dominant or associated soil in the same polygon has 10%.

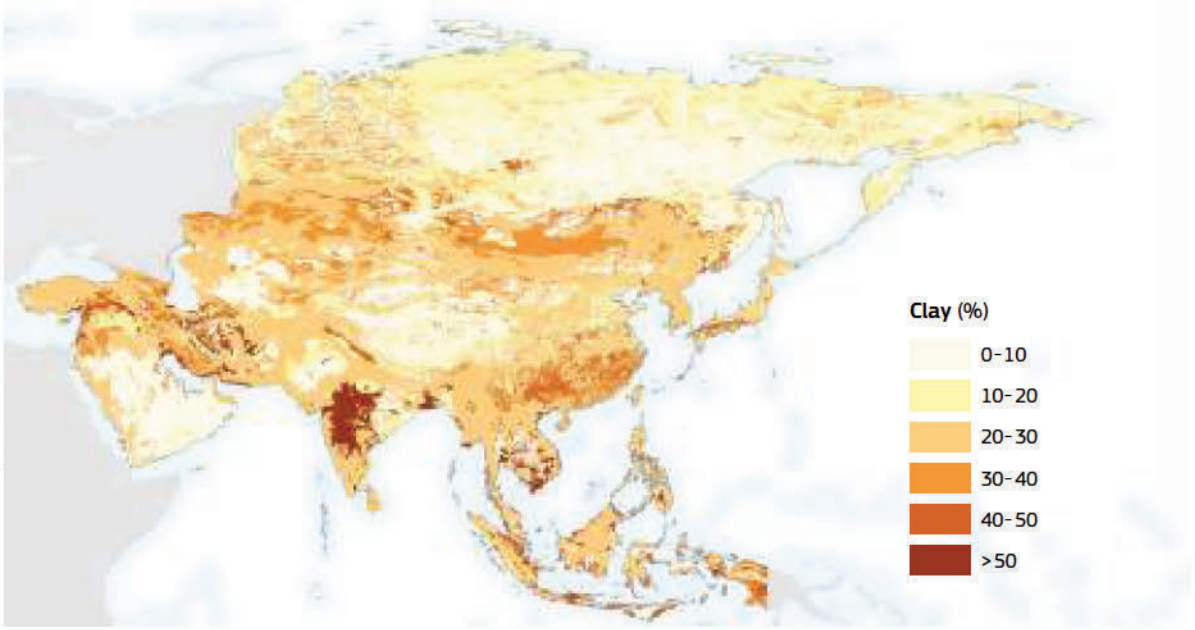
All maps presented on the subsequent pages only show information for the dominant soil type. (JRC/AJ)

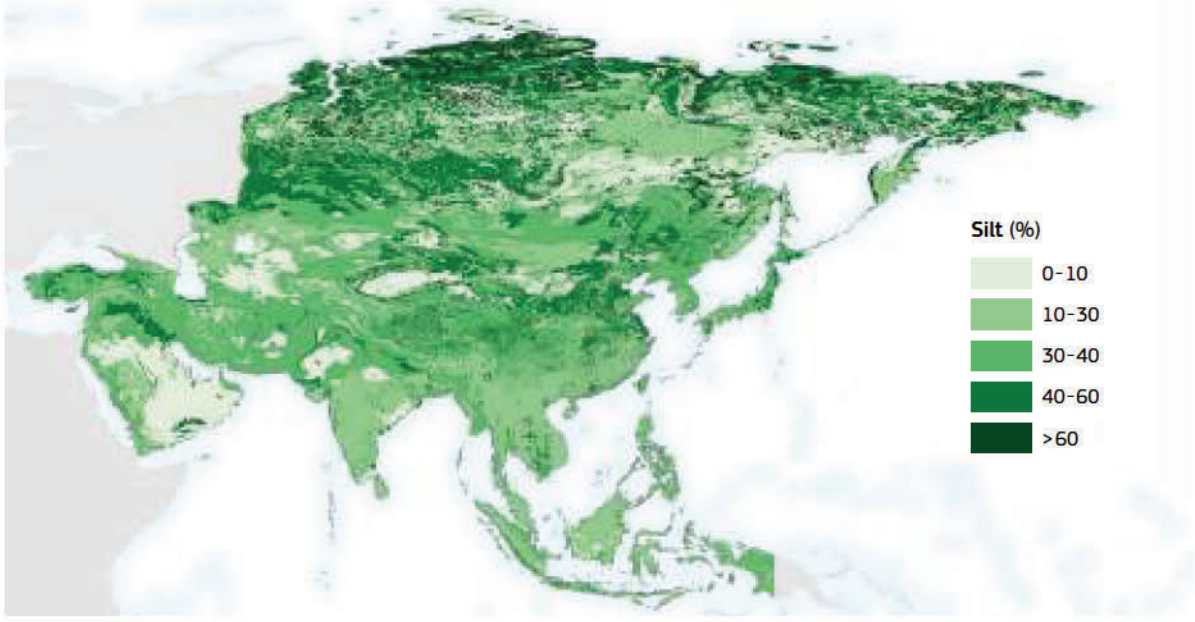




The second dominant soil for the same polygon is a sandy Fluvisol, probably reflecting a different position of the river on the floodplain or even specific flood events. (EM)

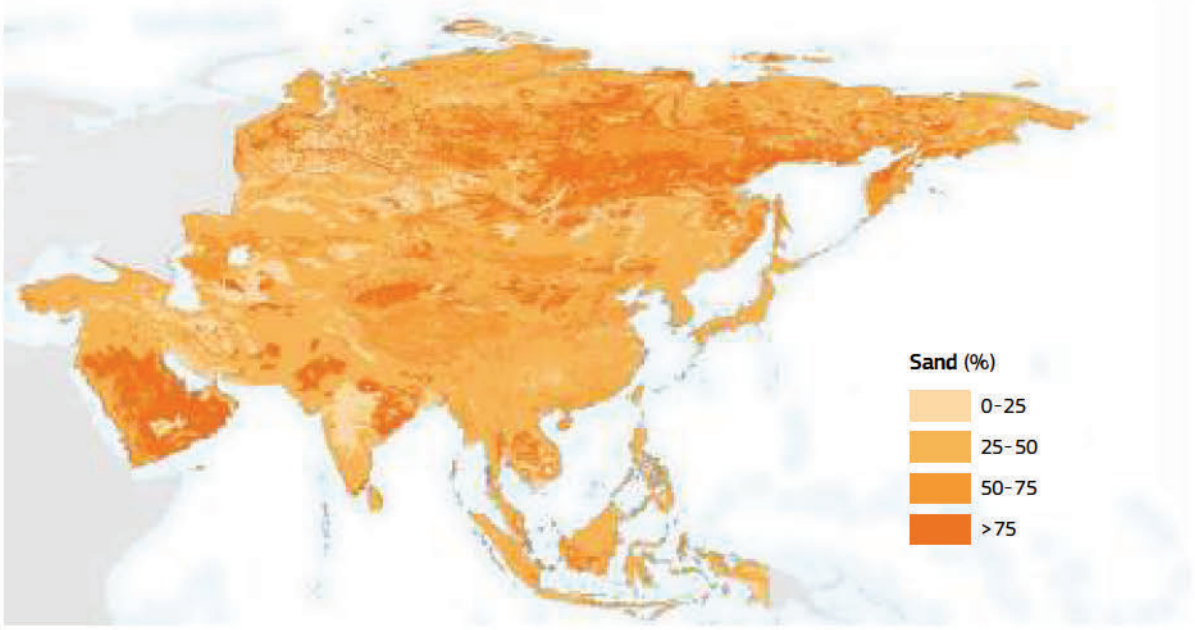
The proportion of clay particles in the topsoil (i.e. mineral matter less than 0.002 mm in diameter). These tiny particles require microscopes to see them. The soil feels smooth when rubbed between one's fingers. Clay-rich soils tend to contain more nutrients and because of their very high surface area can retain large amounts of moisture. As a result, they are favoured for agriculture. However, they can be difficult to cultivate when wet as they become very heavy and slow to drain. Can become very hard when dry. Particularly apparent on the map are the expanses of Vertisols (especially the Deccan Plateau), Gleysols (SE Asia) and saline soils (Central Asia, the Islamic Republic of Iran). High clay content is generally indicative of the chemical weathering (and associated transport) of parent material. (MM/YY)

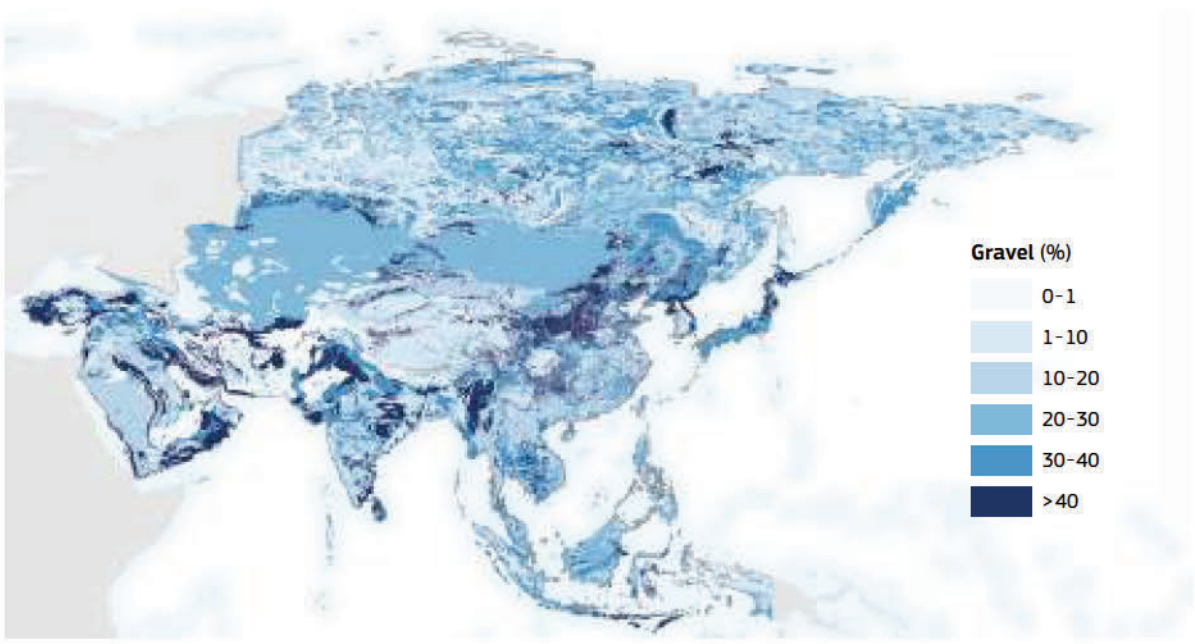




The proportion of silt particles in the topsoil (i.e. mineral matter between 0.002 mm and 0.05 mm - USDA classification - or between 0.002 mm and 0.0625 mm - ISO and FAO classification). Silt is too small to see with the naked eye. It is produced by the mechanical weathering of rock, as opposed to the chemical weathering that results in clays. This mechanical weathering can be due to aeolian abrasion (sandblasting by the wind) as well as from the effects of glacial erosion (e.g. Siberia) or water erosion of rocks on the beds of rivers and streams (e.g. the floodplain of the Tigris-Euphrates is clearly evident). It is the basis for good agricultural soil due to high nutrient levels and good water retention in spaces between particles. Easy to cultivate but very prone to erosion. (MM/YY)

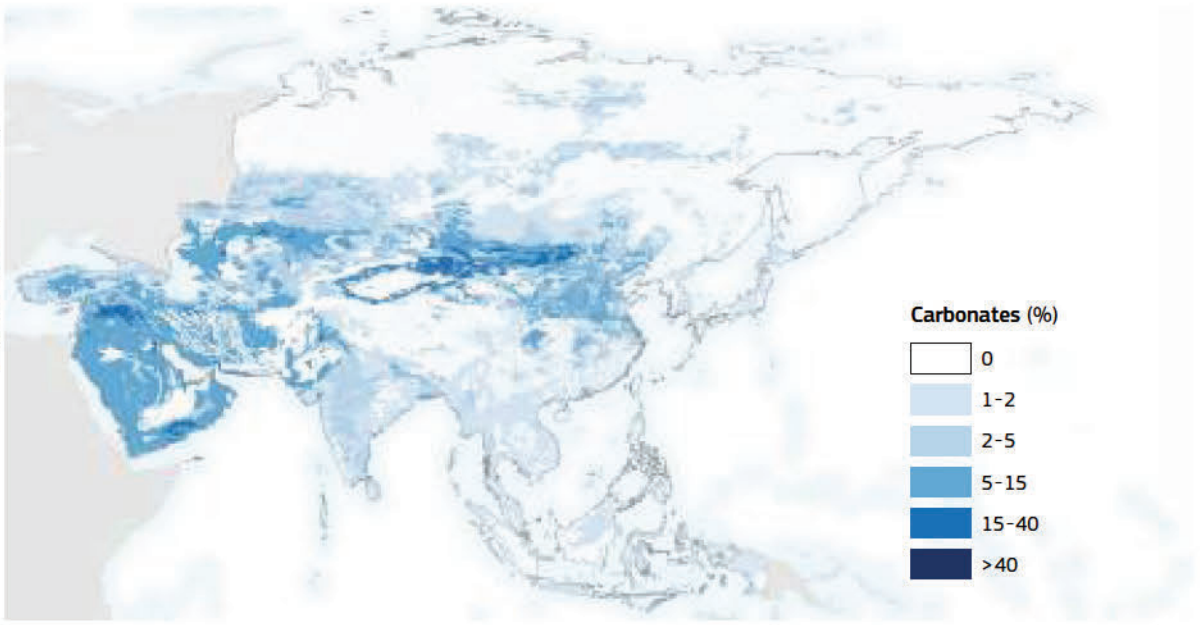
The proportion of sand particles in the topsoil (i.e. mineral matter between than 0.05/0.0625 mm and 2.0 mm in diameter). Most sand grains consist of quartz and are visible to the naked eye. Sand feels gritty when rubbed between the fingers (silt, by comparison, feels like flour). Sandy soils are very easy to cultivate but are generally lacking in nutrients and have low water-holding capacity, making them susceptible to drought conditions. As a result of the large volume of spaces between grains, water is easily drained away. Sand is commonly divided into five sub-categories based on the size of particles: very fine sand, fine sand, medium sand, coarse sand and very coarse sand. The map highlights the sand seas of the deserts (e.g. the Arabian Peninsula) and the coarse grained Ferralsols of the tropics (e.g. India and Southeast Asia). (MM/YY)

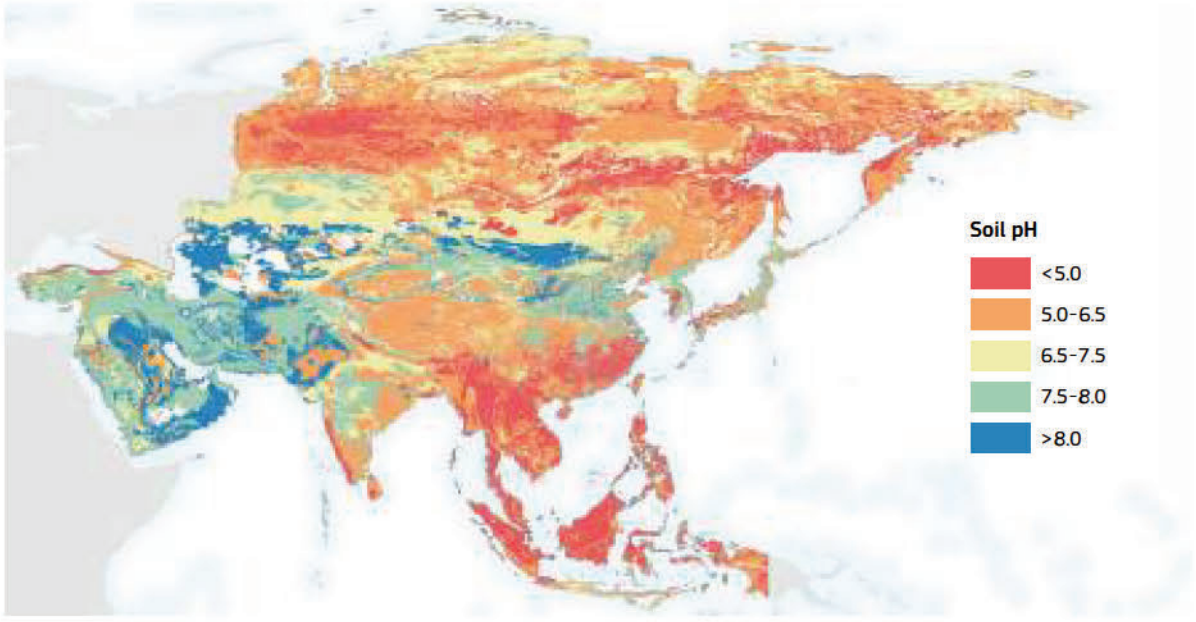




Gravel is generally defined as rounded or angular fragments of rock between 2 mm and 6 cm in diameter and is an indication of the stoniness of the soil. In general, a high gravel content can be an indication that the parent material is close to the surface. High levels of gravels in the mountainous areas (e.g. Hindu Kush) reflect the dominance of physical weathering, often resulting in debris slopes while those of deserts are the result of the removal of fine particles by wind. While some forms of agriculture (e.g. vineyards, olives, some fruit trees) prefer gravelly soils, a high proportion of stones in the soil is generally less desirable due to low water retention, nutrient levels and difficulties during tillage. Some stony soils may support distinctive ecological habitats. (MM/YY)

Calcium carbonate is a compound (actually a salt), with the formula $CaCO_3$. It is a common substance found as rock in all parts of the world and is the main component of shells of marine organisms, snails and eggshells. Calcium carbonate is the active ingredient in agricultural lime and is usually the principal cause of hard water. Calcium carbonate is quite common in soil, particularly in drier areas where it may occur in different forms (e.g. the deserts of Western Asia, Central Asia). Low levels of calcium carbonate enhance soil structure and are generally beneficial for crop production but at higher concentrations they may induce iron deficiency and, when cemented, limit the water storage capacity of soils. (MM/YY)

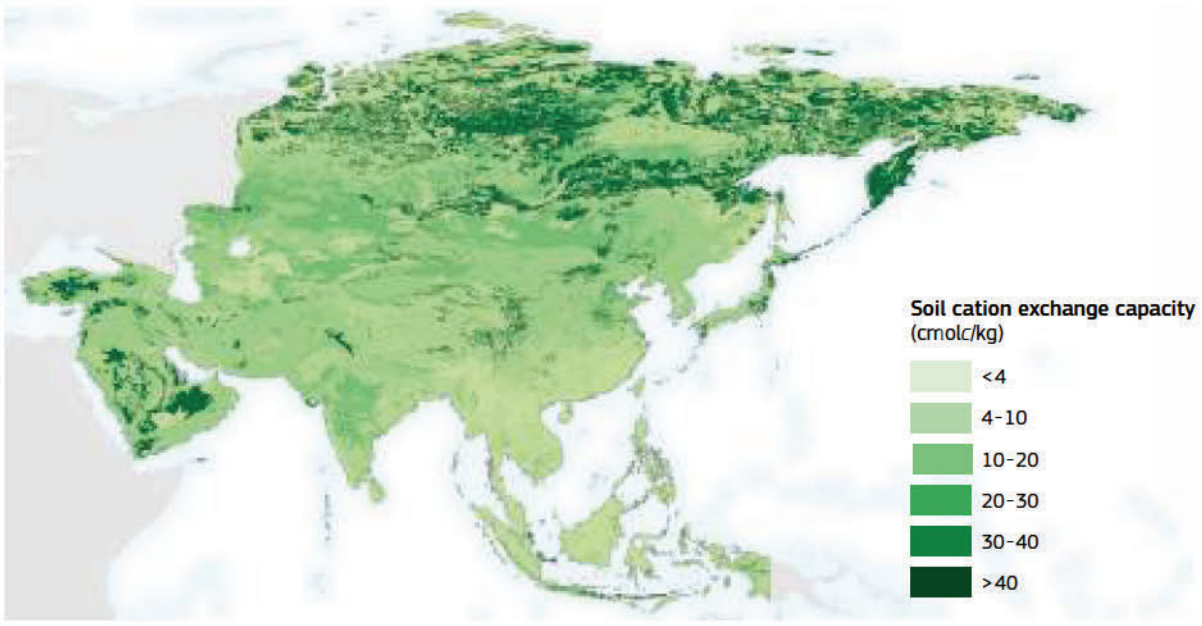


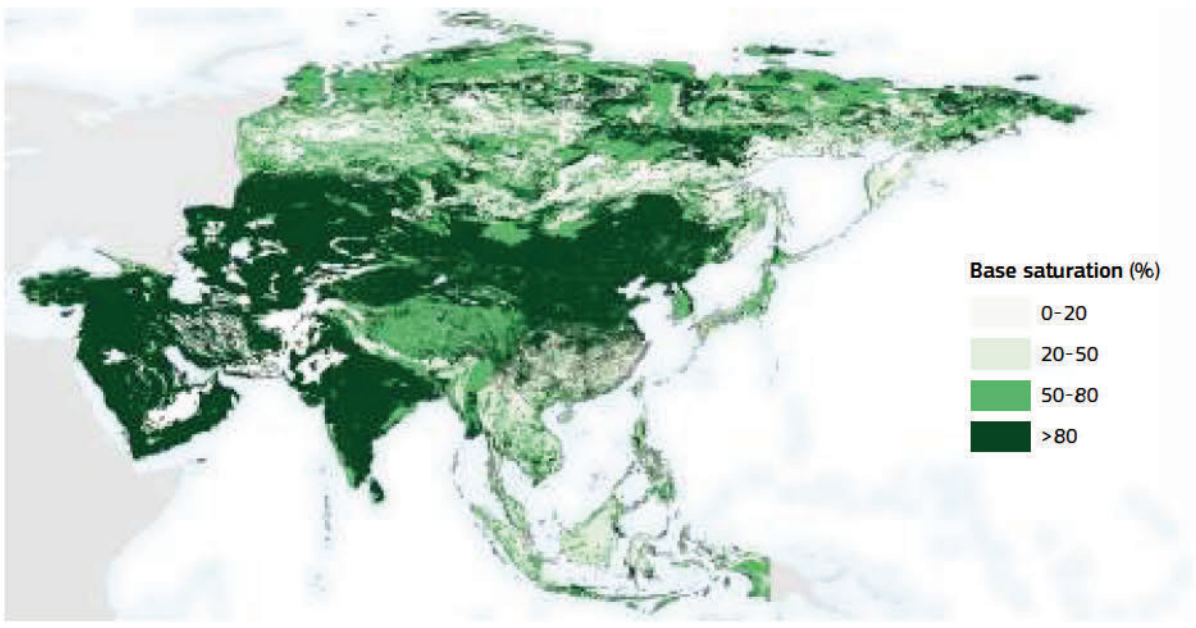


pH is a numerical designation of acidity and alkalinity in soil (see page 32). A value of pH 7 is regarded as neutral. Lower values are referred to as acidic while higher values are alkaline. Soil pH is considered a critical parameter as it controls many chemical processes. Of key importance is its influence on the availability of nutrient to plants. The optimum pH range for most plants is between 6 and 7.5. However, many plants have adapted to thrive in values outside of this range. For example, potatoes prefer soils with a pH range of 5 to 6 but can tolerate conditions as low as 4.5 and as high as 8.0 although the yields and quality will suffer.

Soil pH reflects the chemistry of the parent materials (soils developed on granite re acidic while alkaline on limestone. Acidic soils also reflect areas of high rainfall where the more mobile base cations are leached from the soil, increasing the levels of Al^{3+} and H^+ cations. Alkaline soils are characterised by the presence of soluble salts. The calcium carbonate map (above) shows the distribution of lime bearing rocks - the application of lime to acid soils can raise pH values and allow the cultivation of additional crops - note that carbonates are generally absent in Siberia and Southeast Asia. (MM/YY)

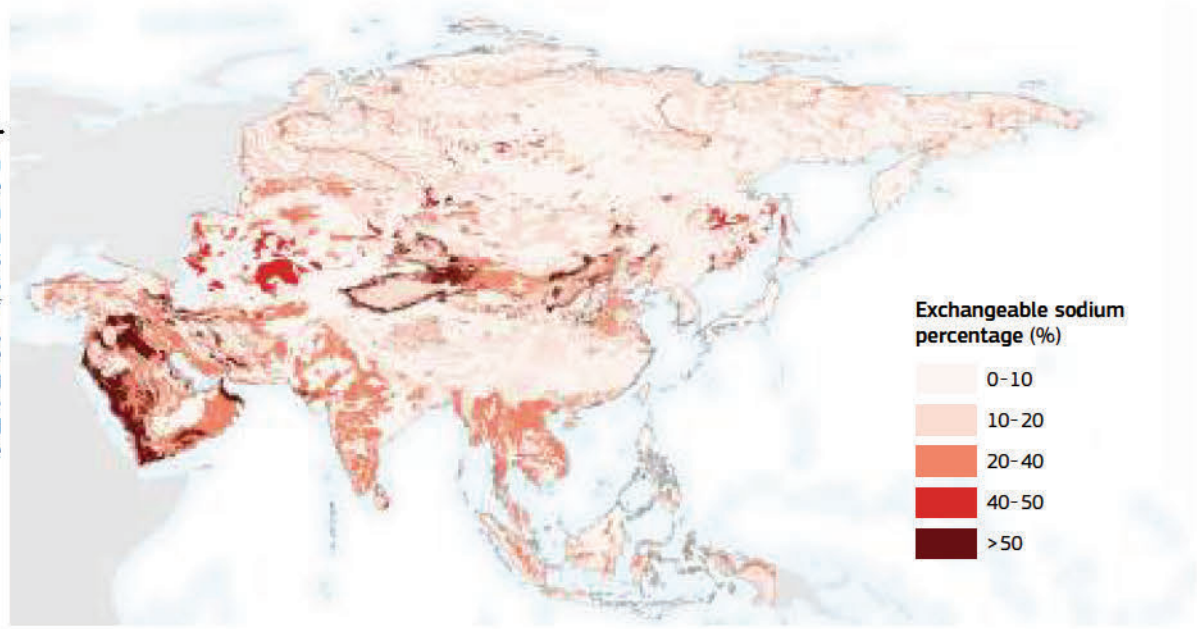
Cation exchange capacity (CEC) is the total amount of exchangeable cations that can be held by the soil and is an indication of a soil's nutrient status. Positively charged ions of elements such as calcium, aluminium, potassium and sodium that are bound to negatively charged soil particles can be replaced (i.e. exchanged) by hydrogen cations in the soil solution. Once in solution, the nutrient is available to plants. Soils with low CEC have little resilience and cannot build up stores of nutrients. Many sandy soils have CEC less than 4 $cmol\,kg^{-1}$. Values in excess of 10 $cmol\,kg^{-1}$ are considered satisfactory for most crops (as long as other factors, such as rainfall are sufficient). Increasing the organic matter content of any soil will help to increase the CEC. (MM/YY)





The exchangeable cations in a soil can be divided into two groups: base cations which are alkaline and therefore raise the soil pH (e.g. Ca^{2+},Mg^{2+}, K^+, Na^+) and acid cations which increase soil acidity and therefore lower pH (e.g. H^+, Al^{3+}). To maintain the soil's charge neutrality, every potential binding site must have a cation bound to it. Whichever type predominates these exchange sites determines the soil pH and acidity levels. Base saturation measures the sum of exchangeable cations as a percentage of the overall exchange capacity of the soil. The value often shows a near linear correlation with pH. (MM/YY)

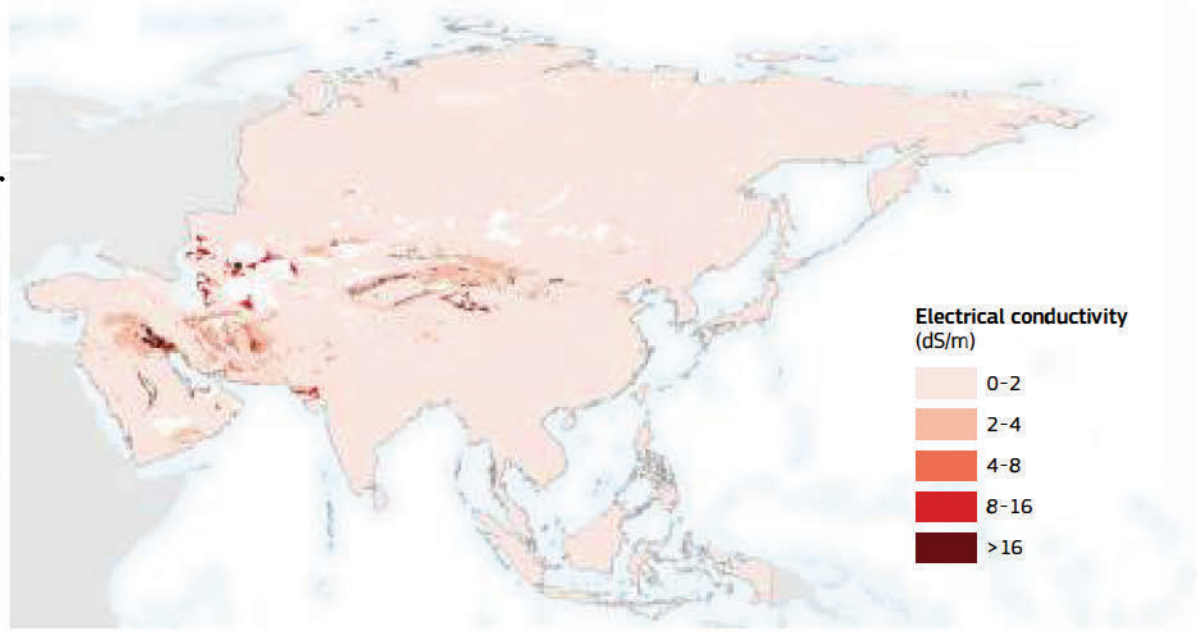
Exchangeable sodium percentage (ESP) measures the amount of sodium ions in a soil, often expressed as a percentage of the total cation exchange capacity (CEC) - see map on opposite page. Soils are considered sodic when the ESP is greater than 6 %, and highly sodic when the ESP is greater than 15 %. The presence of excessive amounts of exchangeable sodium causes soil aggregates to collapse into individual soil particles. This process is known as deflocculation and is characteristic of sodic soils. As a result of the loss of structure, water infiltration slows or stops completely. On drying, sodic soils can become very hard with surface crusts. These factors have consequences on the germination of seeds and root growth while increasing the risk of soil erosion by water. To counteract the effects of excessive sodium, calcium needs to be added to the soil. Areas with sodic soils tend to be characteristic of hot, dry summers or have developed on old marine sediments. (MM/YY)

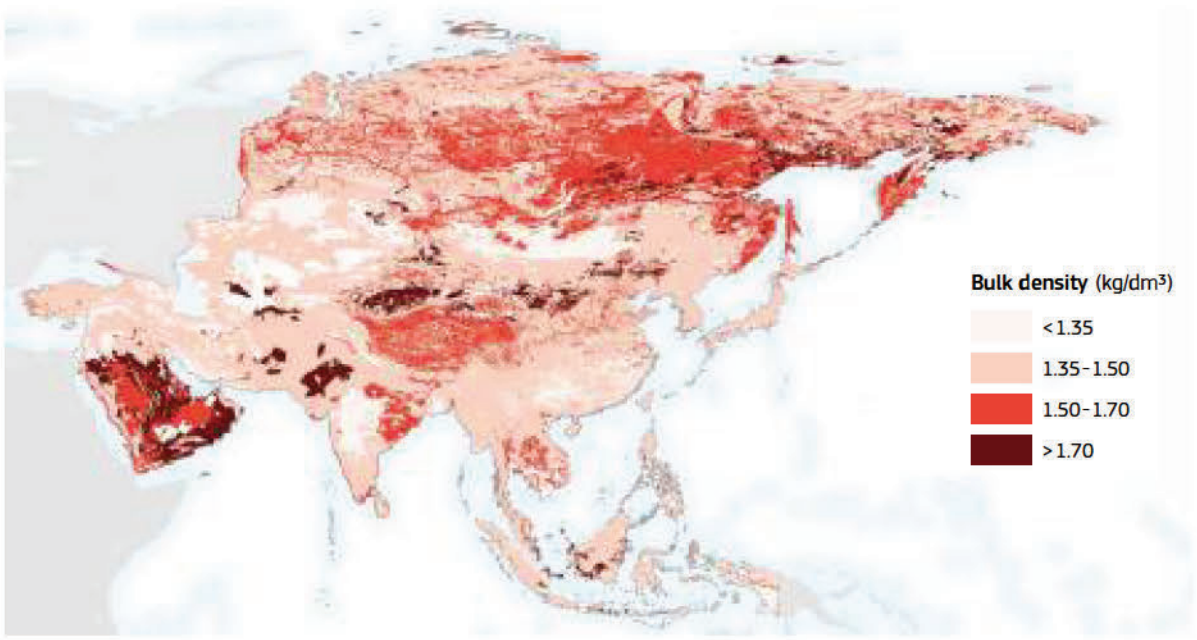




Available water capacity (AWC) is the amount of water that a soil can store that can be used by plant roots, which is plant specific. It is commonly defined as the difference between the amount of water contained in the soil at field moisture capacity (i.e. a saturated soil where all the space in the soil is filled by water) and the amount at wilting point (i.e. the least amount of soil moisture that a plant requires not to wilt, beyond which a plant can no longer recover its rigidity). In areas where plants remove more water than that supplied by precipitation, the amount of available water that the soil can supply plants between rainfall events or periods of irrigation may be critical. In this sense, the soil effectively buffers the plant root environment against periods of water deficit. AWC is commonly expressed as millimetres of water per metre of soil. Traditionally available water capacity is calculated for the nominal root depth. The available water content depends greatly on the soil texture and structure. Organic matter increases the available water capacity. Every 1 % of organic matter adds about 1.5 % to the available water capacity. For this map, arid areas are not considered due to low precipitation levels. (MM/YY)

Electrical conductivity (EC) measures the ability of a soil water to carry an electrical current. Electrical conductivity takes place mainly through pores that are filled with water containing specific cations (e.g. Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and anions (SO_4^{2-}, Cl^{-}) from salts that are dissolved in soil water. On this basis, the higher the concentration of ions the higher the electrical conductivity. The main use of EC is as a measure of soil salinity. EC is expressed in deciSiemens per metre (dS/m). High EC can serve as an indication of high salinity (EC > 4 dS/m), which can impede crop growth and reduce microbial activity. Soils with high EC resulting from a high concentration of sodium generally have poor structure and drainage, and sodium becomes toxic to plants (see map above). Washing soluble salts out of soil and beyond the rooting depth (leaching by irrigation water), can decrease EC. (MM/YY)





Bulk density is expressed as the dry weight of soil divided by its volume, which includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in $g\,cm^{-3}$. Bulk densities in undisturbed mineral soils tend to range from about 1.0 to 1.4 $g\,cm^{-3}$ with higher values typical for sandy soils and with increasing depth. Values for organic and organic-rich soils tend to range from 0.03 to 0.8 $g\,cm^{-3}$.

An increasing bulk density implies a decrease of large pores and a corresponding increase in micropores. A reduction in pore space affects the flow of oxygen into the soil and carbon dioxide out of the soil. Soil compaction is often associated with development of crusts on the surface of soils, which in turn, reduces infiltration and thus an increase in surface runoff. In addition, the growth of plants in compacted soil is greatly reduced.

It is an important parameter since it can measure whether soils are compacted in response to land use and soil management practices. Bulk density determines infiltration capacity of the soil, available water capacity, soil porosity, rooting depth restrictions, soil microorganism activity, root proliferation and nutrient availability. Bulk density is a critical parameter in the calculation of soil organic carbon stocks. (MM/YY)

Producing the soil maps for the Atlas

Geographic Information Systems and the Harmonized World Soil Database

What is a Geographic Information System?

All the maps contained in this atlas, have been produced using a technology known as Geographic Information Systems or GIS for short.

A GIS can be defined as a specialised computer system (both hardware and software) for capturing, storing, checking, merging, manipulating, analysing and displaying data which can be located somehow on the surface of the Earth. In geography, the term 'spatial' is used when referring to such data. Latitude and longitude coordinates, map references, administrative regions, water bodies and settlements are some of the means of relating information to a particular location. In this respect, a GIS is different from a Computer Aided Design (CAD) programme which stores information on features in an abstract space.

Features such as roads, rivers, soil types, or water quality sampling sites are represented in a GIS in digital form as points, lines (arcs), polygons (areas) or as cells (a grid).

Descriptive information or attributes about objects (e.g. names, ownership, depth, soil type) can be associated with the geographical data. This 'descriptive' information is normally stored in the form of tables in a database and is linked to the geographic or map data by a common identifier.

For the most part, spatial data can be converted from one coordinate system into another, thus data from various sources can be brought together into a common database and integrated using GIS software. In this way, a global database on soil profiles using latitude and longitude to mark sampling sites could be combined with soil data compiled on the basis of maps using a national coordinate system.

Spatial data and associated attributes in the same coordinate system can be viewed together and layered on top of each other to create maps.

Higher level analysis can also be carried out on data. Questions such as "What would happen if...pollution accidentally leaked into a sandy soil?", "Where does...a podzol occur next to arable land?" or "Is there a pattern to...landslide events in a national park?" are only feasible on large volumes of information by using a GIS. More complex queries could entail identifying potentially fertile soil in semi-arid areas on flat terrain that is within 200 m of a water source in order to assess irrigation potential.

A further key component of a GIS is the human element. Well-trained people, knowledgeable in spatial analysis and skilled in using GIS software are essential to the GIS process.

GIS is being used by more and more organisations. Originally developed primarily as a research tool for geography departments of universities, the use of GIS is now widespread in facilities management (e.g. water pipes, electricity cables), marketing and retailing (e.g. optimising store location with respect to customer needs), the military (e.g. battlefield maps, terrain evaluation), environmental management (e.g. predicting floods, erosion risk, forest fires), transport (e.g. vehicle routing, noise surveys), health (e.g. relationship between illnesses and social or environmental factors) and many, many more sectors.

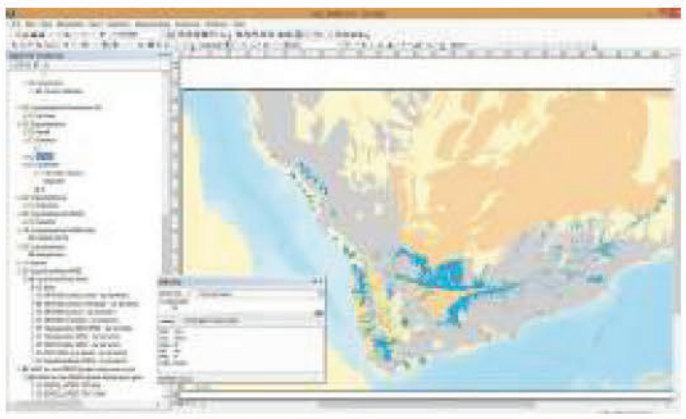
The GIS software used in the production of the maps in this atlas is a product called ArcGIS developed by ESRI Inc. from Redlands, California.

If you would like to learn more about spatial data and Geographic Information Systems, have a look at the following sites on the worldwide web:

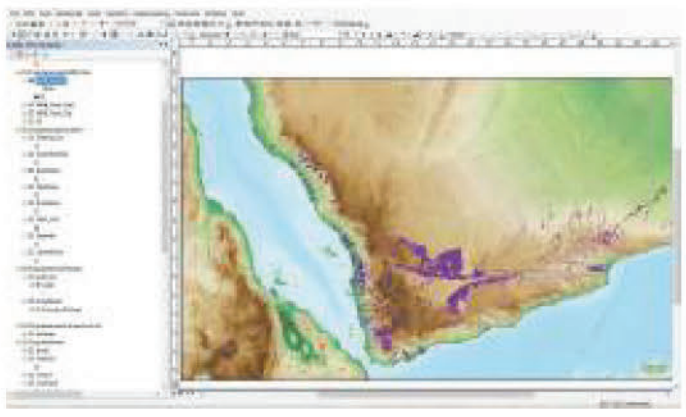
http://www.gis.com

http://tinyurl.com/bwqe4ny

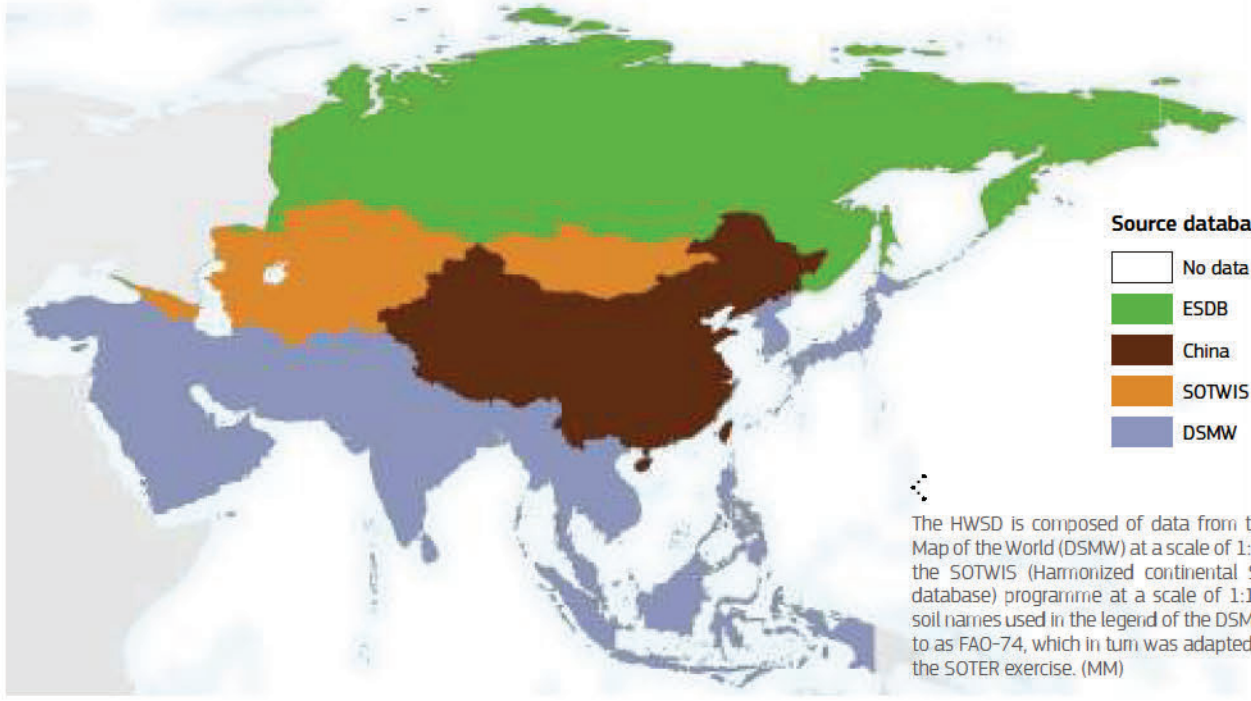
http://www.usgs.gov



The picture shows the interface to the GIS software used to produce the maps in this atlas. The digital cartographic data (map) have been coloured using a legend based on codes indicating the WRB Reference Group. The small window displays the attribute table for the map data. Each polygon or area has been coded with the appropriate WRB code and a unique identifier to link the attribute data to the graphics. (JRC)



The picture shows how GIS software can be used to query or search spatial data and display the results. The map shows the location of all polygons containing the code FL in the WRB-GRP column of the attribute table. In effect, the map shows the distribution of all Fluvisols (JRC).



The HWSD is composed of data from the Digital Soil Map of the World (DSMW) at a scale of 1:5 000 000 and the SOTWIS (Harmonized continental SOTER-derived database) programme at a scale of 1:1 000 000. The soil names used in the legend of the DSMW are referred to as FAO-74, which in turn was adapted to FAO-90 for the SOTER exercise. (MM)

Harmonized World Soil Database

The soil maps presented in this atlas are primarily derived from the Harmonized World Soil Database (HWSD) that has been developed under the Land Use Change and Agriculture Program of FAO and IIASA (Austria) in partnership with ISRIC – World Soil Information and the European Commission Joint Research Centre/ European Soil Bureau Network [99].

The HWSD data for Asia combines a four primary source database. These include the European Soil Database (ESDB), the 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and the Soil Map of the World.

At these small scales, the location of individual soil types can not be delineated. Therefore, the database presents the locations of groups of soil types (also known as associations) that are referred to as a Soil Mapping Units or SMU for short (see page 166 for explanation).

The HWSD is a raster or grid-cell database where the SMUs from the input soil datasets have been gridded to a resolution of 30 arc-seconds (nominally about 1 km). The pixel size was selected to ensure compatibility with important inventories such as the SRTM terrain data and the 2000/2005 global land cover datasets. The HWSD by necessity presents multiple grid cells with identical attributes reflecting the much coarser scale of the original vector data. For each SMU, a standardised set of topsoil (0-30 cm) and subsoil (30-100 cm) characteristics of up to nine STUs are presented. These include organic carbon, pH, water storage capacity, soil depth, cation exchange capacity, total exchangeable nutrients, lime and gypsum contents, sodicity and salinity, textural class, phase information and various soil names.

The HWSD can be downloaded from the IIASA and FAO websites [99].

SoilGrids

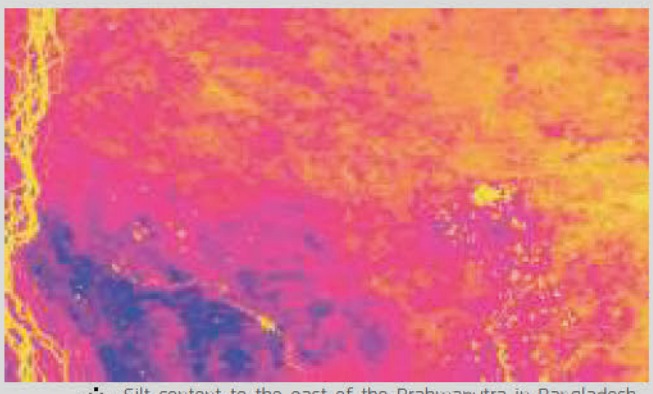
An alternative source of information on soil properties is from the SoilGrids project. The atlas used the HWSD property maps mainly due to the coherence with the polygons in the map spreads.

SoilGrids is a set of raster datasets that have been derived from state-of-the-art machine learning methods to predict the spatial distribution of soil properties across the globe. The predictions are based on the combination of over 230 000 soil profile observations and a series of environmental covariates that describe the main soil-forming factors and processes. Relevant covariates included climate, land cover and terrain morphology. The soil parameters are presented at six standard depth intervals (according to the specifications of the GlobalSoilMap IUSS Working Group) at a spatial resolution of 250 metres. All predictions are accompanied by an uncertainty value, which is calculated as the ratio between the inter-quantile range and the median.

Maps are available for the following soil properties: pH, soil organic carbon content, bulk density, coarse fragments content, sand content, silt content, clay content, cation exchange capacity (CEC), total nitrogen as well as soil organic carbon density and soil organic carbon stock.

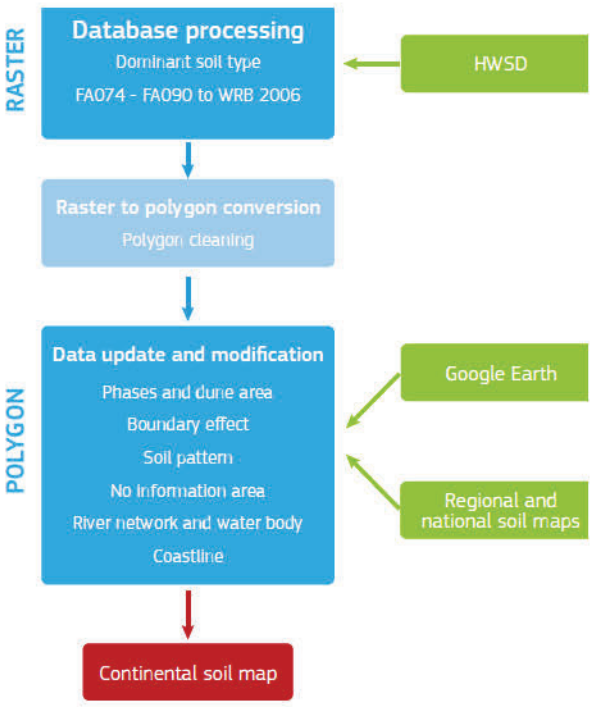
An additional layer predicts the WRB Reference Group.

SoilGrids can be viewed at [100].



Silt content to the east of the Brahmaputra in Bangladesh. Yellow colours denote low silt content while the darker blues, the highest. (JRC - data from SoilGrids, ISRIC)

Data processing



The various data processing stages required to produce the soil maps in the Atlas are described below (JRC).

Step 1. Assigning the dominant soil type

As each pixel or cell of the HWSD can contain up to nine individual soil types, a single soil type was selected as being representative of a particular SMU on the basis of the largest areal extent within the SMU. While it is clear that this approach masks the diversity of soil present within an SMU and presents a simplified view of soil distribution across Asia, the final map is much clearer. The reader should remember that the main goal of this publication is to introduce and highlight the diversity and importance of the soils of Asia to a new audience, outside of the soil science community. Specialists who need more detailed information can download the HWSD from the IIASA web site (see facing page).

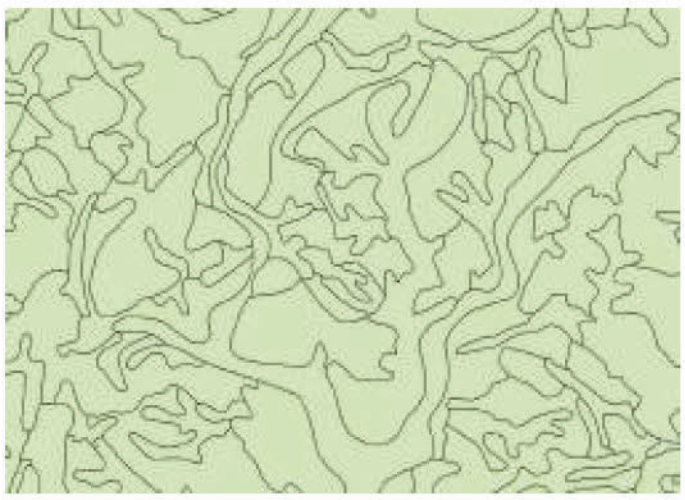
Step 2. Translation to WRB

Within the HWSD, the name of the soil is given using either the legends of the 1:5 000 000 Digital Soil Map of the World (FAO-74) or SOTER (FAO-90). To harmonise these two systems and the existing JRC Soil Atlas series, these names were translated to the WRB scheme.

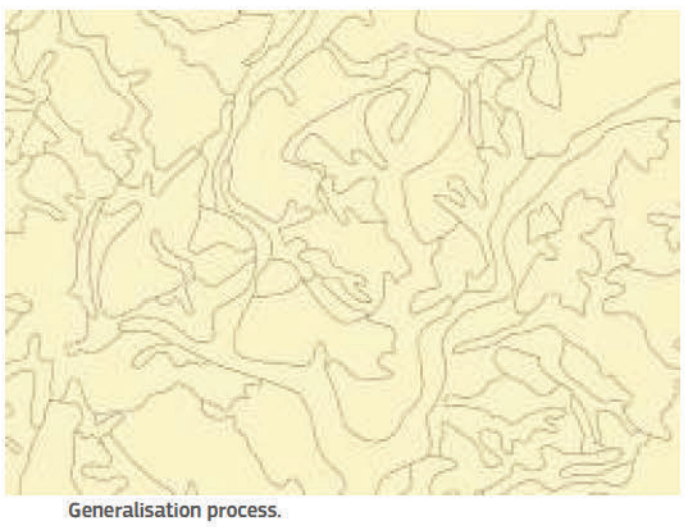
WRB_96		FAO_90		FAO_74	
ACRISOLS					
ACfr	Ferric Acrisols	ACf	Ferric Acrisols	Af	Ferric Acrisols
ACgl	Gleyic Acrisols	ACg	Gleyic Acrisols		
ACha	Haplic Acrisols	ACh	Haplic Acrisols		
ACpl	Plinthic Acrisols	ACp	Plinthic Acrisols	Ap	Plinthic Acrisols
ACum	Umbric Acrisols	ACu	Humic Acrisols		
ALISOLS					
ALgl	Gleyic Alisols	ALgl	Gleyic Alisols		
ALha	Haplic Alisols	ALha	Haplic Alisols		
ALpl	Plinthic Alisols	ALpl	Plinthic Alisols		
ALum	Umbric Alisols	ALum	Humic Alisols		
ANDOSOLS					
ANsn	Silandic Andosols	ANh	Haplic Andosols	To	Ochric Andosols
ANsnmo	Silandic Mollic Andosols	ANm	Mollic Andosols	Tm	Mollic Andosols
ANsnum	Silandic Umbric Andosols	ANu	Umbric Andosols	Th	Umbric Andosols
ANvi	Vitric Andosols	ANz	Vitric Andosols	Tv	Vitric Andosols
ARENOSOLS					
ARab	Albic Arenosols	ARa	Albic Arenosols		
ARbr	Brunic Arenosols	ARb	Cambic Arenosols	Qc	Cambic Arenosols
ARca	Calcaric Arenosols	ARc	Calcaric Arenosols		
ARfl	Ferralic Arenosols	ARo	Ferralic Arenosols	Qf	Ferralic Arenosols
ARha	Haplic Arenosols	ARh	Haplic Arenosols		
ARpr	Protic Arenosols				
ARwt	Hypoluvic Arenosols	ARl	Luvic Arenosols	Ql	Luvic Arenosols
CALCISOLS					
CLha	Haplic Calcisols	CLh	Haplic Calcisols	Bk	Calcic Calcisols
CLhaye	Haplic Yermic Calcisols				
CLpt	Petric Calcisols	CLp	Petric Calcisols		
CLlv	Luvic Calcisols	CLl	Luvic Calcisols		
CAMBISOLS					
CMca	Calcaric Cambisols	CMc	Calcaric Cambisols		
CMcr	Chromic Cambisols	CMx	Chromic Cambisols	Bc	Chromic Cambisols
CMdy	Dystric Cambisols	CMd	Dystric Cambisols	Bd	Dystric Cambisols
CMeu	Eutric Cambisols	CMe	Eutric Cambisols	Be	Eutric Cambisols
CMfl	Ferralic Cambisols	CMo	Ferralic Cambisols	Bf	Ferralic Cambisols
CMgl	Gleyic Cambisols	CMg	Gleyic Cambisols	Bg	Gleyic Cambisols
CMhaty	Haplic Takyric Cambisols				
CMhaye	Haplic Yermic Cambisols				
CMvr	Vetric Cambisols	CMvr	Vetric Cambisols	Bv	Vetric Cambisols

Example of the translation of HWSD soil names to WRB. (JRC)

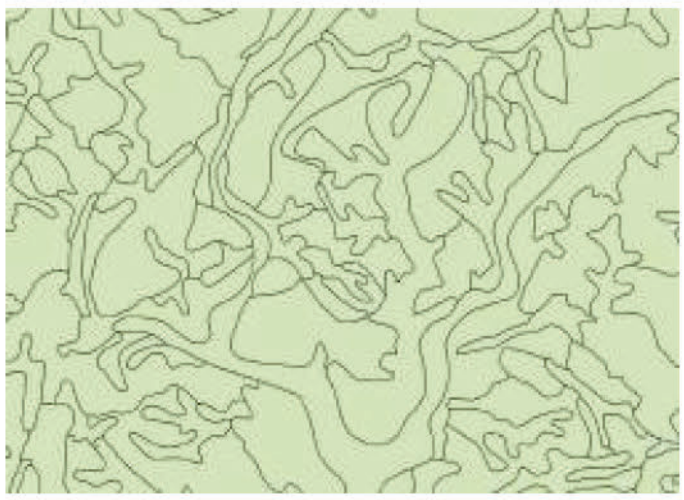
geometric generalisation:



elimination of polygons



thematic generalisation:



elimination of categories



Generalisation process.
On the left, from the top down, is the geometric generalisation process. It can be observed how some small polygons disappear in the generalisation. (JRC)
On the right, from the top down, is the thematic generalisation process. Two classes become one, the whole group falls in Cambisols classification. (JRC)

Step 3. Conversion of raster database to polygons

At the conclusion of the soil name translation stage, the raster database was converted to polygons to facilitate the cartographic stage. Cells with adjacent soil names were merged in this process. 'Micro-polygons' which were too small to be labelled on the map were merged with adjacent polygons in order to produce 'clean' maps. These are indicated by the red speckle on the summary map below.

Step 4: Phase updates

As a result of a visual inspection of the database, a number of modifications were made to the original HWSD using the phase parameters.

Phases 3 and 6 were used to redefine the extent of Plinthosols in central and west Asia, which were previously absent (the green areas in the summary map).

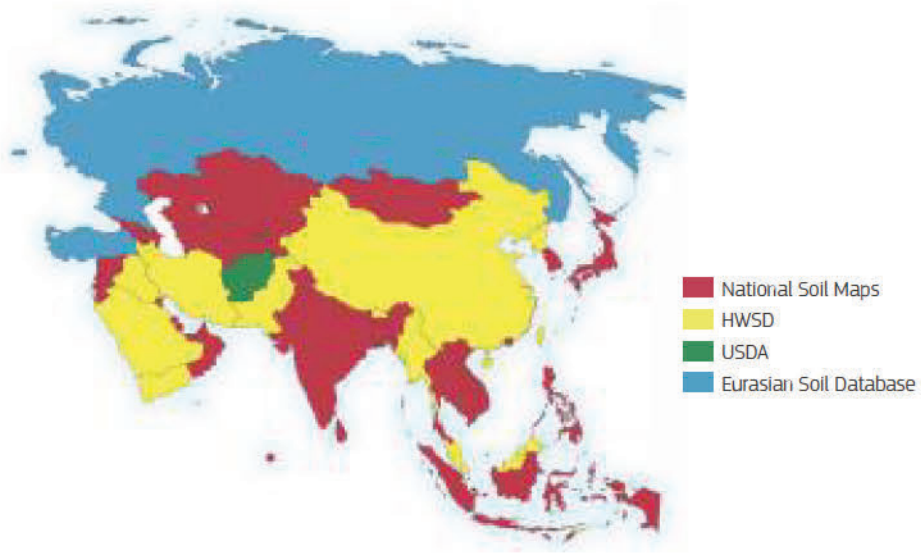
- Areas defined as 'dune sand' in FAO-74 and ARh in FAO-90 were converted to ARpr. Intensive checking of the data with Google Earth also allowed new dune areas to be detected and obvious misclassifications corrected (the yellow areas in the summary map).

At this stage, a decision was taken not to over-clean the SOTER data with respect to the coarser information from the original DSMW. While the preservation of detail at the expense of cartographic harmonisation may have produced some 'noisy' map sheets, the Editorial Board felt that it was better to highlight the lack of data in other parts of the continent.

Step 5. Data updates and modifications

Several major modifications were carried out to the initial data contained in the HWSD on the basis of expert knowledge and the publication of new data (unless otherwise stated, these changes are indicated as red areas on the summary map) :

- Boundary effects at the administrative borders of several countries were removed on the basis of expert knowledge;
- Soil patterns for several countries (e.g. Thailand, UAE) were updated with more recent data;
- Harmonisation of the main river networks and water bodies;
- Grid cells without any data were assigned soil names from secondary data sources (e.g. rocky areas in Thailand, dunes in Pakistan).



Map summarising the sources for the new soil map of Asia. (JRC/FAO)

Digital soil mapping: a new way to create soil maps

What is digital soil mapping?

Because knowledge about the condition and trend of Asian soils is highly fragmented and dated, there is an urgent need for accurate, up-to-date, and spatially referenced soil information to support policies addressing climate, agriculture and associated environmental concerns.

The soil maps presented in this atlas are the result of traditional soil survey which involves the manual delineation of soil boundaries based on soil samples gathered in the field by surveyors to help develop an understanding of the relationship between landscape features and soil-forming factors or processes. However, such surveys are demanding in terms of human resources, cost and time.

In recent years, attention has focused on the possibilities offered by digital soil mapping (DSM), also referred to as predictive or pedometric mapping. DSM uses geo-statistical models to predict soil properties at unobserved locations in the landscape on the basis of known observations. Also, the process to create a map is much quicker than conventional soil surveys [101].

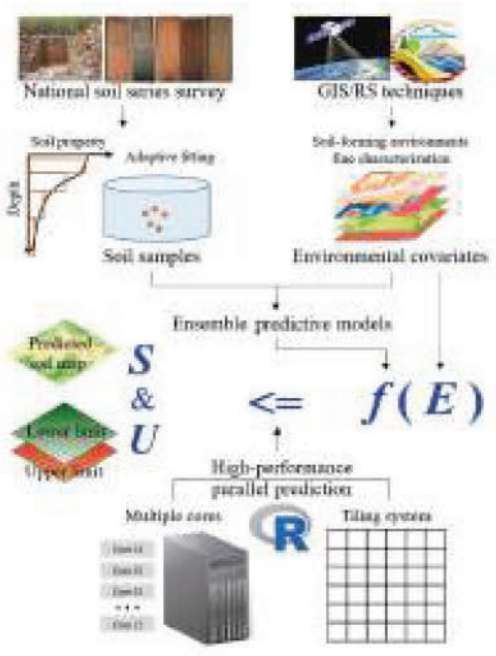
As illustrated in the diagram right, a digital soil map is simply a geographically-arranged database of soil properties (the technical term is often used to describe data relating to an area or location). These properties are based on a statistical elaboration of a sample of known conditions at specific locations or regions that permits the interpolation or prediction of soil properties to unknown areas.

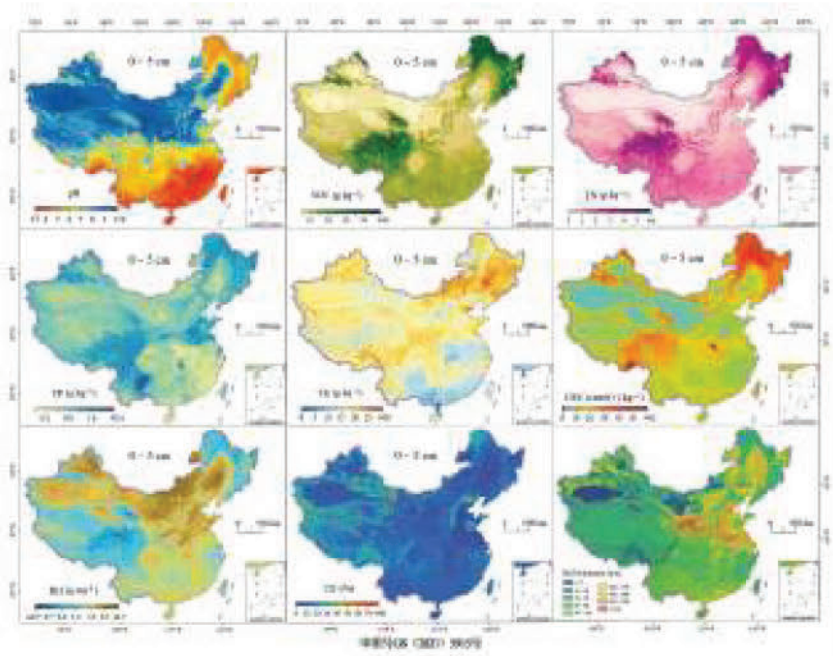
Soil characteristics can be predicted by a variety of statistical approaches which differ in terms of their representational realism and computational complexity. They include classic geo-statistics approaches (e.g. regression kriging, co-simulation, etc.), as well as more recent concepts based on hierarchical models, generalised estimating equations, additive models, Markov Chain and Monte Carlo simulations among others.

The predictions are strongly driven by the relationship between soil conditions at known locations and associated datasets that are responsible for those soil conditions. These are known as covariates. These include parameters such as albedo, land cover, vegetation dynamics (often derived from reflectance data collected from satellite images), topographic factors such as elevation, slope and aspect (derived from digital terrain models) and various climatic conditions (e.g. soil moisture, annual temperature, seasonality, etc.).

This approach essentially attempts to quantify Jenny's classical model of soil formation, which states that a soil condition is a function of a number of factors including climate, organisms, relief, parent material, age (or time) and any other, typically more local and historically significant factors. The basic hypothesis underpinning digital soil mapping is that once the spatial distribution of these factors is known, specific soil properties or conditions may be inferred geographically on the basis of their inter-relationship across the landscape.

A key aspect of DSM is the production of uncertainty statements which indicate the reliability of the predicted soil properties.





A schematic representation of a digital soil mapping approach to develop predictions of soil properties for China. Soil conditions at known locations are combined with associated datasets (referred to as covariates) and used to seed statistical models that predict soil properties for unknown areas. A strength of digital soil mapping is the ability to produce maps rapidly, together with a quantitative assessment of accuracy. However, errors may occur if the model is unable to account fully for the parameter in question or if there are reliability issues with the input data. [103]

GlobalSoilMap.net

GlobalSoilMap.net is a global consortium that has been formed to produce a new digital soil map of the world using state-of-the-art and emerging technologies. This new dataset will use geo-statistical procedures to predict key soil properties at a spatial resolution of approximately 100m (i.e. grid cells of 100 × 100m). Twelve soil properties will be calculated for each cell. These are: (1) total profile depth (cm), (2) plant exploitable (effective) soil depth (cm), (3) organic carbon (g/kg), (4) pH, (5) sand g/kg), (6) silt (g/kg), (7) clay (g/kg), (8) gravel (% volume), (9) ECEC ($cmol^c/kg$), (10) bulk density of the fine earth (<2mm) fraction (excluding gravel) (Mg/m^3), (11) bulk density of the whole soil (including gravel) and (12) available water capacity (mm). Additional soil properties (e.g. electrical conductivity) may also be predicted but these are not mandatory. In the vertical dimension, predictions of soil property values and their associated uncertainties will be reported for six depth intervals: 0-5cm, 5-15cm, 15-30cm, 30-60cm, 60-100cm and 100-200cm [102].

The project was officially launched on 17th February 2009 in New York, United States of America. The GlobalSoilMap.net consortium, which is led by ISRIC - World Soil Information (Wageningen, the Kingdom of the Netherlands), includes the Joint Research Centre of the European Commission (Ispra, Italy), CSIRO (Canberra, Australia), the University of Sydney (Australia), Institute of Soil Science of the Chinese Academy of Sciences (Nanjing, China), the Earth Institute at Columbia University (New York, United States of America), the US Department of Agriculture Natural Resources Conservation Service (Morgantown, United States of America), the Research Institute for Development (IRD) (Montpellier, France), the Brazilian Agricultural Research Corporation Embrapa (Rio de Janeiro, Brazil) and CIAT-TSBF (Nairobi, Kenya).

For further information, please visit [102].

Digital Soil Mapping at FAO

The generation of maps that describe changes in soil properties across a landscape play a crucial role in helping to define soil protection policies or in selecting optimised sustainable management practices. Such maps require not only relevant soil data, but also researchers who can manipulate this knowledge.

For this purpose, FAO's Global Soil Partnership is bridging the global technical divides that limit the application of digital soil mapping through capacity building programmes, both in Asia but also beyond, through workshops that address the use of open-source spatial data processing software and geostatistics.

To support these workshops, capacity building toolkits have been prepared that outline input data requirements, data preparation, soil characteristics and tools, which can support national experts to produce soil information for evidence-based decision making.

The workshops and toolkit generally address:

- Requirements for capacity building
- Data preparation and software installation
- Spatial modelling of soil properties
- Relevant tools such as QGIS (GIS Software), ILWIS (GIS Database) or R (modelling and computing software).

This capacity development effort aims at:

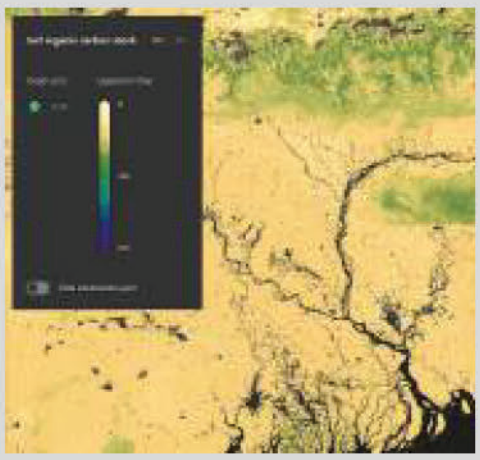
1. building consistent and updated national and regional soil information systems to contribute to Global Soil Information System (GloSIS);
2. Share and transfer soil knowledge and new technology within and beyond the region;
3. Provide soil information to all those with interest in sustainable soil and land management; and
4. train a new generation of experts in soil science, digital soil mapping and sustainable soil management.



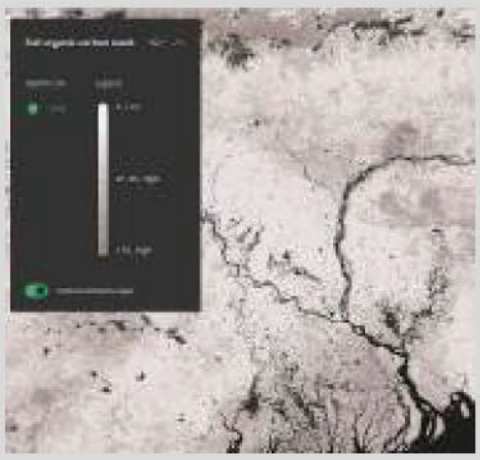
FAO training course on digital soil mapping in Bangkok to the Asian Soil Partnership. (FAO).

Predicting soil organic carbon content

Prediction of soil organic carbon:



Uncertainty of the prediction:



The map on the left predicts the soil organic carbon stocks (t/ha) for the uppermost 30cm of soil for a tile covering parts of Bangladesh and northeast India. Areas with higher carbon stocks are denoted by the green colours. The predictions are based on a combination of legacy soil data, global covariates and a series of global models that are calibrated using a spatial cross-validation procedure. The map on the right shows the standard error of the prediction. On this map, light tones indicate low uncertainty, which means that the predictions are more reliable. Data were extracted from the ISRIC SoilGrids platform [100].

Additional sources of information on the soils of Asia

ISRIC – World Soil Information

ISRIC - World Soil Information is an independent centre of excellence in soil science, established in 1966 with a mandate to serve the international community with information about the world's soils. In this context, ISRIC aims to:

- Inform and educate about the world's soils;
- Serve the scientific community as custodian of global soil information;
- Undertake applied research on land and water resources.

Located in Wageningen in the Netherlands, ISRIC is the World Data Centre for Soils (WDC-Soils) within the International Council for Science World Data System and also maintains the World Soil Museum and World Soil Library. Regarding the soils of Asia, ISRIC offers the following pertinent information sources:

- SoilGrids
- Global Soil Profiles Database
- WISE-derived soil properties on a 5×5 arc-minutes global grid
- Assessment of the status of human-induced soil degradation in south and Southeast Asia (ASSOD)
- Soil and Terrain Database for China (1:1 million), Nepal (1:1 million) and Jordan (1:500000)
- SOTER-based soil parameter estimates (SOTWIS) for the Indo-Gangetic Plains of India (1:1 million)
- ISRIC Scientific Reports
- Archive of soil maps

For further information, please visit [104].



World Soil Survey Archive and Catalogue

Over the past 80 years, tens of thousands of substantial soil surveys have been undertaken across the world by British organisations, mainly funded by governments as well as development assistance donors. A rough estimate, almost certainly on the low side, is that such surveys by today's prices would cost many hundreds of millions of euros to repeat and in all likelihood, such surveys are unlikely to be undertaken again in the near future! Yet until recently, many of these unique materials were scattered, unprotected and in danger of being lost forever. It is in this context that the World Soil Survey Archive and Catalogue (WOSSAC) project aims to develop an archive and catalogue of all substantial soil surveys, reports and maps made by British companies and personnel. WOSSAC will provide a safe repository for endangered copies and make the accrued information available for consultation by interested parties.

The WOSSAC Archive is based at Cranfield University, UK. The archive itself comprises a soil reports section, a soil maps and albums section, a soil books section, an aerial photography section and a satellite imagery section.

Currently, the WOSSAC Archive holds many thousand items for around 370 territories worldwide, of which 25136 objects have been catalogued, many of which cover Asia (for example, 756 items for Indonesia, 662 for Malaysia, 559 for Pakistan, etc.). Items are constantly being added.

For further information, please visit [105].

FAO Soils portal

FAO is a valuable source of information on soils. The FAO Soils portal is designed to provide access to knowledge on the different aspects of soils. The content is adapted to a range of stakeholders that range from policymakers, development planners, soil scientists and agricultural extension officers to students and other practitioners.

In addition to a collection of 12 228 legacy maps and hundreds of technical reports, the portal provides access to a Data Hub. Here, users are given access to data and information on soil properties, soil classification, sampling and laboratory techniques, soil maps and databases, as well as links to national soil information systems.

Specifically in relation to global data, the portal provides access to the original FAO/UNESCO Soil Map of the World but also some more recent innovative products such as the Global Soil Organic Carbon (GSOC) Map (and browser), the Global Soil Sequestration Potential (GSOCseq) Map and the Global Map of Salt-affected Soils (GSAS).

For further information, please visit:

https://www.fao.org/soils-portal/en/ (English)

https://www.fao.org/soils-portal/fr/ (French)

https://www.fao.org/soils-portal/es/ (Spanish)



Institut de recherche pour le développement (IRD)

The IRD is a French research organisation that addresses international development issues throughout the world. Key objectives include the improvement of sanitary conditions and understanding the evolution of society while preserving the environment and natural resources.

As a French science and technology establishment, the IRD is under the joint supervision of the Ministries of Research and Foreign Affairs. It operates internationally from its headquarters in Marseille, and two centres in Montpellier and Bondy.

Thanks to its collaborative activities in research, education and innovation, IRD has been active in more than fifty countries, with particular focus on southeast Asia.

Of particular interest to researchers interested in Asia are three online services:

Horizon – a document archive containing more than 108 000 reports with a full-text search facility available on 80 000 articles;

Sphaera cartographie – a comprehensive map archive containing 18000 cartographic references and 2700 digitised maps and atlases;

Indigo - IRD's image gallery containing more than 67 000 photographs and 600 films.

For further information, please visit:

https://en.ird.fr/ (English)

https://www.ird.fr/ (French)



European Digital Archive of Soil Maps (EuDASM)

For nearly 50 years, ISRIC – World Soil Information has been collecting and archiving regional-, national- and global-scale maps of soils and land resources.

Despite effective procedures for storage and maintenance, most organisations involved in archiving struggle to prevent the deterioration of paper maps and the quality of information they contain. Deterioration occurs for various reasons that include handling, transport, exposure to light, moisture and atmospheric pollution.

Realising the need to conserve the information on existing maps, the European Commission and ISRIC – World Soil Information initiated the European Digital Archive of Soil Maps (EuDASM) to transfer paper soil information into a stable digital format, with the maximum resolution possible. More than 2000 maps were scanned from the ISRIC Asia collection using a wide format colour scanner and stored at 200dpi in JPEG compressed format.

For further information, please visit [106].

National sources of data



While most of the sources described on this page reflect archives outside of Asia, we should not forget that almost all countries have national institutes that are responsible for surveying their soil resources and carrying out assessments on the health of their soils.

For example:

- United Arab Emirates has an online Soil Museum that allows visitors to learn about the different soil types of the region and their relationships with key issues such as climate change and food security. See **https://www.emiratessoilmuseum.org/**
- National Portal of India provides links to both the Soil and Land Use Survey of India as well as a catalogue of websites dealing with Soil Conservation. In parallel, the National Remote Sensing Centre provide a range of products describing soil erosion, flooding extent and salt affected soils. See **https://www.india.gov.in/** and **https://www.nrsc.gov.in/**
- Nepalese National Soil Science Research Center operate a web portal that provides access to an interactive digital map of soil properties. See **https://soil.narc.gov.np/**
- Philippines Bureau of Soils and Water Management provide data on soils and land suitability through a dedicated Information System. See **http://bswm.da.gov.ph/process/sw-info-system/**



Land and soil degradation come in many forms - some more apparent than others. Soil pollution is a chemical degradation process that can disrupt the ecosystem services that are provided by soils, with implications for global food security, human health, climate change and biodiversity. Most contaminants originate from human activities and enter soils because of unsustainable production chains, consumption patterns or inappropriate waste disposal practices. Dumps or landfills, such as this one in Pakistan, are traditionally seen as convenient sites for the disposal of waste. However, if not managed correctly, landfills can export soil pollution problems into the environment. For example, leaching of toxic pollutants to groundwater, litter dispersal and greenhouse gas emissions driving climate change. (MU)



As illustrated by this scene from Nan Province, Thailand, land clearance, driven usually by agricultural expansion, wood extraction or infrastructure development, such as road building and urbanisation, is the main cause of deforestation - a widespread soil degradation process across much of Asia. In addition to the loss of habitat and biodiversity, the removal of trees can cause soil erosion, disruption of natural nutrient cycles, an increased risk of flooding, as well as an increased emission of greenhouse gases to the atmosphere. It is estimated that southern and southeast Asia has already lost more than 50% of its original forest cover while the issue is also a concern in the Mediterranean and on the uplands of Central Asia. (BHU)

Key threats to soil

Maintaining soil condition is essential for ensuring the sustainability of society. However, soil is under increasing threat from a wide range of human activities. These are complex and although unevenly spread across Asia, their dimension is continental. For simplicity they are presented separately below. In reality they are frequently inter-linked. When many threats occur simultaneously, their combined effects tend to increase the problem. Ultimately, if not countered, soil will lose its capacity to carry out its functions. This is known as soil **degradation**.

The main soil degradation processes are highlighted below:

Although a natural process, **soil erosion** as a result of human activity can occur due to inappropriate land management practices, often linked to agriculture and forestry, but also through uncontrolled water runoff from roads and other sealed surfaces. Water erosion greater than 5 tonnes $ha^{-1}yr^{-1}$ which is greater than the rate of soil formation) affects 21% of the total land area of Asia, with Nepal, Viet Nam, Timor-Leste, Tajikistan and the Philippines all displaying mean annual erosion rates in excess of 15 tonnes per hectare.

Soil pollution is due to activities such as industrial production, traffic, the extraction of hydrocarbons and metal ores, poor waste management and inappropriate agricultural activities. It can be diffuse (widespread) or localised. Local contamination constitutes a major problem which has not yet been fully evaluated. Polluted soils are found throughout Asia and often reflect rapid economic development. The extent of diffuse soil pollution is difficult to assess due to a lack of coherent reporting and monitoring.

Salinisation is a problem in where saline groundwater or inappropriate irrigation practices in agricultural areas lead to an accumulation of salts in the soil, which affects plant growth. Salinisation is a major concern in many parts of Central Asia. Precise information on the extent of salt-affected soils does not exist. However, it is estimated that 7% of Asian soils (around 3 million km^2) are affected by salts. Around 20% of this area is a result of human induced salinisation.

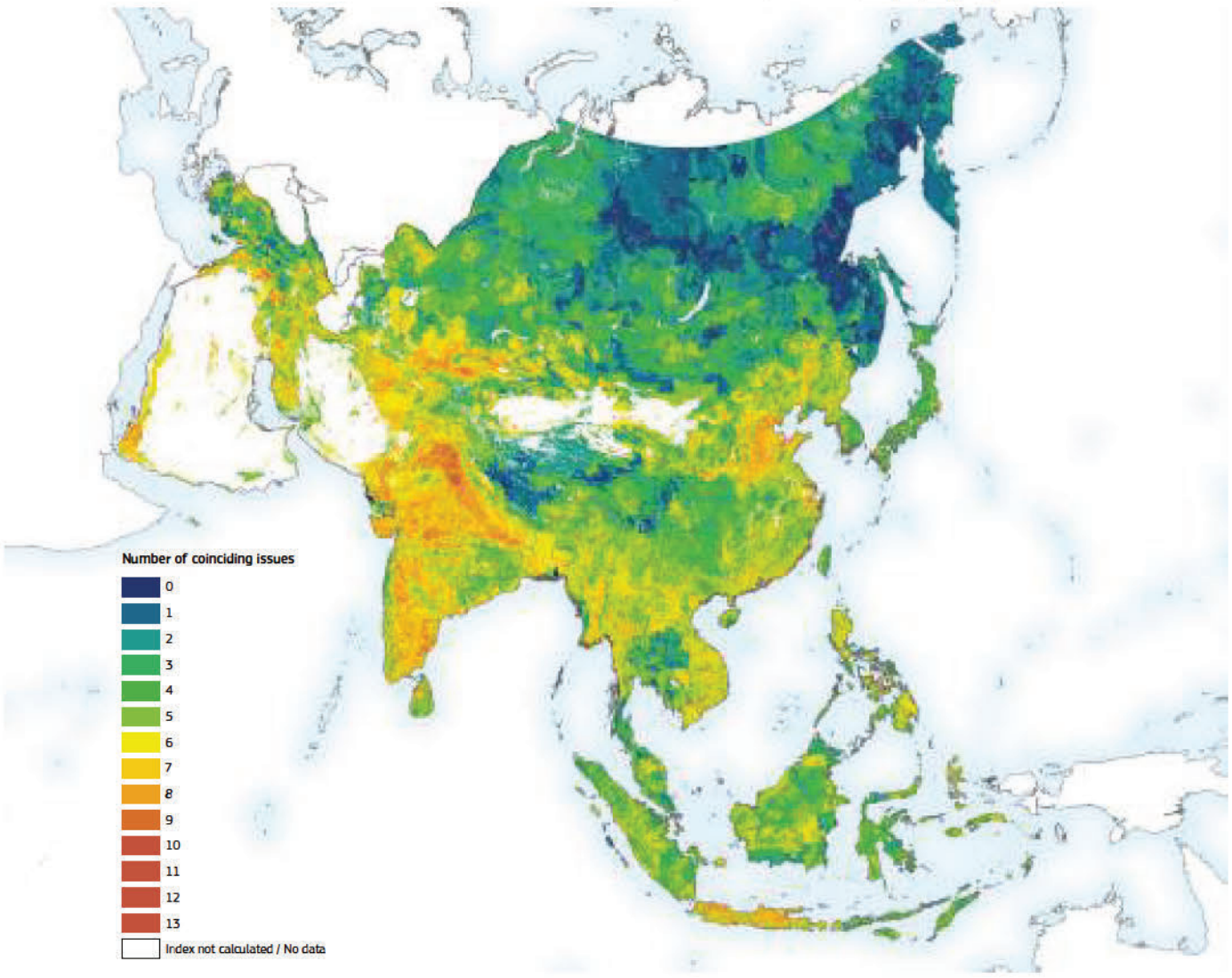
Soil sealing occurs mainly through the covering of soil with impermeable materials as a result of infrastructure development, mainly in urban areas. Soil sealing should be regarded as a loss of soil and almost all ecosystem services it provides. Asia is the home of mega-cities. More than 60 million people live in extended Tokyo. Bangkok has expanded more than 200 km from its original centre. Most estimates predict that more than half of the population of Asia will be urban by 2030.

Loss of nutrients and organic matter occurs as a result of deforestation, the drainage of peatlands or if agriculture is practiced without sufficient application of manure or fertiliser. Increasingly, this is one of the most important pressures on soil as it affects food security and the ability to mitigate the effects of climate change. If left unchecked, it can lead to a failure of the soil system and trigger the onset of desertification and social upheaval. More than 13% of Asian soils are under high intensity agriculture.

Compaction is caused mainly by high pressures on soil through heavily loaded vehicles in agricultural and forest land use. It is also a problem where animal stocking densities are high. Compaction can affect the movement of water and gases through the soil, restrict root growth and increase the vulnerability to erosion. It is often associated with deforestation, which affects 8% of Asia.

Hydro-geological processes, such as floods and landslides, often reflect uncontrolled soil and land use (e.g. sealing, compaction, uncontrolled mining operations). These processes can be exacerbated by climate change, especially increased precipitation intensity. The 2022 floods of Pakistan clearly show the severity of such events.

Soil degradation, when occurring in dry areas, is known as **desertification**. The process reflects changing climatic conditions (predominantly droughts, aridity, irregular and intense precipitation regimes) and human activity (deforestation, overgrazing, over-exploitation). The affected land can no longer support vegetation and associated ecosystem services. Desertification has extremely serious socio-economic consequences and can ultimately cause the destabilisation of societies and the migration of human populations. More than 15% of Asia is arid desert.



The map illustrates the convergence of scientific evidence for land degradation. It depicts where global change issues relevant to land degradation coincide. The premise is that the occurrence of multiple global change issues at a location suggests a potential for land degradation (at least in some form). This map, derived from the World Atlas of Desertification, is constructed using land cover and land use data, together with fourteen biophysical and socio-economic drivers of global change.

Areas with dark red and orange colours indicate a higher convergence of evidence towards land degradation, with blues and greens denoting lower number of issues. (JRC/FG) [107]

Key messages

It is important to analyse these threats in two ways:

- to understand the driving forces behind them and the resulting pressures which lead to adverse effects on soil;
- to understand how the impacts of these threats negatively influence the functions of soils for humankind and the environment.

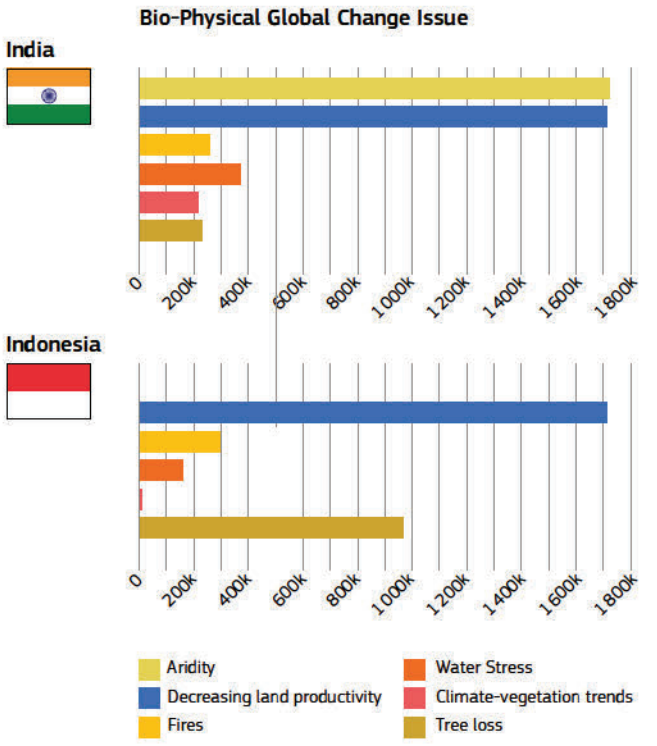
Relating the driving forces with pan-Asian and national strategies reveals that many agricultural, regional planning, environmental protection, transport, energy development policies may have an important influence, because they are partly triggering or inducing soil threats.

Analysing the impacts of threats by relating them to important soil functions reveals that erosion can be correlated with air pollution, water pollution, decline in biomass production, endangering human health and decline in biodiversity.

It should be stressed that the processes described on this page do not occur in isolation. In most cases, there are strong inter-dependencies between them. For example, the loss of nutrients and low levels of organic matter may cause erosion, facilitate compaction, induce decline in biodiversity and, indirectly, decrease water infiltration therefore increasing the danger of floods and landslides.

In many cases, there is not enough information available to quantify the spatial distribution of soil threats and its changes over time. One of the most challenging tasks facing soil scientists and policymakers will be the creation of a soil monitoring system that provides detailed information about the state of these issues across Asia.

Across Asia, complex human-environment interactions are at play, which include differing rates and magnitudes of drivers (e.g. overgrazing, climate change, agricultural practices) and consequences (e.g. soil erosion, changes in productivity, loss of biodiversity). The map shown on this page is built on a systematic framework that provides a convergence of reliable global evidence of human environment interactions. This can help identify local or regional areas of concern where land degradation processes may be underway. Concerns can be validated only by evaluating them within local biophysical, social, economic and political contexts.



These two diagrams show the extent of the main global change issues for India and Indonesia. They clearly show that different parts of Asia are experiencing different land degradation pressures, reflecting diverse drivers and eventually solutions. (JRC/FG) [107]

Asia and land degradation

According to the World Atlas of Desertification [107], the convergence of evidence suggests that over **800 million hectares, representing more than 18% of the total land area of Asia, are affected by some kind of degradation process**. If non-productive land is discounted (i.e. permafrost, salt pans, lakes and mountains), **then some form of soil degradation affects around 25% of the Asian continent**.

Soil erosion

Erosion is the wearing away of the land surface by water and wind. While erosion is a natural process, it can be exacerbated by inappropriate land management, deforestation, overgrazing, forest fires and construction activities. Erosion affects land use, the value of land and has negative effects on habitats and biodiversity.

In simple terms, erosion involves three basic processes:

- the detachment of soil particles by the impact energy of rain or wind,
- their subsequent transport and
- deposition in a new location.

Erosion rates, measured in tonnes/ha/year, are very sensitive to soil texture and moisture, vegetation cover, land use, slope and climate (especially rainfall patterns, wind direction and strength) as well as to soil conservation practices at field level.

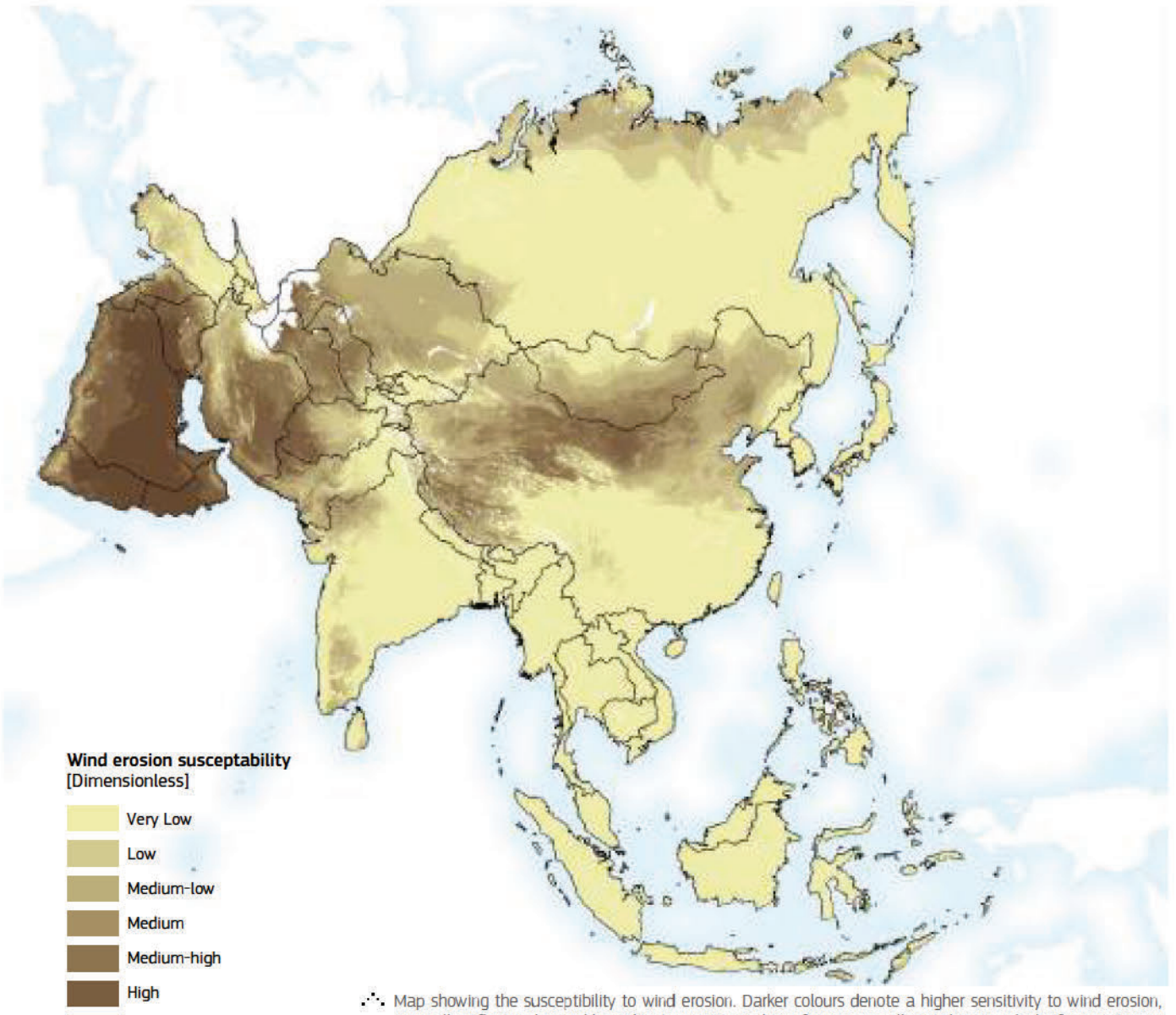
Soil erosion has substantial off-site consequences as well. The soil removed by runoff during a large storm can create mudflows and accumulate below the eroded areas, in severe cases blocking roadways or drainage channels and inundating buildings. By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of the entire soil body. Where soils are deep, the loss of topsoil may often not be conspicuous. Nevertheless, continued erosion may be potentially very damaging if no corrective action is taken (see Preventing Soil Erosion box on page 201).

Soil erosion by wind (aeolian erosion)

Aeolian erosion occurs when strong winds blow across dry soil on unprotected surfaces. As in water erosion, the wind detaches soil particles from the surface. Once detached, the particles are transported to a new location. Wind erosion is particularly evident where annual rainfall is below 600 mm and the dry season lasts more than six months. Large parts of western, central and eastern Asia are particularly affected. It is a major source of land degradation, which can cause crop failure and has significant human health issues.

Three types of wind erosion are recognised:

- Suspension: Fine particles less than 0.1 mm in size are moved parallel to the surface then upward into the atmosphere by strong winds, returning to the ground only when the wind subsides or with precipitation. Suspended particles can travel thousands of kilometres.
- Saltation: Particles from 0.1 to 0.5 mm bounce short distances along the surface, dislodging additional particles with each impact. The bouncing particles, ranging in sizes, usually remain within 30 cm of the surface. This process accounts for 50 to 90% of the total movement of soil by wind.
- Soil Creep: Larger soil particles roll and slide along the ground surface, often aided by impacts of saltating particles.



Map showing the susceptibility to wind erosion. Darker colours denote a higher sensitivity to wind erosion, generally reflecting low soil humidity, temperature above freezing, small particle size, a lack of vegetation or snow cover. It is clear from these data that large parts of Asia, in particular western, central and eastern Asia are highly susceptible to wind erosion over the course of the year (see box on local winds). (JRC/PPS/PBI) **[108]**



A large dust storm (visible in the centre right of the photograph) in Kazakhstan along the eastern side of the Aral Sea, as captured from the International Space Station. The white lines at the lower edge of the storm denote the present coastline. While dust storms are not uncommon, an important change is that the dust now includes fertiliser and pesticide residues that were washed into the waters of the sea from surrounding cotton fields. Long-term use of agro-chemicals has resulted in high concentrations of these pollutants on the sea bed. These are now exposed to the wind and are transported hundreds of kilometres in a generally easterly direction. (NASA)



Sand dunes, such as these in the United Arab Emirates, are the result of the erosion on their upwind sides and then deposition on their downwind sides. Many deserts contain landforms known as pavements, which form when wind removes all of the fine-grained sand leaving only the coarse gravel behind. These are generally mapped as Regosols. (BA)

Regional winds

Throughout Asia, there are numerous examples of regional wind patterns that are major causes of wind erosion. Here are a few examples:

The **wind of 120 days** is a strong summer wind occurring from late May to late September in the east and southeast of the Iranian Plateau. Strong winds, typically in the order of 30-40 km/hr, are the result of the movement of air from northern Afghanistan and the deserts of the eastern part of the Islamic Republic of Iran and western Afghanistan towards Sistan and Baluchestan Province. The wind is relatively hot and carries abrasive sand particles.

The **Simoom** is a strong, hot, dry, dust-laden wind that blows across Jordan, Iraq, the Syrian Arab Republic, and the deserts of the Arabian Peninsula. It is responsible for very high temperatures (> 50 °C).

The **Loo** is a strong, dusty, hot and dry summer wind which blows over the Indo-Gangetic Plain region of North India and Pakistan. Due to its very high temperatures and extremely low humidity, the wind causes vegetation to die thus increasing the risk of wind erosion. Violent dust storms, known locally as Black Storms, are a common precursor to the arrival of the monsoon in the northern plains. They can block the sun, drastically reduce visibility and cause property damage and injuries.

Sukhovey is a dry wind with high temperature and low relative humidity occurring in the steppes, the semi-deserts and the deserts of Kazakhstan and the Caspian region. It is a major driver of evaporation from soils.

Loess

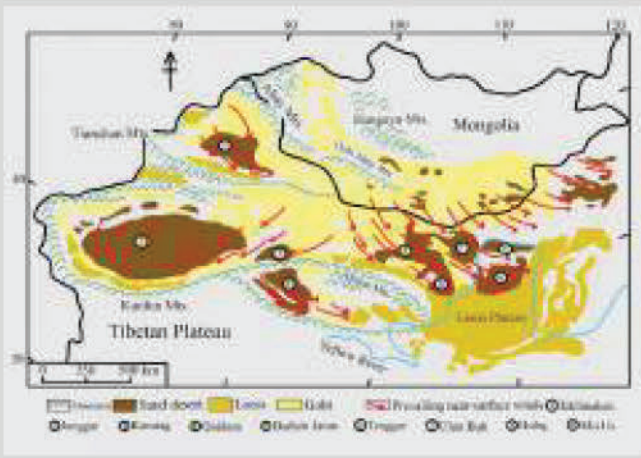
Loess is a pale yellow, predominantly silty, deposit that is formed by the accumulation of wind-blown material. In simple terms, loess can be considered as the end product of wind erosion. Loess generally occurs as a blanket deposit that can cover large areas, often hundreds of square kilometres, usually several metres thick. It is estimated that around 10% of Earth's land area is covered by loess-like deposits

Loess is usually made up of angular crystals of quartz, feldspar or mica grains, that are often cemented by calcium carbonate. Loess generally occurs as a blanket deposit that covers areas of hundreds of square kilometres. The deposits are often tens of metres thick (reaching more than 100 m in parts of northwestern China).

It has been suggested that loess is produced by two processes:

- the transport of material from deserts, dune fields, dry salt lakes and volcanic ash (e.g. Loess Plateau of China).
- the transport of material from dry floodplains in periglacial environments (e.g. on the mountains of Tajikistan).

Despite some structural integrity, loess is easily erodable by water and wind (thus acting as a new source of loess!). The Yellow River of China is so named from the yellowish tint that the loess gives to the water.



The Loess Plateau covers over 640 000 km² around the upper and middle reaches of China's Yellow River. (CC)

Soil erosion by water

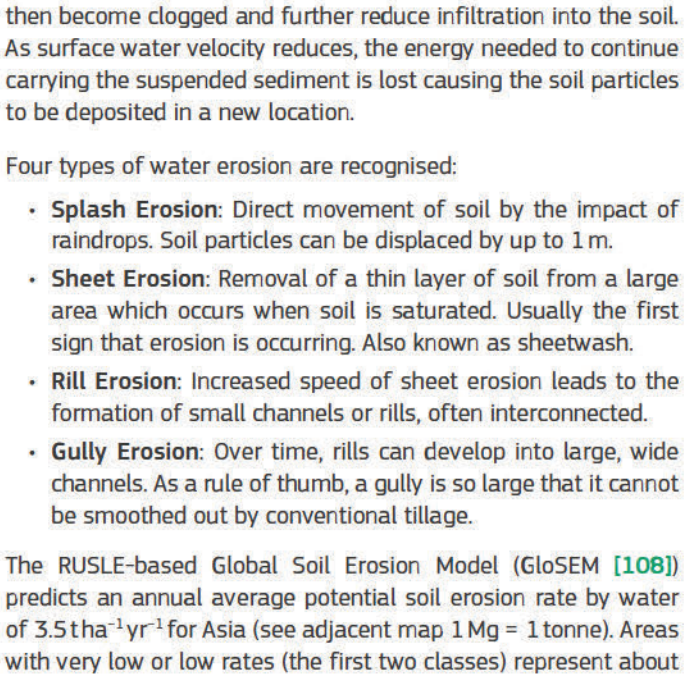
Soil erosion by water is one of the main factors limiting soil productivity and impeding agricultural enterprise in Asia, especially in the humid tropical regions where population pressure, deforestation and high rainfall, often in the form of torrential downpours, can lead to annual soil losses in excess of 50 $t\,ha^{-1}$.

When raindrops hit the soil surface, their impact can shatter aggregates into smaller pieces or displace individual particles laterally by up to 1 m. If the rainfall rate exceeds the rate at which water can infiltrate the soil, the excess water flows down the slope (i.e. as run off), carrying detached soil particles with it. Some particles float into holes or gaps in the soil surface which then become clogged and further reduce infiltration into the soil. As surface water velocity reduces, the energy needed to continue carrying the suspended sediment is lost causing the soil particles to be deposited in a new location.

Four types of water erosion are recognised:

- **Splash Erosion**: Direct movement of soil by the impact of raindrops. Soil particles can be displaced by up to 1 m.
- **Sheet Erosion**: Removal of a thin layer of soil from a large area which occurs when soil is saturated. Usually the first sign that erosion is occurring. Also known as sheetwash.
- **Rill Erosion**: Increased speed of sheet erosion leads to the formation of small channels or rills, often interconnected.
- **Gully Erosion**: Over time, rills can develop into large, wide channels. As a rule of thumb, a gully is so large that it cannot be smoothed out by conventional tillage.

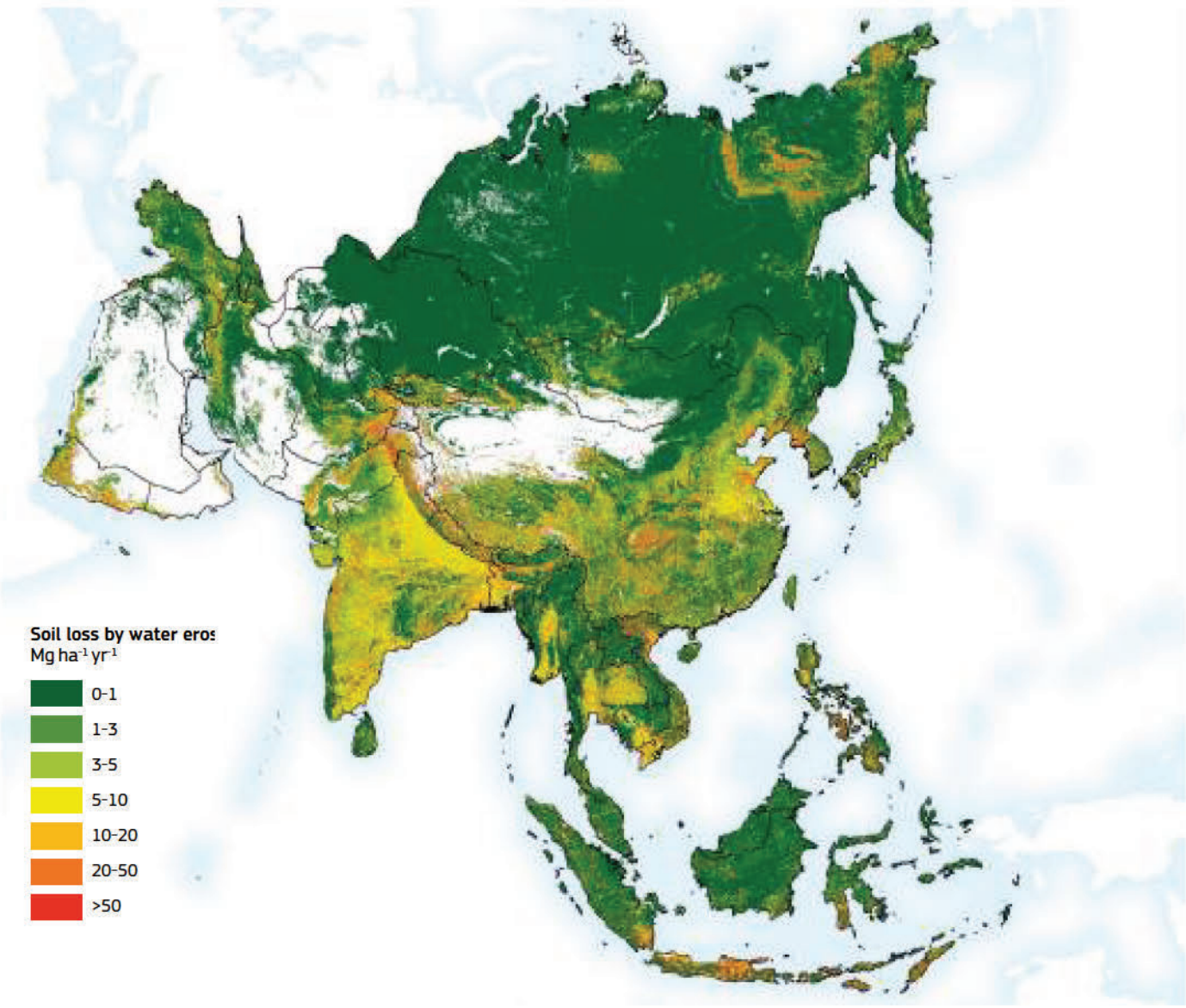
The RUSLE-based Global Soil Erosion Model (GloSEM [108]) predicts an annual average potential soil erosion rate by water of 3.5 $t\,ha^{-1}\,yr^{-1}$ for Asia (see adjacent map 1 Mg = 1 tonne). Areas with very low or low rates (the first two classes) represent about 69% and 11% of the area, respectively. Moderate (class 3) and high (class 4) values are predicted for about 5% and 7% of the study area, respectively. The remaining land surface (classes 5-7), about 3.5 million km^2 in total (or 7% of Asia), exceeds the generic tolerable soil erosion threshold of 10 $Mg\,ha^{-1}\,yr^{-1}$. In absolute terms, more than 6 000 million km^2 have erosion rates higher than 5 $t\,ha^{-1}\,yr^{-1}$ (which could be considered higher than the rates of soil formation). The highest mean erosion rates are found in Nepal, the Philippines, Tajikistan, Timor-Leste and Viet Nam (with mean erosion rates > 15 $t\,ha^{-1}\,yr^{-1}$). These values reflect the rainfall erosivity, which considers rainfall amount, duration and intensity. Southeast Asia has among the highest rainfall erosivity worldwide (see table below right). The mean rainfall erosivity in Asia is 1395 $MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}$.



An example of gully erosion in the Islamic Republic of Iran. Gullies usually form as a result of the expansion of erosional channels, such as rills, through concentrated water flows. (HK)

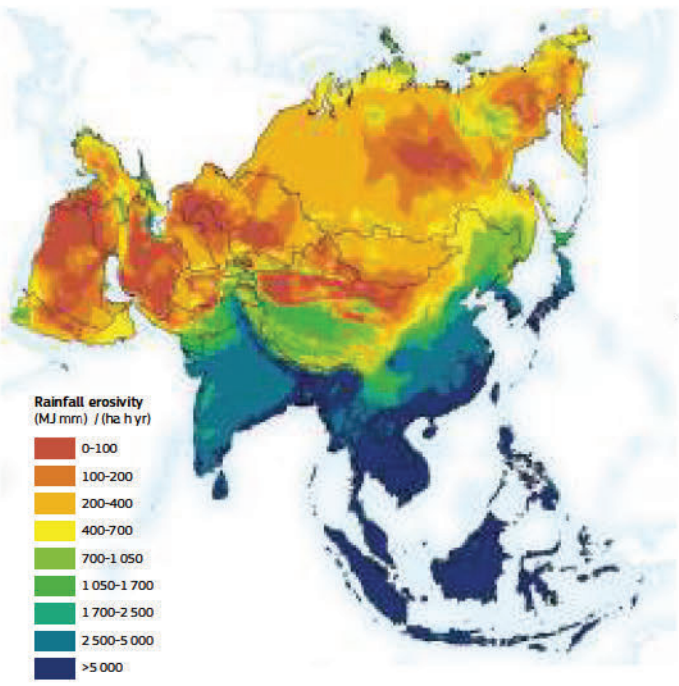


After heavy rains, many rivers turn brown in colour as a result of eroded soil being transported into them. The sediment load of the Yellow River is clearly visible in the photograph. It is estimated that around 90% of the Yellow River sediments originate from the Loess Plateau. (AS)



A map showing the intensity of soil displacement by water across Asia as predicted with the RUSLE-based semi-empirical modelling approach (GloSEM). Estimated soil erosion rates have been divided into seven classes according to the EU Soil Observatory classification. Unsustainable soil erosion by water affects around 7% of the total land area of Asia and is predominant in the hilly and mountainous terrain of China, the Himalayas and Central India, the Indonesian Archipelago, Pakistan, the Philippines and northeast Siberia. Large parts of India exhibit moderate or high rates of soil erosion.

The white areas correspond to dunes, rocks, sealed areas, lakes, deserts, where the model could not make a prediction. (JRC/PPS/PBI) [109]



A map showing rainfall erodability for Asia extracted from the Global Rainfall Erosivity database. This was one of the input layers behind the soil erosion map above (see RUSLE box below). Erosivity describes the kinetic energy of raindrops as they hit the soil surface. Extremely high erosivity (> 9 000 $MJ\,mm\,ha^{-1}\,h-1\,yr^{-1}$ is estimated in Bangladesh, Indonesia, Singapore, Timor-Leste and Viet Nam. Very low erosivity (< 300) is estimated in Kazakhstan, Mongolia, the Near East and the Russian Federation. (JRC/PPS/PBI) [110]

Country	Simulated land [M ha (% of total land)]	Mean soil loss [Mg/ha/yr]	Soil loss >5 Mg/ha/yr [%]
Nepal	14.2 (99)	21.8	90
Viet Nam	31.3 (100)	21.2	55
Timor-Leste	1.5 (100)	20.1	28
Tajikistan	8.8 (63)	18.1	93
Philippines	29.8 (100)	15.7	32
Democratic People's Republic of Korea	11.2 (93)	14.8	79
Yemen	23.8 (45)	13.4	62
Pakistan	56.9 (74)	12.8	60
Oman	3.4 (11)	12.3	62
Kyrgyzstan	16.5 (86)	10.7	65
Bangladesh	13.0 (100)	9.7	98
India	297.3 (100)	9.4	70
Republic of Korea	8.7 (89)	9.2	61
Afghanistan	41.1 (63)	9.0	54
Lebanon	0.9 (89)	8.7	75

Descriptive statistics of the 15 countries with the highest annual average rates of soil erosion by water). [109]

RUSLE

The **Revised Universal Soil Loss Equation (RUSLE)** is a widely used empirical erosion model that calculates the average long-term risk of erosion and sediment transfer by water. It has evolved from the Universal Soil Loss Equation (USLE) that was developed by the US Department of Agriculture [111].

The following input data are required to run the RUSLE model:

- Average annual precipitation
- Properties of the topsoil;
- Terrain information
- Land use and objects that inhibit erosion
- Vegetation

The RUSLE model links erosion factors influencing soil erodibility (K factor), erosivity of the rainfall (R factor), land cover and management practices (C factor), slope length (L factor) and steepness (S factor). By multiplying these factors, the mean relative soil loss in tons per hectare per year is calculated [111].

Soil pollution

Soil pollution occurs when the levels of contaminants are high enough to pose a risk to human health of the ecosystem, or exceed what should naturally be present.

Some contaminants occur naturally in soil (e.g. metals). Others are introduced through human activities. These include industrial production processes, traffic, the extraction of hydrocarbons, mining, poor waste management and agricultural activities. Unlike water, soils are used to deliberately store pollutants. For example, household and industrial wastes have historically been buried is soils as a way of protecting us and the environment. Pesticides and inappropriate amounts of fertilisers are deliberately added to soils to boost crop yields but often without considering the other ecosystem services provided by soils.

Soil pollution is considered in two forms:

- diffuse (which has widespread geographic coverage);
- localised (which is generally contained but often at higher concentrations than those of diffuse pollution).

Local soil pollution / contaminated sites

Throughout Asia, there is a substantial legacy of soil that has been contaminated by a range of toxic chemicals linked to past and ongoing industrial processes. Pollution often reflects poor management of industrial areas and waste disposal sites, inadequate effluent and emission controls, the importation and storage of waste materials. A lack of education in the use and disposal of chemicals and waste products together with rapid urbanisation (where previous industrial sites are often reclassified for urban development) are all factors driving local pollution issues. In these situations, soil contamination occurs around a specific source (e.g. mine) but in a relatively restricted area.

Contaminants may include metals, hydrocarbons and other organic pollutants (especially linked to pesticide production, storage and disposal sites), pathogens, and inorganic substances that are harmful to both humans and the environment (e.g. radioactive isotopes). Human risk comes from contaminated vegetation (e.g. root crops), leakage to ground and surface water bodies through leaching or surface run-off, dermal contact or inhalation (driven by wind erosion). The level of contamination may be a deterrent to future development putting increased pressure on other land.

Mining is often a major cause of local soil pollution. Uranium mining and processing activities have been carried out in the mountainous areas above the Syr Darya River where the borders of Kyrgyzstan, Kazakhstan, Tajikistan and Uzbekistan meet. Poorly managed sites containing uranium and other hazardous wastes from radioactive processing in densely populated areas such as the Fergana Valley pose a threat to the environment and to human health.

Many Asian countries are experiencing high economic growth leading to concerns about inefficient waste management and illegal dumping. Poorly regulated end-of-life disposal of vehicles and ships (Bangladesh has one of the largest ship-breaking industries in the world) is a source of local soil pollution.

In oil-producing countries (e.g. Azerbaijan, China, Kazakhstan, and Turkmenistan) soil pollution by petroleum products are common. An area of more than 15000ha in the Absheron Peninsula of eastern Azerbaijan is considered to be heavily polluted by oil pumping and processing activities. Similar concerns can be found in the western part of Turkmenistan.

In Japan, local soil pollution by radioactive substances occurred as a result of the Fukushima incident in 2011. While initial reports concluded that there were no immediate health impacts from exposure, soils contaminated with caesium-137 remain a concern. Testing the Soviet Union's nuclear weapons at the Semipalatinsk Site in the northeastern steppe of Kazakhstan also resulted in radioactive soil contamination.

Unfortunately, due to limited inventories, the full extent of contaminated sites across Asia is essentially unknown and no relevant map exists.



Soil pollution affects how soils function, which in turn leads to the reduction, and eventually, the loss of ecosystem services. The toxicity caused by contaminants changes belowground communities by the replacement of sensitive species by more pollution-tolerant ones. (FAO) [112]

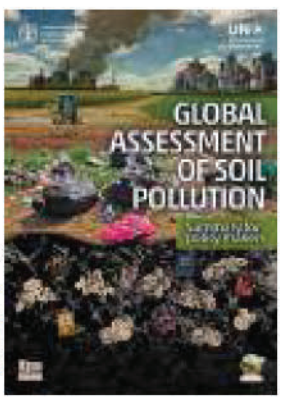


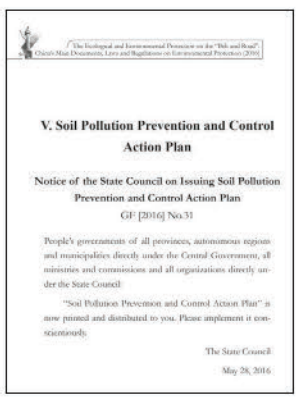
Copper mine above Watarase River, Japan. Mining is a major cause of local soil pollution. (JAA)



Diffuse soil pollution can affect other environmental media. This photograph from Türkiye shows excess irrigation water that is polluted from excess fertiliser, particularly nitrogen and phosphorous. (MAC)

In 2016, China launched the Action Plan for Prevention and Control of Soil Pollution. The plan pledged to make about 95% of polluted arable land and over 95% of polluted sites safe for human use by 2030. Ten special measures were proposed so that these targets would be met. These include new laws to monitor, prevent and remediate the soil pollution [113]





V. Soil Pollution Prevention and Control Action Plan

Notice of the State Council on Issuing Soil Pollution Prevention and Control Action Plan

GF [2016] No.31

People's governments of all provinces, autonomous regions and municipalities directly under the Central Government, all ministries and commissions and all organizations directly under the State Council:

"Soil Pollution Prevention and Control Action Plan" is now printed and distributed to you. Please implement it conscientiously.

The State Council

May 28, 2016

The Global Assessment of Soil Pollution by FAO and UNEP summarises the state of the art of soil pollution, identifies the main pollutants and their sources affecting human health and the environment, techniques for assessing and remediating contaminated soils. (FAO) [112]

Diffuse soil contamination

Diffuse pollution is typically linked to atmospheric deposition, particular farming practices and inappropriate waste recycling and treatment.

FAO's Global Assessment of Soil Pollution [112] noted that agriculture is an important source of diffuse pollution in many Asian countries. Several countries, including China, Bangladesh and the Republic of Korea, have carried out national studies, which show that values of the safety guidelines for trace elements are often exceeded. A 2016 survey in China found that 19.4% of samples taken from agricultural areas exceeded standards for metals and pesticides (i.e Cd, Ni, Cu, As, Hg, Pb, DDT and PAH). This reflects the irrigation of crops by contaminated groundwater, wastewater discharged from industrial parks and transport areas, and from historical pollution by long-term use of cadmium and fluorine contaminated phosphate fertilisers.

In parallel, the large-scale application of persistent pesticides has contaminated large areas of southern, eastern and central Asia with dioxines and furans (i.e. PCDDs, PCDFs respectively). In Japan, some rice fields have been contaminated with more than 450kg PCDD/PCDF, while these pollutants have been transported, in association with soil particles, by water leading to their accumulation in the sediments of rivers, lakes and oceans. The Indian subcontinent has long used persistent pesticides, including DDT and HCH, while in Bangladesh, organochlorine pesticides are present in soil and water due to their widespread use before they were banned by the Stockholm Convention in 2001. Agricultural soils in China also show high concentrations of organic contaminants, but to a lesser extent than by metals.

However, there are many other substances where scientific knowledge on their fate, potential toxicity or risk to human and environmental health is lacking. This leads to a growing societal concern. These contaminants include pharmaceuticals, antimicrobials (that result in bacteria resistent to antibiotics), new industrial chemicals (such as PFAS), and plastic residues.

Natural contamination: arsenic

As described in the section on soil-forming factors, certain elements can be found in soil as a result of weathering and breakdown of rocks and other deposits. This means that soils can naturally contain certain elements that can be toxic to humans, animals or plants.

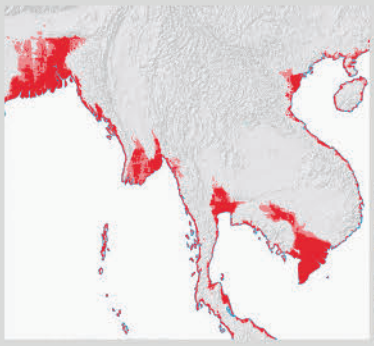
Most of the time, these substances (generally in the form of metal oxides or ions), occur at low concentrations and do not represent a risk. In some cases, the natural vegetation can adapt to the presence of these elements.

However, where the soil parent material has high levels of these elements, concentrations can be elevated to a point that posses a real risk to health. In that case, these soils should also be considered as polluted and must not be used in a manner that poses a risk of contaminating the food chain.

Southern Asia is particularly affected by the contamination of groundwater by arsenic, which is derived from arsenic-bearing sediments. The ingestion of high levels of arsenic causes damage to skin, liver, lungs, digestive and other organs, as well as genetic abnormalities.

While geothermal and volcanic activity on the Pacific "ring of fire" are sources of arsenic and other metals to soils and waters of the region, the main driver in the mobilisation of arsenic is the reductive dissolution of iron oxyhydroxides, in combination with organic matter and microbes.

Drinking water from contaminated wells and heavy groundwater withdrawals for irrigation are thought to be the main pollution pathways for arsenic. In particular, the Bengal Delta region is a major hotspot for arsenic pollution from geogenic sources. Estimates show that at least 36 million people drink water contaminated with arsenic [114].

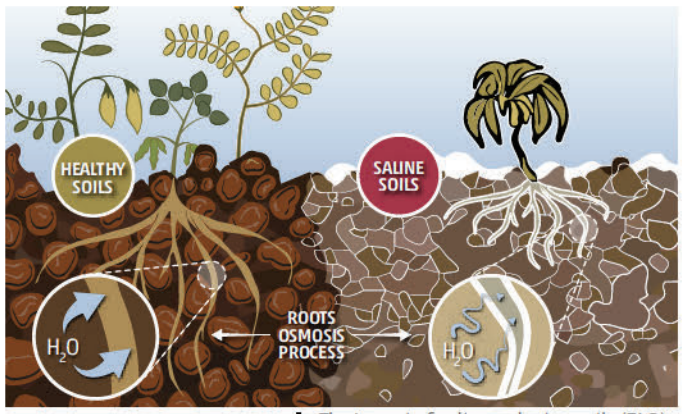


There are increasing concerns for arsenic contamination of groundwaters in the deltaic regions of Cambodia, Thailand and Viet Nam. (JRC/LJ)

Salinisation and sodification

Salt-affected soils include saline, sodic, and saline-sodic soils - and many sub-categories depending on the type of salts.

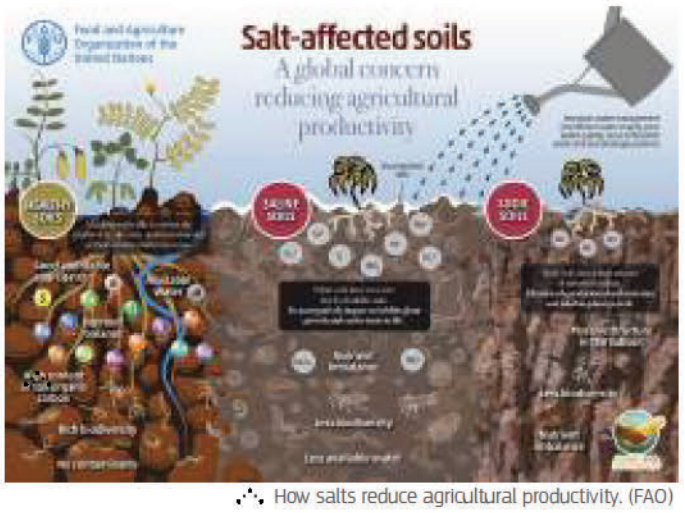
Saline soils contain an excessive amount of soluble salts. Most of salt ions are not toxic to plants but their presence in soil solution reduces the ability of plants to take up water from soil. Water moves into plant roots by a process known as osmosis, which is controlled by the level of salts in the soil water and in the water contained in the plant (see diagram below).



The impact of salts on plant growth. (FAO)

In nonsaline soil, the roots of the plant have a higher solute concentration than the surrounding soil, so water flows into the roots. If the level of salts in the soil water is too high, water may flow from the plant roots back into the soil causing them to dry out. Only specially adapted plants - halophytes and salt tolerant crops - can grow well in these soils.

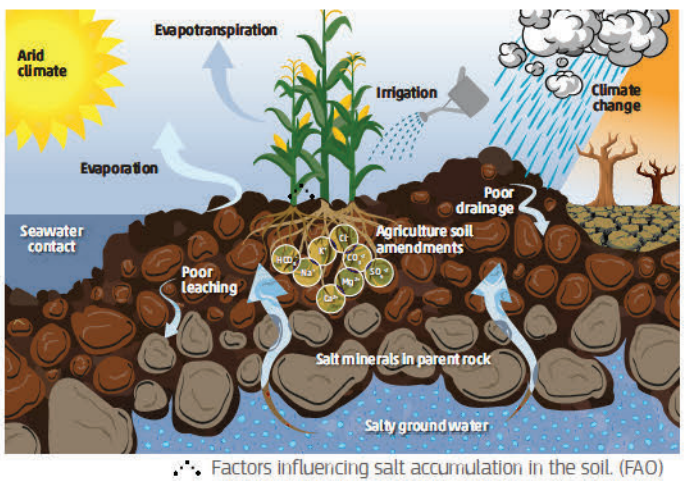
Sodic soils contain high amounts of adsorbed sodium ions which causes the degradation of the soil structure. As a result, aeration and water movement is restricted within sodic soil. Both saline and sodic conditions considerably reduce the agricultural productivity of these soils.



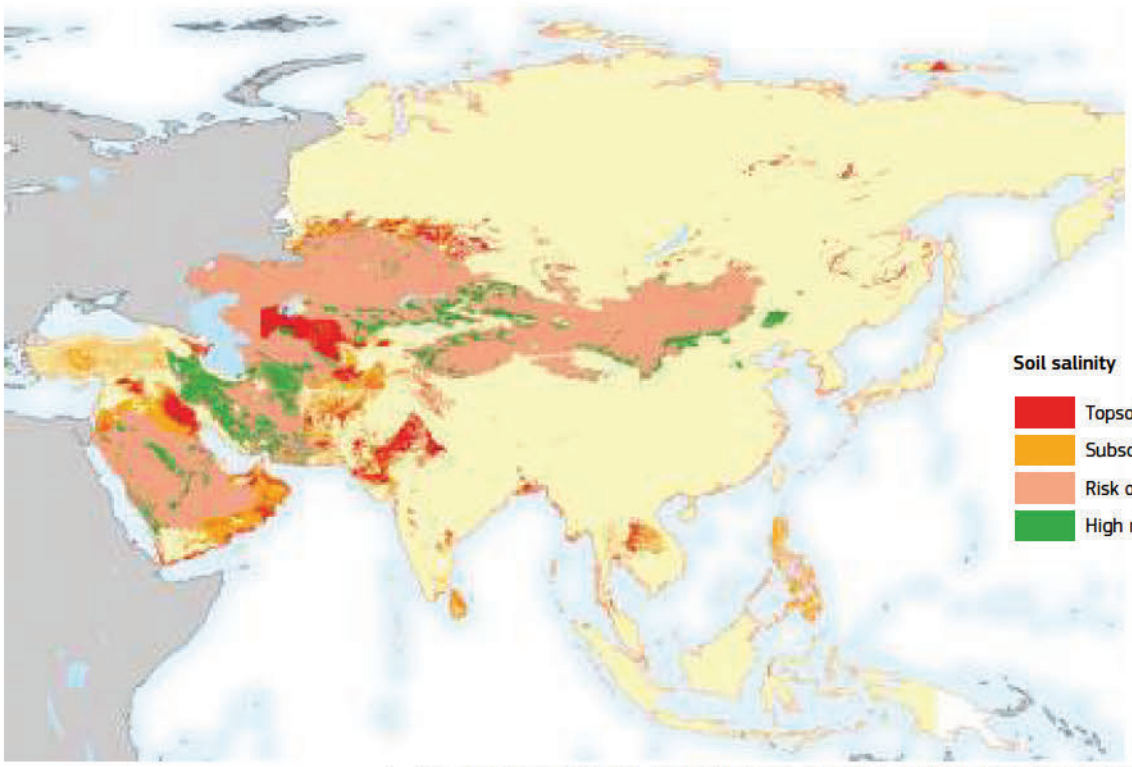
How salts reduce agricultural productivity. (FAO)

Saline and sodic soils can occur naturally as a result of one of the following factors (see page 50): weathering of salt bearing rocks or minerals, restricted drainage either due to hard pan or land topography, shallow saline ground water, aeolian input of salts from saline playas and coastal areas, sea water intrusion, volcanic activity, water scarcity or aridity.

Soils can become salt-affected very quickly due to mismanagement, the process called secondary (human-induced) **soil salinisation and sodification** which can be caused by (i) irrigation with poor quality water; (ii) inadequate drainage and/or irrigation methods/practice; (iii) deforestation and removal of deep-rooted vegetation (dryland salinisation); (iv) excessive water pumping and seawater intrusion in the coastal area; (v) misuse of fertilisers; (vi) mining activity.



Factors influencing salt accumulation in the soil. (FAO)



Map showing the principal areas affected by topsoil and subsoil salinisation as assessed by the Global Map of Salt-affected Soils. Regions with a risk of salinisation reflect dry soils where evaporation generally exceeds precipitation or are close to the coast where saltwater intrusions or sea level rise can cause salinisation. Areas in green depict areas where irrigation is used to support the growth of crops. Care must be taken in these areas to limit the build-up of salts in the soil. (FAO/MK/JRC/AJ) **[116, 117]**

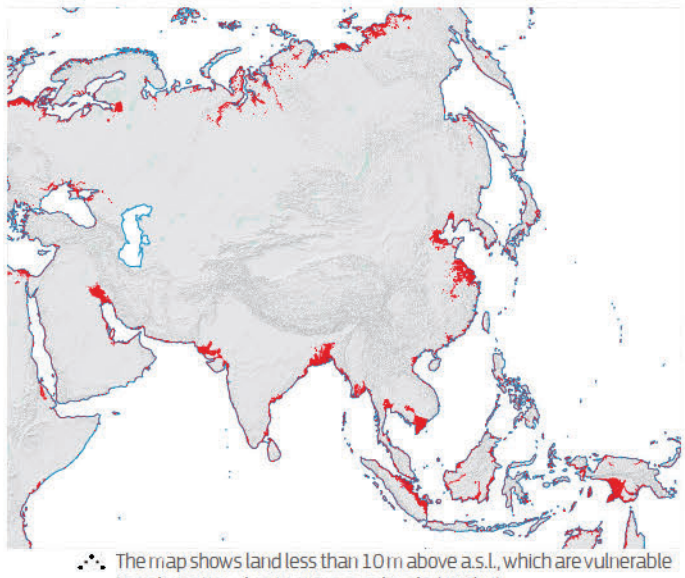
Prevention measures include irrigation with good quality water (low EC, low SAR), use of proper irrigation methods or practices, improved drainage, leaching of salts (however this demands a lot of water), reforestation, controlling the pumping and monitoring the salinity of soil and ground water, and a balanced use of fertilisers.

Adaptation measures:

In case of salinisation: mulching, interlayers of loose materials, surface levelling, cover film to decrease evapotranspiration. Crops resistant to salinity (halophytes and salt tolerant varieties).

In case of sodification: application of gypsum, lime and organic matter amendment. Selection of crops resistant to compaction and waterlogging.

For both cases: agroforestry, improved crop rotation, agro-biodiversity, crop diversification, biotechnologies (including bioinoculants, biofortification), change use from cropland to one matching soil capabilities, adoption of practices that sustain soil health (high soil biological activity, adequate organic carbon content and good structure).



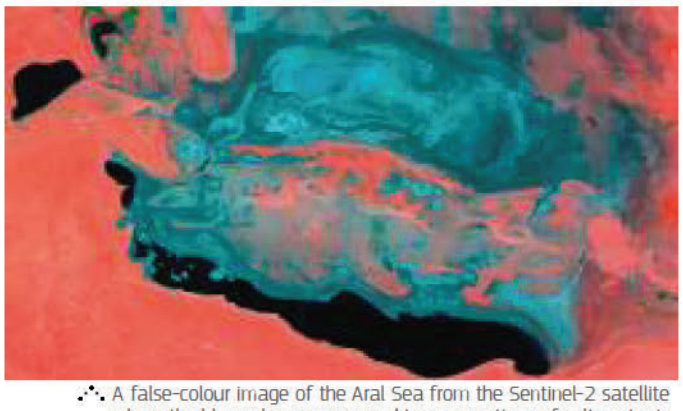
The map shows land less than 10 m above a.s.l., which are vulnerable to salinisation due to rising sea levels (JRC/LJ)

Country	Population occupying vulnerable land	
	Millions	Percent
Maldives	0.25	100
Bahrain	0.6	82.2
United Arab Emirates	3.7	74
Bangladesh	110	68.8
Viet Nam	60	66.7
Brunei Darussalam	0.22	55
Macao	0.3	53.6
Cambodia	7.1	50.7
Qatar	0.37	44
Malaysia	12	42.9
Taiwan	9.6	41.7
Singapore	1.9	40.4
Oman	1.2	40
Hong Kong	2.8	39.4
Japan	48	36.9
Philippines	36	36
Myanmar	18	34
Thailand	22	32.8
Sri Lanka	6.8	30.9
Indonesia	72	30
Democratic People's Republic of Korea	6.1	26.5
Kuwait	0.71	25.4

More than 300 million people in Asia are living on land at risk of sea level rise. **[115]**



Photograph of a farm with halophytes in Uzbekistan. Halophytes are particularly important in biomelioration and improvement of productivity of marginal lands with saline soils and scarce water. Halophytes (from Greek: ***halas*** – salt and ***phyton*** – plant) are salt-loving plants capable of tolerating high levels of soil salinity. Halophytes have naturally evolved and acquired morphological, physiological, and anatomical features that allow them to persist in and even benefit from saline soil and water. Their yield may reach 20-40 t/ha of green fodder. Halophytes are nutritious and 1 kg of dry matter may contain 350-500 kilocalories. (KP)



A false-colour image of the Aral Sea from the Sentinel-2 satellite where the blue colours correspond to aggregations of salt, water is black, barren ground is red and vegetation is green. (ESA)

Salt in soil – understanding the terminology

Salinity – presence of water soluble salts

Sodicity – presence of exchangeable sodium

Alkalinity – high pH

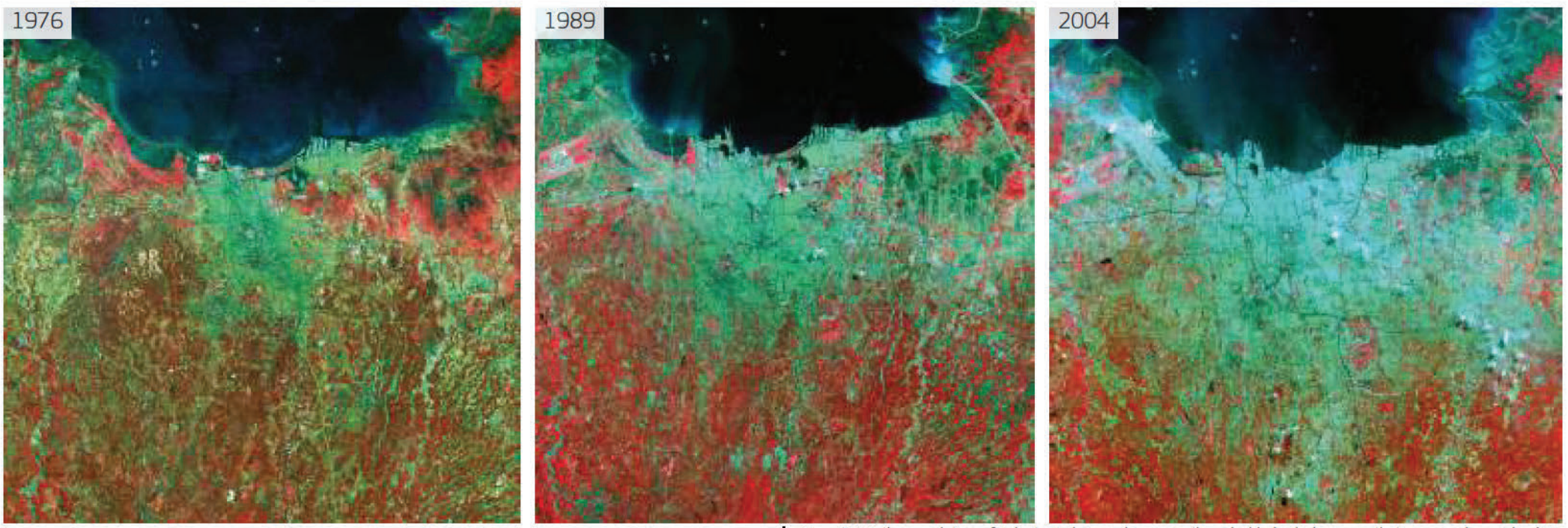
Salinisation/sodification/alkalisation – the process of salinity/sodicity/alkalinity increase due to natural or human-induced factors

Halophytes – plants that can grow under high salinity levels (> 200 mM NaCl in soil solution)

Salt tolerant crops – plants that can grow under moderate salinity levels (80-200 mM NaCl in soil solution

Osmosis – a process of movement of solvents through a semi-permeable membrane from a region of lower solute concentration to higher solute concentration. Osmosis is responsible for the ability of plant roots to absorb water from soil.

Soil sealing

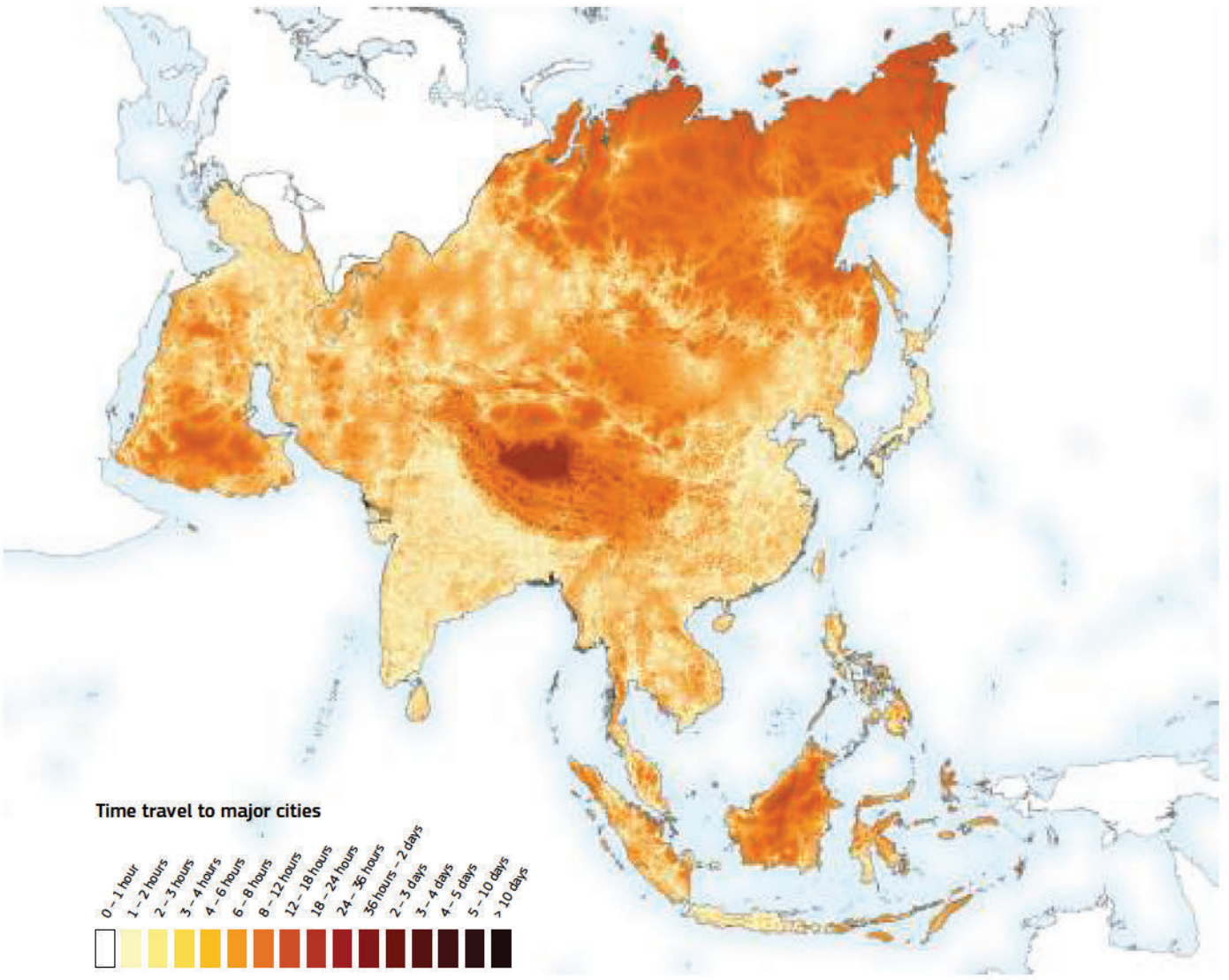


Since 1976, the population of Jakarta, Indonesia, has more than doubled, which means that more and more land is needed for housing, transport infrastructure, retail and business. This series of satellite images shows the growth of the city between 1976, when the population was 6 million, and 1989, when the population was 9 million, and 2004, when the population reached 13 million (each image covers an area of 49 by 49 km). Vegetation appears red while built up areas are light green. In the 1976 image, the extent of the city is denoted by a green patch in the centre and along the coastline, surrounded by vegetated land (red). By 1989, the city had spread considerably to the east while by 2004, significant westward expansion can also be seen with few pockets of vegetation remaining. (NASA)

More than a third of Asia's 1 billion inhabitants currently live in urban areas. By 2030 that proportion will have risen to half [55]. Such a trend will have significant impacts on soils. In the vicinity of urban areas, one of the main issues is soil sealing. In fact, eight of the world's largest megacities are in Asia. For example, Guangzhou in China currently has a population of over 18 million and covers an area of 7 434 km^2.

Sealed soils can be defined as the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.). It is the most intense form of land take and is essentially an irreversible process. Sealing also occurs within existing urban areas through construction on residual inner-city green zones. The sealing of soil surfaces, by covering them with buildings, roads and other developments, reduces the area available to carry out essential functions such as food production, filtering and absorbing rainwater (reducing surface run-off, flood control and replenishing groundwater) and providing a habitat for soil organisms. It should be noted that most urban areas were located initially close to fertile land and sources of water. For this reason, urban expansion very often consumes high quality agricultural soil at a time when food production needs to match demand.

An associated issue of soil sealing is the increased risk of urban flooding. Sealed soils are unable to absorb rainfall. This increases both the volume and speed of run-off of rain water to the natural drainage system. Flood peaks develop much quicker leading to rivers bursting their banks and to drains being unable to cope with the flow of water. With an increasingly urbanised population, such events are likely to be even more catastrophic in the future.



A map showing an index of accessibility for Asia based on travelling time to cities with more than 50 000 inhabitants. The index takes into account infrastructure development and, as such, is a good proxy for soil sealing. The main urban agglomerations are shown in bright tones while the yellow tones indicate areas within four hours travelling.

While the map does not show actual sealing, the image gives a sense of where human activity is concentrated across the continent and the pattern of the principal road network along which urbanisation takes place. The dark coloured areas indicate remoter regions that are less developed.

The data show that many parts of Asia, such as the Arabian Peninsula, Siberia, Tibet and the island of Kalimantan are classified as very inaccessible. (JRC/FG) [118]



Urban development in Asia can take many forms ranging from modern, multi-story developments to a more haphazard, piecemeal expansion along principal infrastructure routes (high rise developments in China). (CG)



Flooding in Jakarta during 2013 as a result of an exceptional rainfall of 74 mm in 5 hours causing the Ciliwung and Cipinang Rivers to burst their banks. The resulting flooding was widespread, with flood water levels over 1 m deep in some areas of the city. Extensive soil sealing exacerbates flood peaks. (RB)

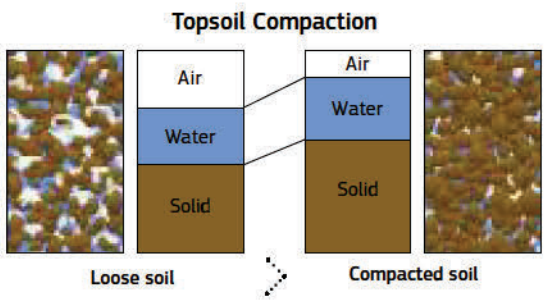


Urban expansion often consumes the most productive soils, putting increased pressures on other soils. This example from the city of Ibb in the Southern Highlands of Yemen clearly shows construction on agricultural terraces. (MHAH)

Compaction and landslides

Soil compaction

Soil compaction is a form of physical degradation caused by the reorganisation of soil aggregates, which are deformed or even destroyed as a result of pressure on the surface of the soil. Occurring below the surface, compaction is a hidden problem. The location of compacted soils across Asia is not consistently assessed and no map is available to show the extent of the problem.



Compacted soils (right side figure) contain less large pores, less pore volume and, consequently, a greater density than uncompacted soils (left side figure). Compaction reduces biological activity, nutrient uptake, porosity and permeability. The latter two affect water infiltration capacity and increase erosion by accelerating runoff. (LJ)

Topsoil compaction occurs when soil is subjected to surface pressure from the passage of heavy machinery or by repeated trampling of grazing animals, especially under wet conditions. In arable land with annual cultivation, subsoil compaction is caused by tractors driving directly on the subsoil during ploughing, by the design of the plough or by very heavy axle load weights being transmitted deep in to the soil. Unlike topsoil, the subsoil is not loosened annually, and compaction becomes cumulative.

A feature of compacted soils is the formation of a pan-layer that is less permeable for roots, water and oxygen than the soil below. This becomes a bottleneck for the functioning of the subsoil. It should be noted that soils of paddy fields are deliberately compacted to slow the passage of water (a process known as puddling).

The collapse of macropores by compaction leads to reduced infiltration rates, increased surface run-of and therefore an increased risk of erosion. In irrigated areas, compaction can lead to poor water use efficiency and increased costs (i.e. more water is needed).

Increased mechanisation of agriculture across Asia has led to greater loading of soils. Soil compaction also occurs during deforestation and forestry operations, especially if organic or organic-rich topsoils are present. Heavy grazing is a major driver of compaction in the extensive pastoral steppe regions of Mongolia and Inner Mongolia of China.



The reduced growth of the plants on the right side of this example from Sri Lanka, is the consequence of a pan-layer at a depth of 15 cm, which is less permeable for roots, water and oxygen than the soil below. This becomes a bottleneck for the functioning of the subsoil. (UV)



Deforestation of tropical forests as shown by this example from Malaysia, significantly impacts soil properties and functions. A major cause is topsoil and subsoil compaction. While reforestation can reverse many of the effects of deforestation, subsoil compaction often remains, hindering the future use of those soils. (PR)

Landslides

A landslide is the gravitational movement of a mass of rock, debris or soil down a slope. Landslides occur when the condition of a slope changes from being stable to being unstable. Such changes can be caused by a range of triggering factors, acting together or alone. Landslides are usually classified on the basis of the type of material involved (rock, debris, earth, mud) and the type of movement (fall, topple, slide, flow, spread). Landslides can be slow moving or very rapid.

Natural causes of landslides include intense rainfall, prolonged periods of wet weather or snowmelt, earthquakes, volcanic activity, loss of vegetation cover (e.g. after wildfires), earthquakes (e.g. China and Indonesia in 2022) and the undercutting of slopes by rivers or ocean waves. Anthropogenic causes of landslides include deforestation, inappropriate agricultural practices and infrastructure construction such as slope cutting and loading.

Landslides occur more frequently in areas with steep slopes and highly erodible soils, clayey subsoils or weathered and jointed bedrock, usually following intense and prolonged precipitation or earthquakes.

Landslides threaten soil functions in two ways:

1. removal of soil from its in situ position; and
2. covering the soil downslope from the area where the slope has 'failed'.

Where a landslide removes all soil material, all soil functions will be lost and weathering processes of the hard rock or sediment now exposed at the surface need to operate for hundreds if not thousands of years to produce enough material for soil functions to resume. When only a part of the soil profile (e.g. the A horizon) is removed by a landslide, some soil functions may remain, although most are likely to be impaired.

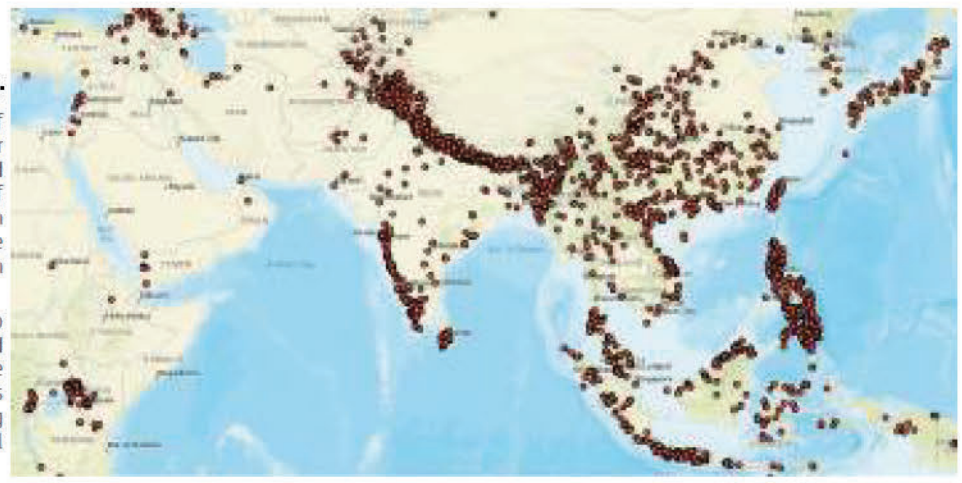
Landslides are a major hazard in most mountainous and hilly regions as well as on steep river banks and coastlines. Their impact depends mainly on their size and speed, the elements at risk in their path and the vulnerability of these elements. This problem is particularly acute in Asia where less adaptable populations (e.g. those constrained by poverty, land availability) are much more vulnerable to geohazards. Every year landslides cause fatalities and result in significant damage to infrastructure (roads, railways, pipelines, artificial reservoirs, etc.) and property (buildings, agricultural land, etc.). Landslides can also affect mine waste tips, tailing dams and landfills, causing fatalities and contaminating soils, surface water and groundwater.



In 2014, some 5.5 million m³ of rock slid into the Sunkoshi valley in Nepal. This buried many homes, killed 156 people and created a 55 m tall dam that completely blocked the river. Before breaking through the barrier a month later, the upstream expansion of the lake drowned a hydropower plant that caused a 10% decrease in Nepal's electricity generating capacity. (IWP)

A positive aspect of landslides is that they are a major provider of sediments and nutrients for floodplain soils.

Given that much of Asia is a level landscape with low rainfall, landslides are not widespread. They mainly occur in high mountain ranges of the Himalayas, the Caucasus, and Western Ghats, as well as the mountains and hilly regions of southeast Asia. Landslides are also found on sensitive geological formations, such as volcanic slopes in Indonesia and the Philippines.



The NASA Landslide Viewer gives an overview of the location of landslides across Asia, together with information on their types, triggers and impacts. Analysis shows that slope, relative relief and annual precipitation are the main factors in predisposing slope instability. Highly susceptible terrain covers 5% of the mapped area, more than the 93% of which is steeper than 15°.

Landslide activity and impact are expected to increase in the future in response to increased urbanisation and development in landslide-prone areas, deforestation and the associated changes in land use and land cover, and the changing climate conditions (higher or more intense rainfall patterns). (NASA) [118]



On December 12, 2014, the Banjarnegara area, in central Java, Indonesia, was hit by a landslide, leading to 98 casualties and the destruction of an area of around. 125 000 m². The landslide ocurred in weathered andesitic rocks, began as a rotational slide, which spread out, leaving a central spur intact. At the western side of the spur, it developed into a mudflow, which caught onlookers by surprise and lead to the majority of casualties. The slide was triggered by rainfalls of 112 mm and 101 mm on the two preceding days. (PKW)

Land management: the impacts for soil

Competition for land and how soils are managed as a result, have a major impact on the condition of soils across large parts of Asia.

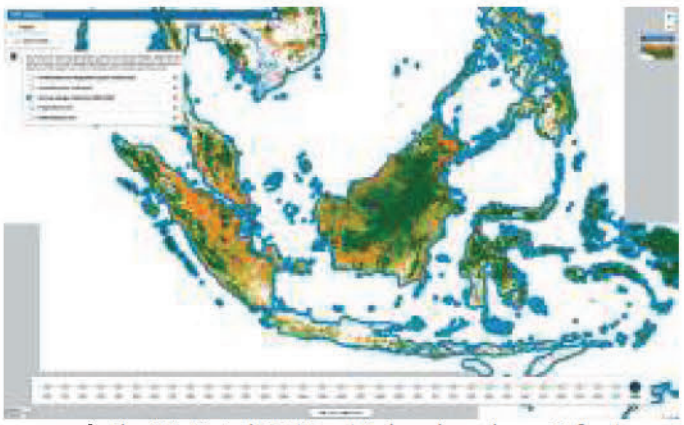
In recent years, increasing pressure on land to support growing populations is driving soil degradation. This section describes three issues that affect soil health and their impact on food security.

1. Land use change and soil quality

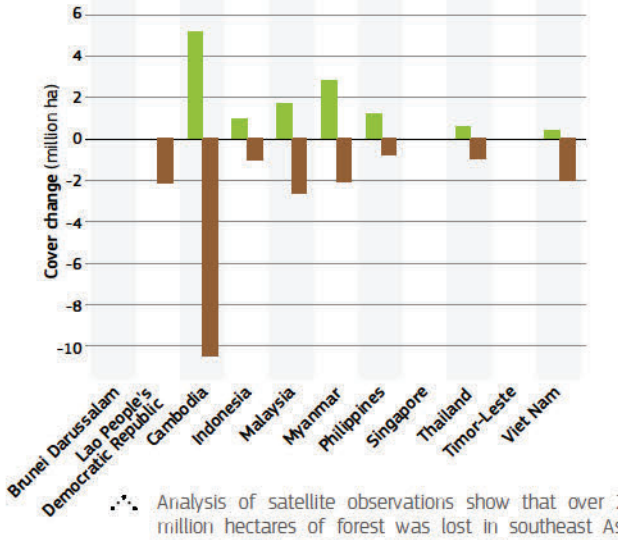
Changing how land is used is not a new phenomenon. Practices such as ploughing, liming (for example, through slash-and-burn cultivation), drainage, and forest clearance, have been modifying soil properties for millennia (see below). Indeed, where climatic conditions support long-term arable farming practices, current soil characteristics may be very different to when the land was under natural vegetation.

However, since the late 1960s, there have been unprecedented land cover and land use changes in many parts of Asia. This has been especially evident in the southern, southeast and eastern Asian countries where a high rate of population increase and economic development have placed increasing demands and pressures on land resources. These pressures are often manifested as a conversion of natural vegetation to other uses. While the loss of soil through land take and sealing has been described on page 180, in this section we will look at the consequences of deforestation on soil.

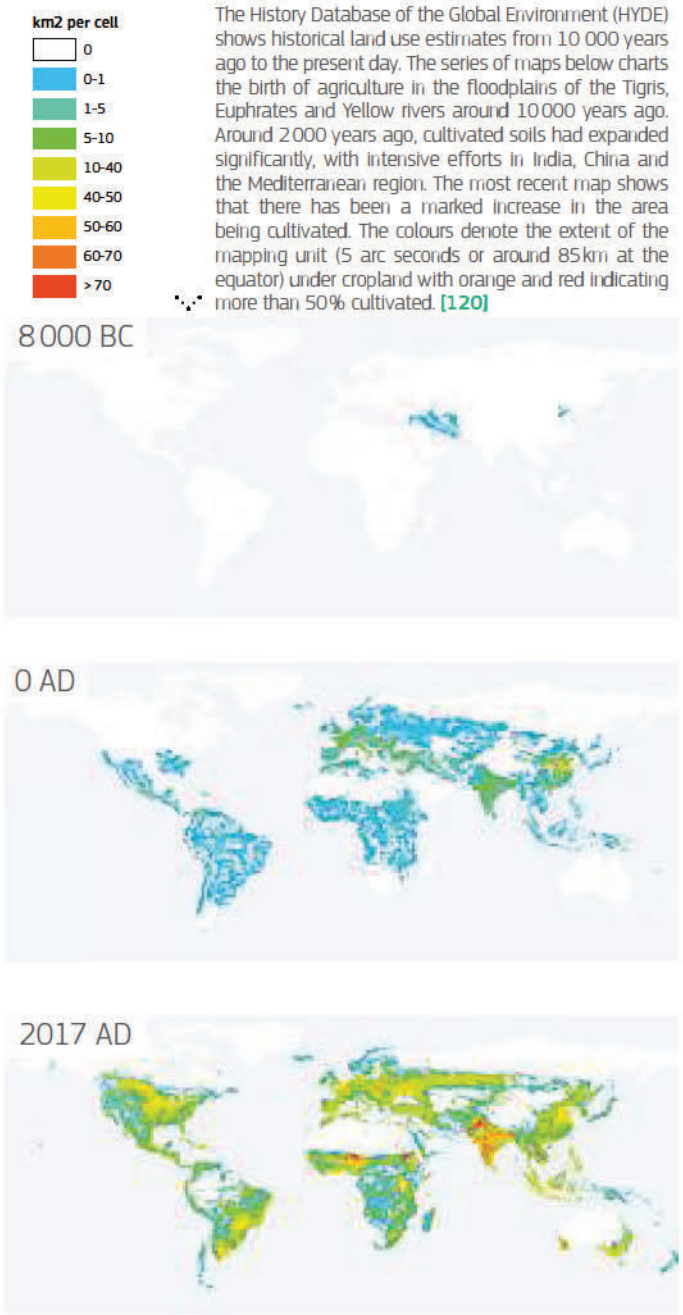
The FAO estimates that around 13% of the world's tropical forests are located in southeast Asia [122]. These consist of mixed deciduous forest and evergreen dipterocarpus forests, with peat swamp forests and mangrove on many coastal areas. These forests host an incredible range of biodiversity and sustain local communities. Tropical forests are also important in the context of the global carbon balance since deforestation around the equator contributes to around 15% of global greenhouse gas emissions. Over the past decades, deforestation rates in southeast Asia have been among the highest in the world, losing at least 1% of its forests annually.



The JRC's Tropical Moist Forest Explorer shows changes in forest cover over the past three decade. Orange and light green colours highlight a loss of trees. These data clearly show the extent of forest loss in Indonesia and Malaysia. (JRC) [121]



Analysis of satellite observations show that over 21 million hectares of forest was lost in southeast Asia between 1992 and 2015, with Indonesia accounting for nearly half. The data also show efforts in most countries to restore forests. [122]



The History Database of the Global Environment (HYDE) shows historical land use estimates from 10 000 years ago to the present day. The series of maps below charts the birth of agriculture in the floodplains of the Tigris, Euphrates and Yellow rivers around 10 000 years ago. Around 2 000 years ago, cultivated soils had expanded significantly, with intensive efforts in India, China and the Mediterranean region. The most recent map shows that there has been a marked increase in the area being cultivated. The colours denote the extent of the mapping unit (5 arc seconds or around 85 km at the equator) under cropland with orange and red indicating more than 50% cultivated. [120]

Impact on soil

The removal of natural vegetation has a complex impact on soil characteristics, often breaking the fragile nutrient cycles that sustain aboveground habitats. As a consequence of their inherently low nutrient status, many cleared forest soils often show a marked loss in productivity after a few years of cultivation (unless lime and mineral fertilisers are added). The removal of the protective forest canopy also increases the risk of soil erosion by water, especially in areas where rainfall is high and intense. Carbon locked in the soil is more likely to be oxidised by the clearance process or washed away by erosion. Compaction which reduces the water retention capacity can be an issue, for example, in soils with coarse textures such as Ferralsols.

Conversely, in drier grassland regions, the change to soil conditions may initially appear beneficial. The cultivation of irrigated cereal crops with low-tillage techniques may, in the short term, actually increase soil moisture, organic matter and biodiversity levels and give higher yields than the natural savannah. However, the reduction in natural grazing areas in adjacent marginal or semi-marginal areas may increase the level of burden on other lands. Over-stocking and over-grazing can lead to compaction, a loss of soil cohesion and structure that increases the risk of erosion. The build up of salts in the soils of irrigated areas can eventually lead to a reduction in yield if not managed correctly.

2. Soil nutrients

The FAO has predicted that 60% of the world population increase over the coming four decades will be in Asia. This rapidly growing population needs to be fed while minimizing harm to the environment. One approach is to increase the productivity of agricultural soils, which in many parts of Asia are experiencing declining soil fertility.

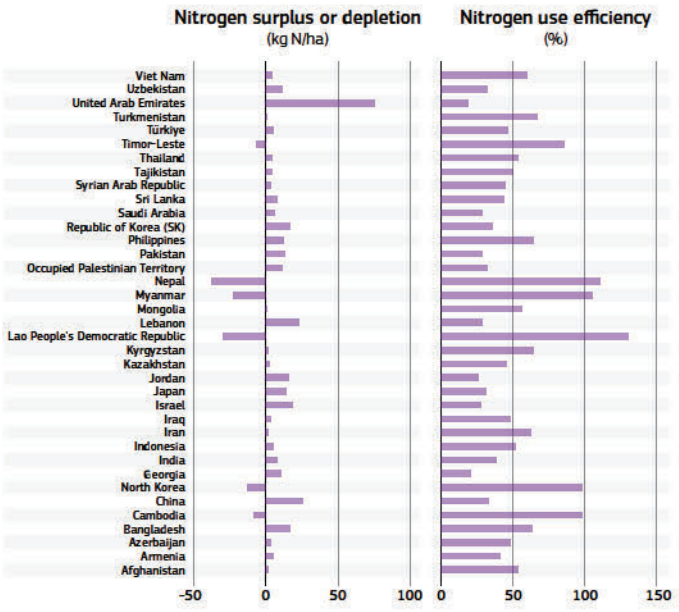
Harvested crops remove nutrients from soils. Therefore, maintaining agricultural production requires the retention of residue or the replacement of those nutrients through the addition of animal manure or mineral fertiliser. While a balanced nutrient supply is essential for achieving high crop yields, the overuse of fertilisers can cause damage to the environment, human health and the functioning of ecosystems.

Nutrient inputs in Asia vary considerably and depending on the crops being grown. In some parts of Asia, the removal of nutrients from the soil substantially exceeds inputs through natural replacement or fertiliser application. For example, negative soil nutrient balances have been reported for the 15 agro-climatic regions of India. Problems are also caused by imbalances in fertiliser application. Fertiliser use is often dominated by nitrogen, relative to phosphorous and potassium. The FAO Status of the World's Soil Resources Report for Asia reported a nitrogen deficit for Cambodia, the Democratic People's Republic of Korea, the Lao People's Democratic Republic, Myanmar, Nepal and Timor-Leste but a nitrogen surplus in all other Asian countries [24].

China is the largest user of fertilisers in the world, with an annual consumption of more than 45 million tonnes in 2019, followed in second place by India with 28.4 million tonnes. In fact, nutrient additions in some Asian countries are much higher than those of the United States and northern Europe. For example, fertiliser consumption of Indonesia has increased from 12.6 kg per hectare in 1971 to 248.2 kg in 2020, growing at an average annual rate of over 7%. This situation is compounded in most Asian countries by low levels of nitrogen use efficiency, which means that most of the fertiliser applied is not taken up by the crop. Excess nitrogen fertiliser in turn pollutes water bodies and increases greenhouse gas emissions.

In many countries, the consumption of phosphorous and potassium has not followed the same trend. This is partly due to the fact that nitrogen fertilisers are cheaper, more accessible, and impact crop response more directly. Soils with a low pH, which are common across southern and southeast Asia, also reduce the uptake of phosphorous by plants.

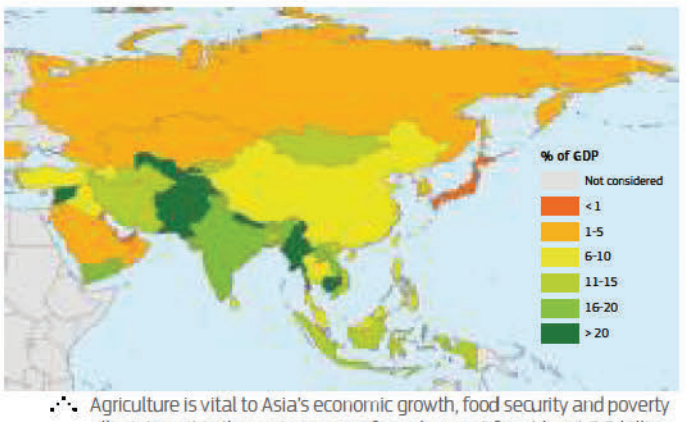
For secondary nutrients and micronutrients, sulphur deficiency has been reported for Bangladesh, India, Pakistan and Sri Lanka, while zinc deficiency has been reported for India and Pakistan.



Nitrogen surplus or depletion, and nutrient use efficiency in crop production in Asia in 2010. [24]

Impact on soil

Trends in soil nutrient management put tremendous pressure on agricultural soils which increases with higher demands. The continued increase in the area of cultivated land shows that farmers in Asia are being forced to cultivate larger areas of marginal soils to maintain production levels. In many areas, this expansion is often at the expense of Asia's wildlife and forests. Over time, decreasing fertility will cause the crop cover to be less extensive.



Agriculture is vital to Asia's economic growth, food security and poverty alleviation. It is the main source of employment for at least 2.2 billion people in the region and accounts for a significant portion of the gross domestic product (GDP) of most Asian countries. In this respect, the sustainable management of soils should be of paramount importance and a priority of national governments. (JRC/LJ) [55]

3. Overgrazing

The grasslands of Asia have been long used as pasture for different grazing herbivores (e.g. sheep, goats, cattle, camels, horses). Such animals play a critical role in how ecosystems function by controlling the composition of plant communities, grassland to woodland transitions, nutrient cycles and seed dispersal, while contributing to the food web as prey for carnivores.

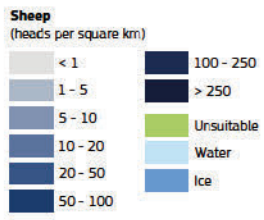
However, if too many animals are kept for too long on marginal land, then the carrying capacity of a pasture can be exceeded. This situation is referred to as overgrazing. In some circumstances, the land may be unable to recover its vegetation communities (e.g. if accompanied by droughts or harsh winters - such as the dzuds of Mongolia). Overgrazing can also occur on land that is not suitable for extended grazing as a result of certain physical parameters, such as its slope. Overgrazing can also be compounded by climate change, which in turn changes vegetation patterns.

Overgrazing is a major problem in many Asian countries. Recent increases in livestock numbers, combined with declines in pastoral mobility, have led to high livestock densities and long-term heavy grazing. This process has been reported for large parts of the Altay Mountains, India, Kazakhstan, the Mediterranean countries, Mongolia and the Tibetan Plateau. A report by the UNCCD noted that overgrazing is a significant problem in northeast Asia, affecting soil, air and water quality, which in turns threatens rangeland agriculture (almost half of Mongolia's population depends on livestock production for their livelihoods). [123]

Impact on soil

Plants provide a protective cover to the land, which is removed by overgrazing. The loss of plant roots cause the soil to lose its structure and cohesion to the point at which it becomes more easily eroded. As erosion will remove the topsoil first, plant growth will be more difficult once this nutrient-rich layer has gone.

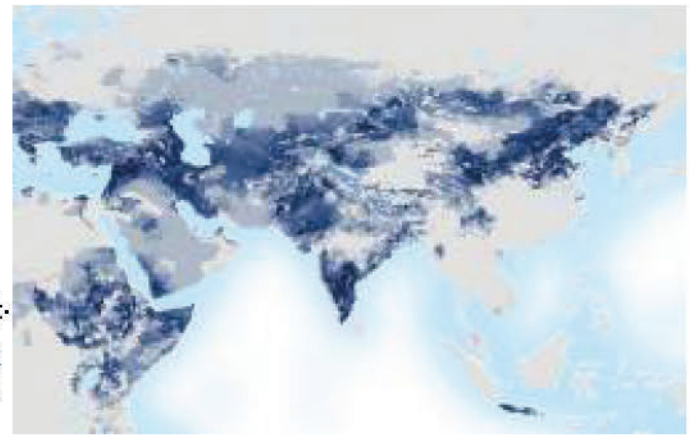
Without soil and plants, the land becomes barren and unable to support animal or human life - this process is called desertification (see below). It is very difficult and often impossible to restore highly degraded land, especially in the context of human time spans. The incidence of overgrazing and its consequences have become greatly exacerbated under the effects of climate change.



Map of estimated global sheep density for 2006. Darker tones indicate higher numbers of sheep. Note the general absence of sheep in southeast Asia - however, this is offset by higher numbers of cows (derived from [124]). (JRC/LJ)



Growing populations of grazing animals have led to serious degradation of many grasslands. Exposed soils and a lack of mature grass, as shown by this landscape from Georgia, increases the risk or soil erosion and onset of desertification. (IK)



4. Desertification

Land degradation is a global phenomenon that is reflected by a reduced capacity of the land and soil to sustainably deliver ecosystem services and produce economic value. It is linked to complex patterns of extreme events, climate and land use change. According to the UN Convention to Combat Desertification, the term 'desertification' denotes "a reduction or loss of the biological or economic productivity of soils in arid, semi-arid and dry sub-humid areas resulting from a combination of human activities, a deterioration of the land to support core ecosystem functions, coupled with a long-term loss of natural vegetation" [2].

Climatic conditions and intensive agriculture render many parts of Asia particularly vulnerable. Ever more demanding land use leads to water scarcity, hence limiting several ecosystem services normally provided by soil. Amplified variability of aridity limits the recovery of intensively used human-environment systems to recover from specific pressures such as drought or fire.

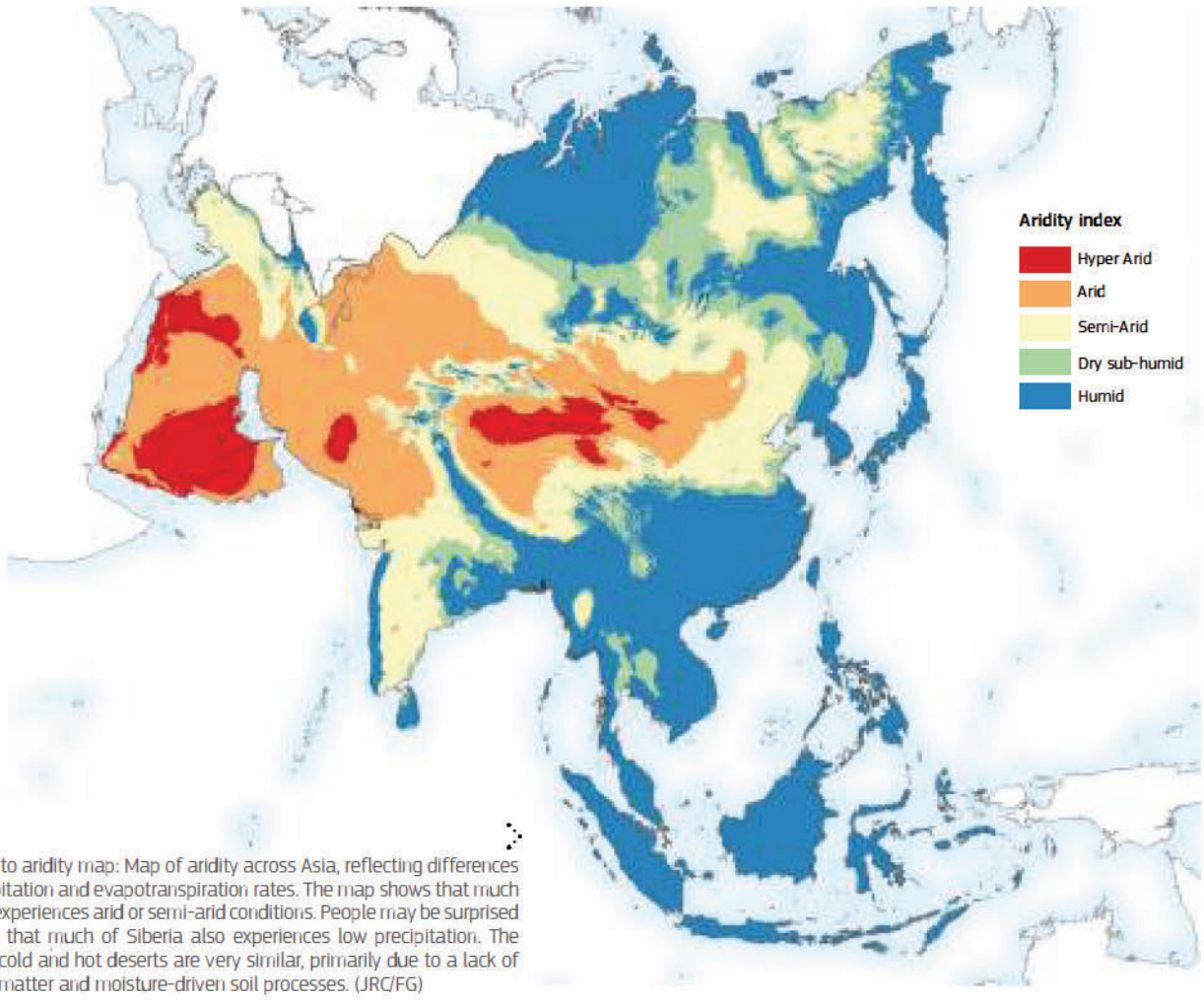
Various estimates show that desertification is affecting about 40% of Asia, a remarkable statistic given that a further 27% of the land area is characterised as desert (less than half of Asia is classified as having a humid climate). From the map below, around 3 million km^2 are classed as being under a very high risk of desertification. The region that has the highest propensity is located along desert margins.

Most rural inhabitants of dry lands suffer from poor economic and social conditions, made worse by soil degradation and the associated reduction in the productivity of the land. Overpopulation, overgrazing, land exhaustion and over-exploitation of groundwater resources of existing marginal lands creates a cycle which ends in the collapse of agriculture and the social system.

Due to its complex pattern and inter-relational aspect of the key drivers, accurate projections of desertification are difficult to produce and verify. Increased recurrence of extreme events, such as droughts, combined with risks, such as fires, and an expansion of intensive land use will probably induce higher levels of land degradation, including soil erosion, and, in turn, reduce the quality and availability of natural resources and ecosystem services.

Key measures to reduce desertification include adopting sustainable land management practices to cope with higher risks of droughts, for example by changing tillage, crop selection and rotation, and reducing overgrazing.

See [107] for more information.



Caption to aridity map: Map of aridity across Asia, reflecting differences in precipitation and evapotranspiration rates. The map shows that much of Asia experiences arid or semi-arid conditions. People may be surprised to learn that much of Siberia also experiences low precipitation. The soils of cold and hot deserts are very similar, primarily due to a lack of organic matter and moisture-driven soil processes. (JRC/FG)

Deserts

The term 'desert' is used to describe land that receives an extremely low amount of precipitation and where the soil moisture balance is negative (i.e. more water is lost by evapotranspiration than received from precipitation). Average annual precipitation of less than 250 mm is insufficient to support the growth of most plants.

Some of the driest places on Earth are located in the desert climates of western Asia, the steppes of central Asia, as well as parts of China and Mongolia. Generally, around twenty deserts are recognised in Asia. The Arabian and Syrian deserts make up one of the world's largest deserts, while the Gobi Desert between China and Mongolia is the fifth largest. Around 28% of China is considered as desert.

It should be stressed that not all deserts are hot! Regions characterised by low precipitation and low temperatures are known as cold deserts. Being quite northerly and over 1000 m a.s.l. in elevation, the Gobi is a cold desert, with frost and occasionally snow occurring on its dunes. Much of Siberia also experiences low precipitation. The soils of cold and hot deserts are very similar, primarily due to a lack of organic matter and moisture-driven soil processes.

The United Nations Convention to Combat Desertification (UNCCD) is a legally binding international agreement aimed at addressing land degradation and desertification (see page 13) [2].

World Atlas of Desertification

The European Commission's Joint Research Centre (JRC), in partnership with the United Nations Environment Programme (UNEP), has compiled a new World Atlas of Desertification that builds on recent scientific progress. It aims to be a pragmatic exercise and an example of how to implement up-to-date concepts and robust approaches for assessing and mapping land degradation and desertification.

The World Atlas of Desertification is expected to be the foundation for better addressing and including desertification and land degradation in strategies that address food security, resource efficiency, energy and emissions schemes, development and poverty reduction.

For more information, please visit [107].

Climate change

What is climate change?

In the most simple terms, climate can be defined as the typical weather pattern for a specific location over a long period of time. The Earth is divided into several zones that share similar climatic attributes such as temperature, humidity, atmospheric pressure, wind, and precipitation, all of which are affected by latitude, altitude and proximity to the ocean. The World Meteorological Organization uses the weather records over a thirty-year period to define the climate for a particular location. For example, in the Köppen climate classification system, the tropical rainforest climate is characterised by high rainfall (minimum annual rainfall between 1750 and 2000mm), all twelve months must have an average precipitation of at least 60mm and mean monthly temperatures must exceed 18°C [61].

It is clear from the geological and historical records that the climate of a location can change. Over extremely long time scales (tens or hundreds of millions of years,) plate tectonics can reposition continents, create oceans and build or erode entire mountain chains. All these factors can greatly influence the climate. In fact, the collision of the North and South American tectonic plates approximately 3 million years ago, which shut off direct mixing of the Atlantic and Pacific Oceans, has been suggested as one of the main causes of the Pleistocene Ice Ages.

The energy of the sun is a key external factor in determining the Earth's climate. Astronomers believe that, over hundreds of millions of years, the sun is slowly getting brighter, which would mean that the Earth's atmosphere will eventually heat up. On a shorter time scale, the sun exhibits an 11-year sunspot cycle that affects solar radiation levels and weather patterns. While the 11-year cycle does not manifest itself clearly in the climatological data, variations in solar intensity are considered to have been influential in triggering glacier advances and for some of the global warming trends observed from 1900 to 1950.

Similarly, slight variations in the Earth's orbit can lead to changes in the distribution and intensity of sunlight reaching the Earth. Such orbital variations, known as Milankovitch cycles, are considered to be the main driving factors behind the swing from glacial to interglacial periods.

Recently, the term 'climate change' has been mainly used to refer to changes in modern climate as a result of human activity. The term is often applied synonymously to describe the rise in average surface temperature known as global warming. Scientists have shown that this warming is caused by increased concentrations of carbon dioxide (CO_2), one of the major greenhouse gases. Since the Industrial Revolution of the 18th and 19th centuries, the consumption of fossil fuels (i.e. coal, oil, natural gas) has raised CO_2 levels in the atmosphere significantly. Along with rising methane levels, current emission rates are predicted to increase average global temperature by 5°C during the period 1990 to 2100 [125].

Greenhouse Gases

The Earth's atmosphere contains approximately 78% nitrogen, 21% oxygen, a variable amount of water vapour (generally around 1%), argon (just under 1%), 0.04% carbon dioxide and traces of hydrogen, helium and other gases.

Certain gases in the atmosphere absorb solar radiation and trap heat. This phenomenon is called the 'greenhouse effect' and the gases which contribute to this effect are referred to as greenhouse gases (GHGs). The major GHGs are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and ozone (O_3). Other GHGs include nitrous oxide (N_2O), sulphur dioxide (SO_2) and hydro-fluorocarbons (HFCs).

Climate change: Adaptation or Mitigation?

Mitigation describes efforts to reduce the sources and enhance the sinks of greenhouse gases. Examples include the more efficient use of fossil fuels, switching to renewable energy and expanding forests or increasing soil carbon stocks to remove greater amounts of carbon dioxide from the atmosphere.

In contrast, **adaptation** involves altering practices to tolerate the effects of climate change. Examples range from the use of drought-tolerant crops, increased rainwater storage and updated irrigation technology to wholesale changes to the agricultural production system.

Climate change and soil

As shown on pages 36-38, climate is a major soil-forming factor and a driver of soil-forming processes. Therefore, it is clear that climate change is likely to affect soils in a variety of ways, including the capacity of soils to carry out their key functions and ecosystem services.

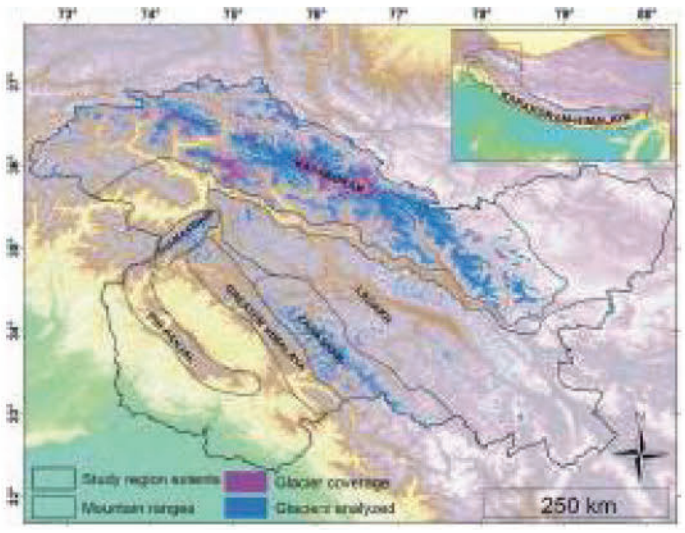
Temperature, rainfall and changes in atmospheric carbon dioxide also affect soil ecology and organic matter levels, which in turn determine soil characteristics such as structure, water regimes, pH and nutrient levels. Over time, changes to these properties will lead to significantly different soil types. It is very difficult to accurately predict the effects of climate change on varied and complex, three-dimensional soil systems. However, higher temperatures also promote a more rapid breakdown of organic matter in the soil due to a thermal boost to microbial activity. Depending on other soil specific factors that determine decomposition, increased soil temperatures might accelerate the release of carbon dioxide and methane into the atmosphere through increased soil respiration.

Changes in precipitation and more extreme hydrological cycles (as predicted across much of Asia) means that soils will either experience intense rain storms or prolonged periods with lower levels of precipitation. Either situation, or even a combination of both, could lead to increased vulnerability to erosion, which can result in the loss of topsoil nutrients and stored carbon either as greenhouse gas emissions to the atmosphere or as particulate organic carbon. Additionally, the rate of organic matter decomposition also depends on soil moisture levels. Changes in rainfall patterns can also affect soil structure and acidity levels. Together with organic matter content, these characteristics define the ability of a soil to store water and sustain many of the organisms that live within it.

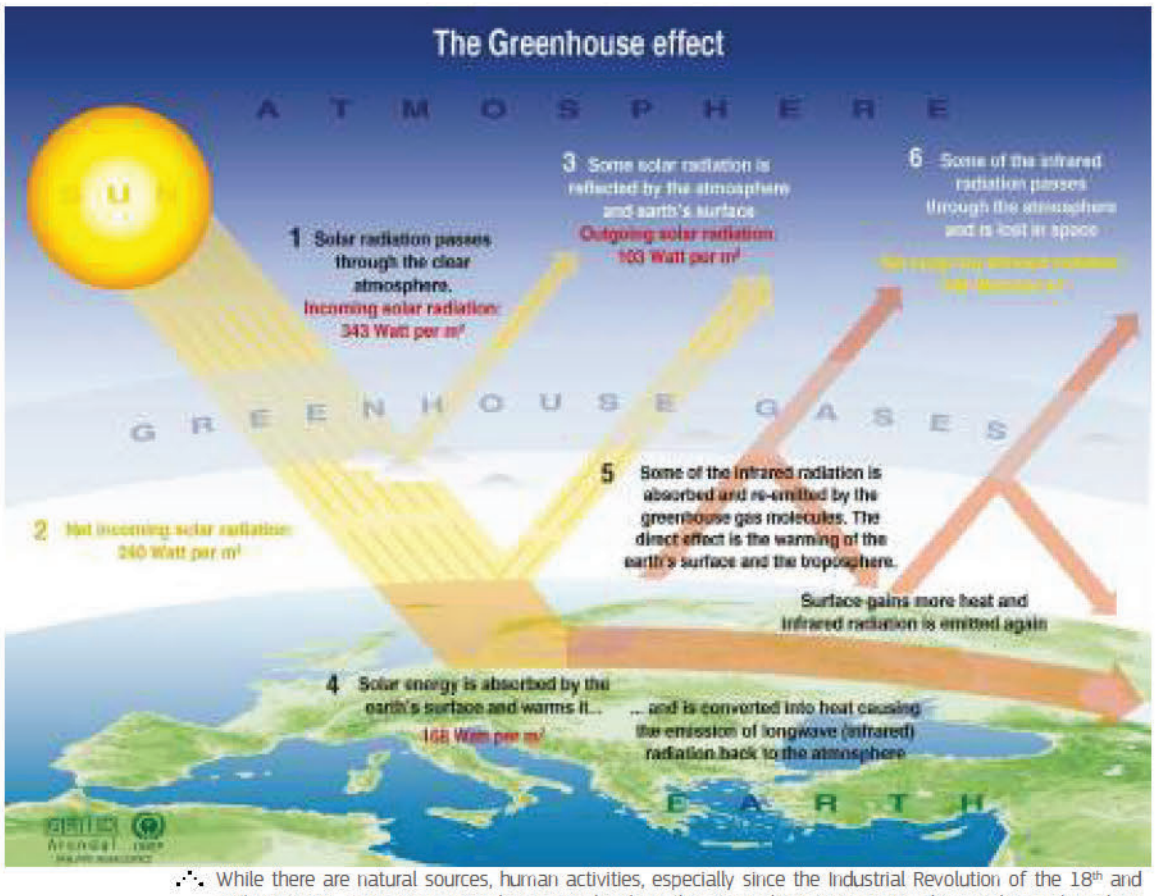
One positive aspect of climate change is that a combination of elevated CO_2 levels, together with slightly warmer and wetter conditions, will generally stimulate higher levels of plant growth with increased production of biomass and organic matter in the soil. Such conditions also heighten chemical weathering, which in turn releases essential minerals and nutrients from parent material and contributes to the development of the soil body. Under such conditions, crop growth may be possible in areas where currently the constraints to agriculture are too severe. However, such conditions will also support the migration and establishment of invasive plant species and pests (e.g. insects, fungi, pathogens, etc.). In addition, it is very likely that the overall net area with conditions favourable to plant growth conditions may be outweighed by the reduction in favourable plant growth conditions.



A zone that is sensitive to climate change is the high, snow-capped equatorial peaks of Asia. The effects of climate change in the Himalayas are real. Glaciers are melting, erratic and unpredictable weather conditions give rise to changing rainfall patterns and increasing temperatures. These changes then have impact on the people and environment of the region. (LPG)



Warmer air and reduced precipitation are thinning most of the Himalayas' glaciers. This change could have far-reaching consequences for a billion people who rely on meltwater for their water security, while at the same time increasing the risk of catastrophic floods. A recent scientific study of glacier thickness changes in the Upper Indus Basin showed that glaciers have thinned, on average, around 35cm per year between 2000-2012. A reduction of over 1.5m per year was observed in the Pir Panjal while only around 10cm per year for glaciers in the Karakoram. Higher reductions were observed on glaciers situated at lower altitudes, with shallower south-facing slopes. [126]



While there are natural sources, human activities, especially since the Industrial Revolution of the 18th and 19th centuries, are causing greenhouse gas levels in the atmosphere to increase. This graphic explains how solar energy is absorbed by the earth's surface, causing the earth to warm and to emit infrared radiation. The greenhouse gases then trap the infrared radiation, thus warming the atmosphere. (UNEP)

What's happening to the climate of Asia?

The Intergovernmental Panel on Climate Change (IPCC), Sixth Assessment Report, published in 2022, contains a series of observations and predictions on the climate of Asia [129].

The report notes that there is clear evidence that climatic patterns across Asia are already changing. There is no doubt that the observed mean surface temperature has increased compared to 1850–1900. Heat extremes have increased while cold extremes have decreased. Glaciers are declining across the region and permafrost is thawing. In addition, mean surface wind speeds have decreased. Worryingly for millions of people who live on low-lying deltas, islands and coastlines, relative sea level around Asia has increased faster than the global average, leading to a loss of coastal areas and shoreline retreat.

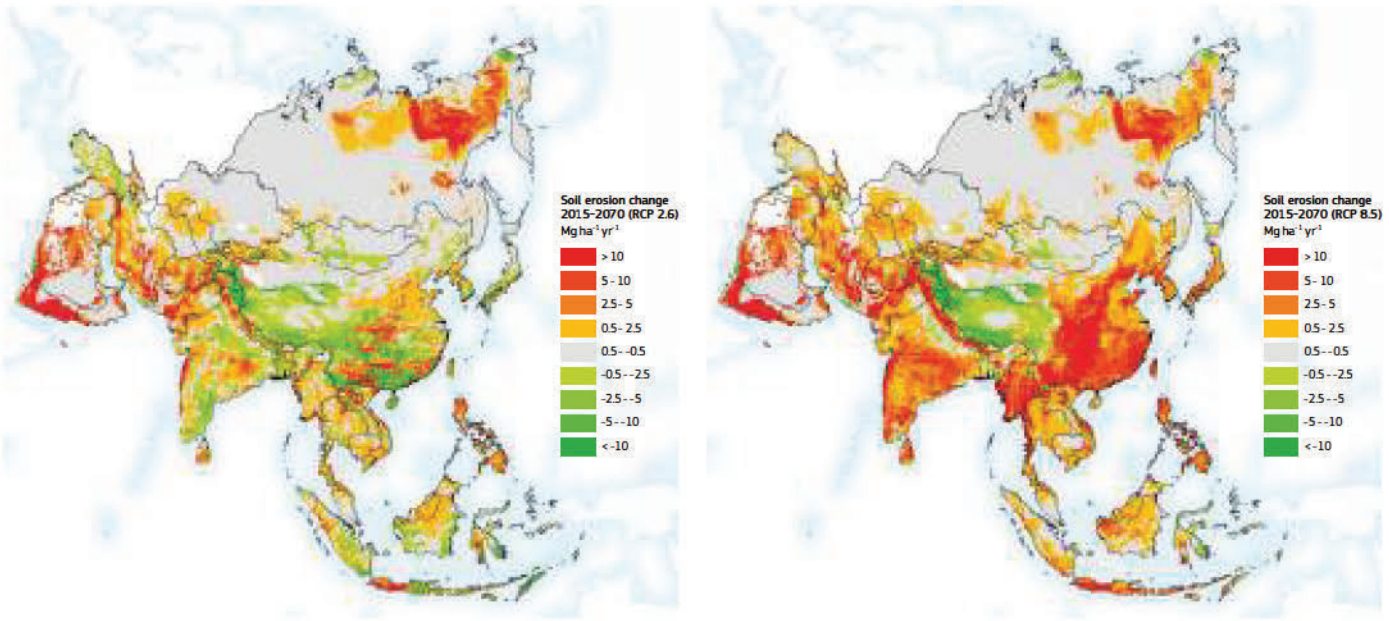
In addition, meteorological observations show that the South and Southeast Asian monsoon weakened in the second half of the 20th century, with an observed decrease of precipitation (most likely due to anthropogenic aerosol forcing).

What is likely to happen to Asia's climate?

Climate change scenarios for Asia, based on results from several general circulation models, indicate (with medium to high confidence) that the following trends will occur In the future:

- Trends in heat extremes will continue over the coming decades.
- Marine heatwaves will continue to increase around Asia. Fire seasons will lengthen and intensify, particularly in northern Asian regions.
- Average and heavy precipitation will increase over much of Asia.
- Mean surface wind speeds will continue to decrease in central and northern parts of Asia.
- Seasonal snow duration, glacial mass, and permafrost area will decline further by the mid-21st century.
- Glacier runoff in the Asian high mountain ranges will increase up to the mid-21st century. However, subsequently runoff may decrease due to the loss of glacier storage.
- Sea level will continue to rise.
- In the near-term, precipitation changes in the South and Southeast Asian monsoon, a well as the East Asian summer monsoon, will be dominated by internal variability. However, in the long-term, monsoon precipitation will increase.

It should be stressed that this assessment of climate change is marked by uncertainty. The diversity of Asian climates, high rainfall variability and a very limited observational network make predictions of future climate change difficult at the sub-regional and local levels.



Projections of soil erosion by water, according to new IPCC greenhouse gas emissions and land use scenarios, show a potential substantial increase in average rates (>0.5 t ha^{-1} yr^{-1}), affecting between 32-50 % of Asia, depending on the scenario. In contrast, a potential decrease is expected only in around 7-17 % of Asia. This increase is driven largely by higher rainfall erosivity, which by 2070 will be close to 100 % in South Asia. Erosion increases range from 1.26 t ha^{-1} yr^{-1} (up 36 %) for the SSP1-RCP2.6 scenario to 2.95 t ha^{-1} yr^{-1} , an increase of 85 % in the worst case scenario (SSP5-RCP8.5). Major increases are expected for southeast China, Myanmar, Nepal, Pakistan and Yemen while some decrease is expected in Lebanon and Tajikistan. The effect of climate change on erosion may be so pronounced that it could overwhelm the mitigation potential of adopting soil-conserving agricultural practices. (JRC/PPS/PBI) [127, 128]

Regional perspectives

It is clear from the maps in the box below that the effects of climate change will manifest themselves differently across the vast land mass of Asia.

Northern Asia

- Permafrost has thawed, its temperature increased, and seasonal snow duration and extent decreased. Maximal snow depth has increased over the past decades. Permafrost extent and volume will shrink with further global warming.
- Annual precipitation has increased since the mid-1970s, with heavy convective showers causing more intense floods. Projected increase in precipitation almost doubles the annual maximum river discharge, with increased flooded area in major Siberian rivers by mid-21st century.
- The number of dry days has decreased for much of the region but increased in southwestern regions, where total soil moisture will decline and the fire season will lengthen.

East Asia

- Daily precipitation extremes have increased over some parts. Heavy precipitation will increase in frequency and intensity leading to more frequent landslides in some mountain areas.
- Droughts have become more frequent in much of continental east Asia, while arid eastern central Asia has become wetter.
- The number of strong tropical cyclones have increased, and tropical cyclone tracks likely migrated poleward.
- Snow cover has reduced over most of the Hindu Kush since the early 21st century. Glaciers have retreated and lost mass since the 1970s. Karakoram glaciers have remained in a balanced state or slightly gained mass. During the 21st century, snow covered areas and snow volumes will decrease in most of the Hindu Kush, and snowline elevations will rise and glacier volumes will decline.
- A general wetting across the whole Tibetan Plateau and the Himalaya is projected, with increases in heavy precipitation.

South Asia

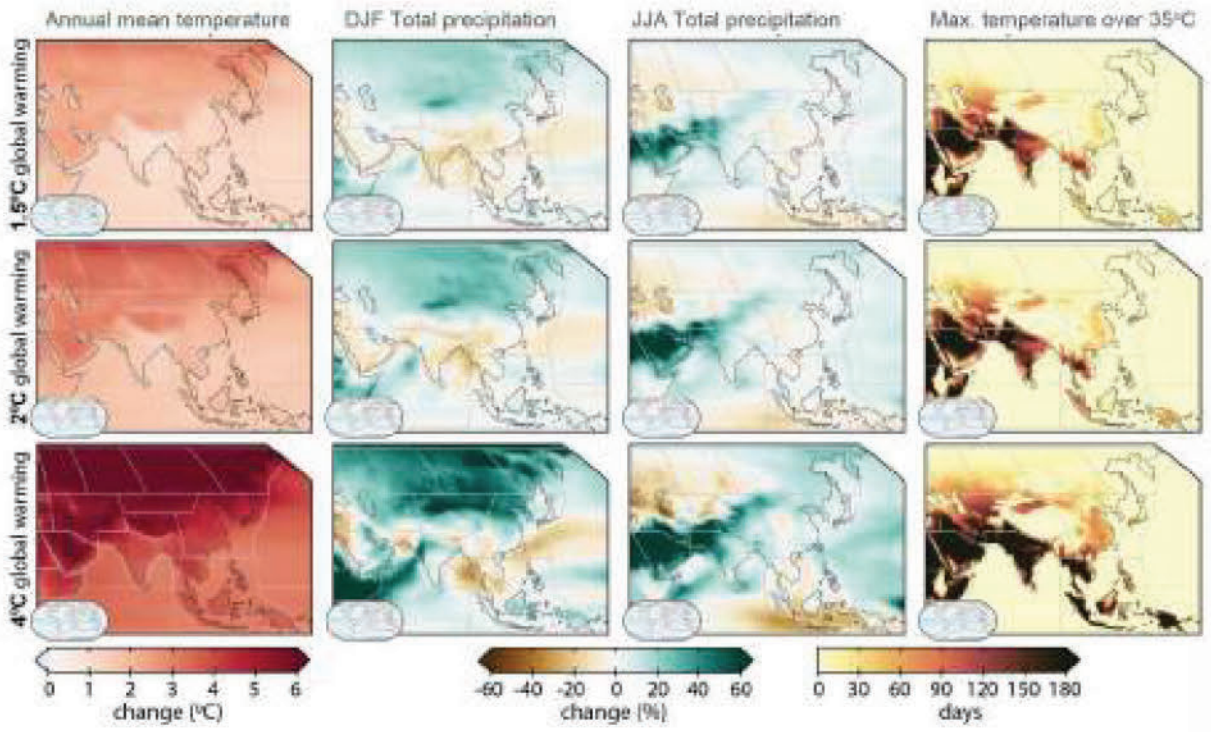
- Heatwaves and humid heat stress will be more intense and frequent during the 21st century.
- Both annual and summer monsoon precipitation will increase during the 21st century, with enhanced interannual variability.

Southeast Asia

- Future warming will be slightly less than the global average.
- Observed mean rainfall trends are not spatially coherent or consistent across datasets and seasons. Rainfall will increase in northern parts and decrease in the Maritime Continent.
- Compound impacts of climate change, land subsidence, and local human activities will lead to higher flood levels and prolonged inundation in the Mekong Delta.
- Although there has been no significant long-term trend in the overall number of tropical cyclones, fewer but more extreme tropical cyclones have affected the region.

Western Asia

- Anthropogenic warming has amplified droughts since the 1980s.
- An increase in extreme precipitation has been observed, mostly in elevated areas.
- Mountain permafrost degradation at high altitudes has increased the instability of mountain slopes in the past decade. Reduction of the annual maximum amount of snow increases with elevation in mountain areas.
- Annual precipitation totals, intensity and frequency of heavy precipitation are projected to increase. Strong spatio-temporal differences in projections across the region with overall decreasing precipitation in summer but the opposite tendency in winter.
- Observed increase in hydrological, agricultural and ecological droughts in the Mediterranean part of Asia. Projected increase in aridity and fire-risk conditions at global warming of 2 °C and above.
- A combination of warming, temperature extremes, increase in droughts and aridity, precipitation decrease, increase in fire weather, mean and extreme sea levels, snow cover decrease, and wind speed decrease) is projected by mid-century and at global warming of at least 2 °C and above.



Climate change projections for Asia given 1.5 °C, 2 °C, and 4 °C global warming. Changes are relative to the 1850-1900 baseline in annual mean surface temperature, total precipitation (Dec–Feb, DJF), and total precipitation (Jun– Aug, JJA). The last column shows the total number of days per year with maximum temperature exceeding 35 °C. (IPCC) [129]

Key soil issues for Asian countries









Clockwise from top left: a striking view of the city of Dubai in the United Arab Emirates. The Palm Jumeirah Island development was created from sediments dredged from the harbour to allow larger ships to dock. This is an example of new soils being created. Soils that show high levels of human activity are known as Technosols. Along the coastline, the expansion of Dubai City has resulted in significant land take and soil sealing. (ET); While many traditional agricultural systems, such as this scene from Bangladesh, can provide sustainable soil management solutions especially at a smaller scale, modern technologies are crucial to achieve the levels of food productivity needed to feed Asia's growing urban population. While some of these technologies can contribute to the degradation of the soil, appropriate and sustainable practices can be part of the solution for soil preservation. (MMC); Climate change will play a critical role in how soils function across Asia. Higher temperatures and lower or irregular precipitation may lead to changes in traditional land use patterns. (HIPPOPX); Preserving soil health is vital for food security. For this reason, it is critical to halt the degradation of soil, both directly due to human-induced erosion, pollution and unsustainable agricultural practices, as well as climate change (ID).

A summary of soils in each country

While the preceding section has described the main pressures on soils throughout Asia, this section provides a national perspective and additional details for each country. The following texts outline the main geographical features and climatic characteristics that govern soil-forming factors and processes. This is accompanied by a short overview of the soil resources of each country and the specific pressures that they face. Population data are a combination of national statistics and estimates from the United Nations Statistics Division [54].



The adjacent map showing the local term for 'soil' across Asia. This reflects the broad range of language groups found on the continent (see the box lower down the page). In many cultures, the word used for soil has significant cultural associations, often reflecting the role of soils in sustaining life. In fact, the English word soil is derived from the Anglo-Norman French language, possibly representing the Latin word solium for 'seat' (as in the sense of where people come from), which in turn is derived from solum for 'ground'.

In contrast, the term 'dirt' is derived from the Scandinavian Old Norse word drit, meaning 'excrement' or 'manure'. Eventually, the order of the r and the i were reversed when it was adopted in Middle English.

Finally, the word 'earth' has a German origin, which simply means 'the ground'. (LJ)



Mountain soils are an essential component of the Earth's hydrological cycle. (UV)

'Soil' in Asia

It is estimated that there are more than 2300 distinct languages throughout Asia. The major Asian language groups include Sino-Tibetan, Indo-European, Altaic-Congo, Austronesian and Semitic languages. Chinese is the most spoken language in Asia as well as in the world, with approximately 1.3 billion speakers.

Japanese *tsuchi* (written as Chinese *tu* or *di*) means "the land" or "(above) the ground". Japanese *chi* means "spirit", whereas *tsu* is perhaps a vowel ablaut (where an inflected form of a word is formed by changing a vowel) of the character to "place". Thus, Japanese *tsuchi* did not signify soil in general, but was a name that called forth something spiritual concealed in the ground. In ancient times there were many occult rites for the spirits of the land. The ground is linked to blood (*chi* in Japanese), spirits (*hi* in Japanese), fire (*hi*) and the sun (*hi*), which underpin human life. *Hi* and *chi* are etymologically the same. In Japanese, the word for soil, *tsuchi, tsu* indicates the presence of sacred power, whereas *chi* means spirit or soul. *Tsuchi* referred to the all-embracing source of sacred spirits and was also believed to be the embryonic source of life.

A Japanese word for those who engage in agriculture, *hyakusho* (farmer) literally means "people who know all about many things".

The central concept of the Chinese ideogram *tu* is neither the economic "land" nor the material "properties" of soil. The Han scholar Xu Shen (AD 58-147) explained that *tu* is "that which produces all things from the land". *Tu* is expressed as follows. The two horizontal lines represent the ground surface and underground. In other words, soil is the layer between the upper line representing the meeting of the atmosphere and soil and the lower line indicating the bottom of the root development zone. The vertical line shows a plant growing from underground to above ground.

The word *почва* (Russian for soil) is etymologicaly related to the word *подошва* (sole - as in a foot). These original and ancient meanings - 'hemmed lower part of the shoe, shaped like a foot' and 'lower part of the foot' - are preserved in the word soil in some regional dialects (for example, Olonets). From here, on the basis of a metonymic transfer, the meaning developed to become `bottom, base, that on which the foot stands', which is the top layer of the earth.

Language Familes of Asia

- Indo-European
- Afro-Asiatic
- Turkic
- Sino-Tibetan
- Austronesian
- Austroasiatic
- Kra–Dai
- Koreanic
- Japonic
- Mongolic
- Kartvelian



Afghanistan

The Islamic Republic of Afghanistan





Region: Southern Asia
Capital: Kabul
Population: 37 170 000
Climate: Arid / Semi-arid
Land Area: 652 237 km² (1.5% of Asia), arable soil covers 12%

Landscapes and climate

Land-locked Afghanistan is bordered by Turkmenistan, Uzbekistan, and Tajikistan to the north, with Pakistan to the east and south, the Islamic Republic of Iran to the west and China to the northeast. As the western end of the Himalayas, Afghanistan is a mountainous country with high peaks and rugged terrain, cut by deep river valleys and broad basins. Semi-arid plains are found in the north and southwest (the snowy peak of Noshaq in the Hindu Kush reaches 7 492 m a.s.l. on the border with Pakistan). The Helmand River, the longest in Afghanistan, drains to the saline Sistan Basin. Much of Afghanistan has an arid continental climate with long cold winters and hot summers. The mountainous northeast has a cold polar climate all year round and blocks the passage of the moist monsoon rains. Temperatures vary widely from more than 35 °C in the summers of the southwest to −15 °C in the winters of the northwestern mountains. The country is generally arid in the summer, with most precipitation falling in the winter (as snow at higher altitude). Precipitation is lowest in the west, increasing towards the east. Hot wind storms are common in the summer months.

Soil characteristics

The soils of Afghanistan generally reflect the dry climate, altitude and calcareous nature of most parent materials. Most soils show limited development and are low in organic matter content. At lower levels, stony and shallow Regosols, Leptosols and Cambisols are the most extensive types. The more arid southwest is defined by gravelly Regosols, Leptosols, Arenosols (often in the form of mobile sands and dunes) and Calcisols, often with hardpans. Solonchaks are found in closed basins and depressions. The sub-arctic climate of the mountains in the northeast gives rise to Cryosols. The central highlands have Kastanozems that grade to Chernozems in the loess sediments of the northern plains. Loamy and gravelly Fluvisols are found in the alluvial deposits of river valleys.

Soil related issues

Land degradation is a major factor across Afghanistan as soils have low fertility and low organic matter content (usually less than 2%), which is compounded in places by high alkalinity. High salinity also affects some areas, but these are generally limited in extent. Only about 5% of the total land area is cultivated annually through irrigation. Large areas are used for grazing. Droughts have a major impact on water resources given the arid climate. Deforestation, compounded by overgrazing and habitat destruction, has contributed to increased floods, soil erosion and landslides. Soil erosion by both wind and water affects many agricultural areas. Poor waste management has resulted in local soil pollution, especially in urban areas.

Azerbaijan

The Republic of Azerbaijan





Region: Western Asia
Capital: Baku
Population: 10 139 177
Climate: Slightly continental
Land Area: 86 699 km² (0.2% of Asia), arable soil covers 24%

Landscapes and climate

Azerbaijan is bordered by the Russian Federation to the north, the Caspian Sea to the east, the Islamic Republic of Iran to the south, Armenia to the west and Georgia to the northwest. The Nakhchivan Autonomous Republic (an exclave of Azerbaijan) borders Armenia, the Islamic Republic of Iran and Türkiye. The centre of the country is an extensive low-lying alluvial plain and delta. Elevations increase markedly to the north (Mount Bazardüzü climbs to 4 485 m a.s.l. in the Greater Caucasus, the traditional boundary between Europe and Asia) while the southeast is mostly gently undulating. The Caspian Sea lies 28 m below sea level. A continental climate gives relatively cold winters while summers are hot. The mountains are colder and rainier with heavy snow falls in winter. The coast of the Caspian Sea is semi-arid in the northern part and arid in the centre, while it is rainy in the southernmost stretch. Annual precipitation decreases from a maximum in the Talysh Hills (1 500 mm) towards the border with Georgia (300 mm).

Soil characteristics

Topography is the major factor in soil formation leading to a broad zonal distribution of soil types that reflect changes in altitude. At higher elevations, stony, shallow and acidic Leptosols or Umbrisols are the most abundant soils, with small pockets of Histosols where conditions permit. With increasing density of vegetation cover at lower altitudes, a zone of dark Phaeozems grades to organic-rich Kastanozems on foothills (with small pockets of Chernozems), interspersed with heavier Luvisols. On the plains, the evaporation of saline groundwater together with sodium-rich parent materials gives rise to Solonchaks and saline Gleysols. Gravelly Fluvisols are found along the main river valleys in the mountains, becoming finer textured on floodplains, around lakes, along the coast and on deltas (commonly with Gleysols). Cambisols and Calcisols are widespread. Acrisols and Lixisols are found in the Lankaran region. Arenosols and Gypsisols are found along the Caspian Sea. Anthrosols are widespread and important locally.

Soil related issues

Arable land and permanent crops cover over 25% of the country following the most fertile soils. However, salinity is a problem in the lowlands. Industrial emissions, together with the inappropriate use of agro-chemicals, predominantly pesticides and fertilisers in the cultivation of cotton, has resulted in severe soil pollution in the lowland areas, especially around the Caspian Sea coast. Soil erosion by water is widespread in the mountains. Both droughts and floods are common while a consistent rise in the level of the Caspian Sea is threatening coastal areas. Technosols cover a large area, especially in relation to oil spills in the Absheron Peninsula.

Armenia

The Republic of Armenia





Region: Western Asia
Capital: Yerevan
Population: 2 963 243
Climate: Dry continental
Land Area: 29 743 km² (0.1% of Asia), arable soil covers 16%

Landscapes and climate

Just south of the boundary between Europe and Asia (traditionally defined by the crest of the Caucasus Mountains), Armenia is a landlocked country bordered by Georgia to the north, Azerbaijan to the east and south, the Islamic Republic of Iran to the southeast, and Türkiye to the west. It is a mountainous country consisting of high ranges and peaks, plateaus, deep valleys and basins, with an average elevation of 1 800 m a.s.l. above sea level (the crater of Mount Aragats reaches 4 090 m) : there is no land below 400 m a.s.l. while 3% is covered by Lake Sevan. Volcanic and seismic activity are widespread. Armenia's climate is continental with hot summers (25 °C) and cold winters (-5 °C). Temperatures are lower at higher elevations and snow falls on the mountains. Since Armenia is located in the rain shadow of the Lesser Caucasus, annual precipitation on the mountains is around 800 mm, dropping to less than half the amount towards the west of the country. Evaporation rates are high.

Soil characteristics

Topography and the volcanic nature of parent materials are major factors in soil formation leading to a broad altitudinal zonal distribution of soil types. At higher elevations, acidic Leptosols or Regosols are the most abundant soil types. At lower altitudes, increasingly dense vegetation cover gives rise to a zone of dark Phaeozems that grades to organic-rich Chernozems and Kastanozems under grasslands or Cambisols under forests (some are leached where precipitation is higher). Kastanozems become more evident to the west, reflecting increasingly drier conditions. Along the border with Türkiye, semi-desert conditions give rise to soils with low organic matter content. Coarse Calcisols and Gypsisols formed from the weathering of lava intermix with saline Solonetz and Solonchaks. Gravelly Fluvisols are found along the river valleys, becoming finer textured on floodplains and around lakes. Anthrosols can be important locally reflecting terraced agriculture.

Soil related issues

Volcanic parent materials result in highly fertile soils with agricultural land covering over 20% of the country. However, steep slopes and deforestation mean that rates of soil erosion by water are high and most managed soils are eroded. Landslides are common. A lack of waste management strategies results in widespread soil pollution from landfills while contamination from mining and metal processing activities are local concerns. Seasonal precipitation and high evaporation rates results in pronounced water shortages during the summer while salinisation is an increasing concern in the west of the country. There are fears that the situation could deteriorate as a result of climate change.

Bahrain

The Kingdom of Bahrain





Region: Western Asia
Capital: Manama
Population: 1 701 575
Climate: Hot arid
Land Area: 780 km² (> 0.01% of Asia), arable soil covers 2%

Landscapes and climate

Located just off the eastern coast of the Arabian Peninsula, Bahrain is an archipelago of around 100 islands in the Persian Gulf (more than half of which are artificial). Bahrain Island accounts for over 80% of the land area. A 25 km causeway connects Bahrain to Saudi Arabia. After Singapore and Maldives, Bahrain is the third smallest country in Asia. Bahrain consists of a low-lying plain, which rises gradually to an escarpment (highest point is Jebel ad Dukhan at 134 m a.s.l.). The climate is arid and most of the country is classified as hot desert. Summer temperatures are high (sometimes reaching 50 °C) and accompanied by high humidity. Winters are relatively cooler in comparison. Annual precipitation, which tends to fall between December and April, is around 70 mm but can be highly variable. Sandstorms and dust storms are common. There are no permanent water bodies.

Soil characteristics

Soils are typical of arid environments with almost all soils low in organic matter content. Large areas are characterised by dune sands (Arenosols) composed primarily of quartz but also containing varying amounts of gypsum and calcium carbonate grains depending on the location. The plains and slopes of the central escarpment of Bahrain Island are characterised by stony unconsolidated Regosols and Leptosols (often the finer particles have been removed by wind erosion). Gravelly Fluvisols demarcate dry ephemeral channels (wadis) and their floodplains. Saline gypsum-rich Solonchaks, often with surface crusts and polygon patterns, are common, especially along the west and south coast (locally known as sebkha). Solonchaks are associated with the evaporation of groundwater that rises through the soil leaving deposits of salts behind or the evaporation of rainfall. Solonchaks are also found on old marine sediments, in which case the levels of sodium salts are higher. Anthrosols with higher organic matter levels can be found in oases.

Soil related issues

The low levels of rainfall, high temperatures and prevalence of sandy soils, means that the organic matter content of most soils is naturally low (< 1%). Wind erosion is widespread. Secondary salinisation, associated with the intrusion of sea-water into aquifers, is an increasing concern in irrigated agricultural soils. Significant land reclamation means that Technosols are common, especially in the artificial islands. As with other Gulf states, there are concerns on the impact of climate change, especially in relation to sea-level rise (resulting in a loss of land) and increased aridity (increased wind erosion and dust storms). Soil pollution is associated with the oil industry.

Bangladesh

The People's Republic of Bangladesh





Region: Southern Asia
Capital: Dhaka
Population: 161 376 708
Climate: Tropical monsoon
Land Area: 147 570 km² (0.3% of Asia), arable soil covers 60%

Landscapes and climate

Bangladesh is bordered by India to the north, east and west, with Myanmar to the southeast and the Bay of Bengal to the south (Nepal and Bhutan are separated by the narrow Siliguri Corridor). Bangladesh is dominated by the low-lying and flat floodplains and delta of the Ganges (called the Padma locally), the Brahmaputra and the Meghna rivers. While the plains are less than 10 m above sea level, hillier ground is found towards the northern borders and in the southeast (Saka Haphong on the border with Myanmar is estimated to be 1052 m a.s.l.). Bangladesh has a sub-tropical climate with hot humid summers (where temperatures can reach 40 °C and humidity close to 100%), warm dry winters (minimum temperature ranges from 12 to 26°C) and a rainy monsoon season from June to September. Most of the country receives around 2000 mm of precipitation annually while the proximity of the Himalayas in the northeast sees values around 4500 mm.

Soil characteristics

Almost 80% of the soils of Bangladesh are formed in sediments deposited by the Ganges, the Brahmaputra and the Meghna rivers, and reflect drainage issues, their proximity to the Bay of Bengal and the low-lying landscape. Cambisols are dominant, reflecting the young age of river sediments. Changes in texture denote the strength of the water flow while the pH depends on the source (Fluvisols on the floodplain of the Brahmaputra and Meghna are neutral to acidic while those on the Ganges floodplain and the delta are calcareous). Gleysols are widespread often in depressions caused by changes in the position of channels over time and shallow water table. Towards the coast, saline Fluvisols and Gleysols display acid sulphate conditions in some areas. Histosols are extensive in marshy areas. The hills on the Myanmar border are characterised by Regosols, Acrisols and Cambisols. Leptosols also occur in some cases.

Soil related issues

Floodplain soils are generally fertile although nitrogen deficiency is increasing and drainage is required outside of rice cultivation. Soil acidity, especially in the north, is affecting crop yields. The high population density is driving high rates of soil sealing. There are concerns on increasing soil salinity in the coastal areas of the south-west due to sea water incursion into aquifers. Intensive cropping and an unbalanced use of fertilisers is driving a loss of organic matter in cultivated soils. Deforestation in the hilly areas causes soil erosion and the covering of agricultural land by sandy sediments during floods, which are common during in the monsoon season and compounded by tropical cyclones (which can cause extensive flooding to coastal areas, often with high loss of life).

Brunei Darussalam

Nation of Brunei





Region: Southeast Asia
Capital: Bandar Seri Begawan
Population: 424 800
Climate: Tropical rainforest
Land Area: 5765 km² (0.01% of Asia), arable soil covers <1%

Landscapes and climate

Located on the north coast of the island of Borneo, Brunei Darussalem borders the Malaysian state of Sarawak. Brunei Darussalem consists of a narrow coastal plain that becomes increasingly hilly to the south (highest point is Pagon Peak at 1850 m a.s.l.). The climate is characterised by a lack of marked seasonality, constantly high temperatures (around 28 °C) and monthly precipitation (160 mm in the driest month), heavy cloud cover, and high humidity. Annual precipitation is generally around 3000 mm but can increase with elevation, usually heavier from October to January. Monsoon winds blow from the northeast from December to March and from the southwest from May to September.

Soil characteristics

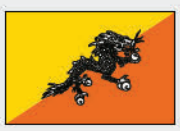
Deeply weathered and highly leached Acrisols predominate, covering around 60% of the country, especially on sloping ground. Fluvisols and organic Histosols are found along rivers valleys and in some parts of the coast, together with clay-rich Vertisols on alluvial plains. Deep Podzols are evident in old costal dunes. Acid sulphate conditions are observed within most soil types. The soils support extensive tropical rainforest with notable biodiversity (primary forest cover 80% of the country). Temporary and permanent crops account for less than 2% of total land area. Peat swamps are found along the rivers while mangroves are common along the coast and in estuaries.

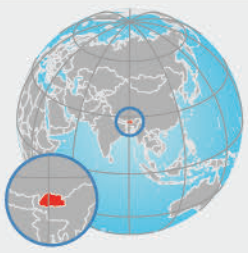
Soil related issues

Soil acidity is a widespread issue in Brunei Darussalem with pH values typically below 5.0, with many soils showing much more acidic conditions (even below 3.5). Soil acidity affects crop production as aluminium becomes increasingly soluble below pH 5.5, which is toxic to plants. Other related effects are manganese toxicity, and deficiencies of calcium, magnesium, potassium and some micronutrients. Liming is required to raise the pH. Acid sulphate soils require careful management to avoid the release of sulphuric acid into the environment which can kill fish, pollute drinking water and corrode pipes. The preferred option is not to develop them. The combination of high rainfall, shallow groundwater table, low subsoil permeability and low gradients on flat lowlands means that much of the country is affected by waterlogged soils. The normal practice of digging drainage ditches is not recommended due to the widespread occurrence of acid sulphate soils. Drainage of organic soils for agriculture causes the organic matter to be oxidised. This causes subsidence and brings sulphide-rich material closer to the surface. In addition, large quantities of greenhouse gases are released while drained peat is prone to fire. Soil erosion on slopes can be an issue if the vegetation cover is removed during the rainy season.

Bhutan

The Kingdom of Bhutan





Region: Southern Asia
Capital: Thimphu
Population: 734 374
Climate: Varies with elevation
Land Area: 38 394 km² (0.1% of Asia), arable soil covers 2.8%

Landscapes and climate

Land-locked Bhutan is bordered by China to the north and east, with India to the south and west. Rising northwards from the narrow low-lying alluvial plain of the Brahmaputra River (only 100 m above sea level), the land surface rises through forested hills and mountains, to the high, glaciated peaks of the eastern Himalayas and the Tibetan Plateau (at 7570 m a.s.l., Gangkhar Puensum is the highest point in Bhutan and reputedly the highest unclimbed mountain in the world). Several rivers drain southwards in very deep valleys and gorges. The climate of Bhutan reflects the range of elevations with dry, wet and humid subtropical conditions below 1200 m, followed by a temperate zone up to 2500 m a.s.l.. Above this elevation, temperatures fall markedly with Alpine and Arctic conditions above 4400 m a.s.l.. The annual average maximum temperature is around 23 °C while the annual average minimum temperature is around 11 °C. A strong summer monsoon means that annual precipitation generally decreases from west (2000 mm) to east (1000 mm).

Soil characteristics

Soils in Bhutan follow a distinctive altitudinal zoning, broadly reflecting changes in climate, and are often highly leached. Most soils are acidic in nature. The high ice covered mountain peaks are marked by Cryosols and Leptosols that give way to shallow, stony Regosols and Cambisols (the most extensive soil type in Bhutan), with Umbrisols and Phaeozems at vegetated lower elevations. Fluvisols are extensive, being gravelly in the deep river valleys and on alluvial fans but are generally sandy in the lowland plains (reflecting the lithology of the watershed). Gleysols are found along the valley floors and old river channels in the plains and support rice cultivations. Red coloured Luvisols are common locally, generally on stable footslopes. Anthrosols are found across the country in terraced irrigated paddy fields, which allow agricultural development on steep slopes.

Soil related issues

The mountains play an essential role for life in Bhutan, but they are also a complex and fragile ecosystem. The risk of land degradation is a major factor in Bhutan. Deforestation, compounded by steep terrain, heavy rain and unsuitable farming (e.g. overgrazing and habitat destruction), has contributed to floods, soil erosion and landslides. Soil erosion affects many agricultural areas, especially outside of the plain areas. Increasing use of chemical fertilisers and pesticides is of concern but there is a strong movement towards the uptake of organic farming practices. There are increasing concerns about the loss of glaciers due to climate change.

Cambodia

The Kingdom of Cambodia





Region: Southeast Asia
Capital: Phnom Penh
Population: 15 552 211
Climate: Tropical savannah
Land Area: 181 035 km² (0.41% of Asia), arable soil covers 21%

Landscapes and climate

Cambodia is bordered by Thailand to the northwest, the Lao People's Democratic Republic to the northeast, Viet Nam to the east, and the Gulf of Thailand to the southwest. A low-lying country (mostly <250 m) consisting of a central plain surrounded by low hills. The only significant areas of elevation are the Dangrek Escarpment along the Thai border and Cardamom Mountains in the southwest (where Phnom Aural reaches 1813 m a.s.l.). The lowlands contain the Tonlé Sap Lake and the Mekong River, including the upper part of the delta that extends into Viet Nam. Mangroves are found along the coast. The climate is dominated by monsoon winds that bring distinct wet and dry seasons. The country has a constant temperature of around 25 °C all year. Temperatures can rise dramatically just before the rains while November to March are cooler (these changes are less pronounced in the coastal regions). With a pronounced dry season, annual precipitation is around 1200 mm, mostly falling during May to October. Precipitation over the coastal mountains is double that of the lowlands.

Soil characteristics

Soil-forming processes reflect the main topographic settings. Forested highlands are characterised by highly weathered, red and yellow Acrisols, which are coarse textured, acidic in nature with high levels of aluminium and iron oxides. Conversely, most of the lowland areas consist of fine-grained Gleysols and Fluvisols reflecting their formation in the alluvial sediments of floodplains (especially the Mekong) and under mangroves. Soils on older, higher river terraces tend to have coarser textures giving better drainage. Pockets of Vertisols in the valleys floors and in the east of the country reflect soil development in the weathering products of basaltic lava.

Soil related issues

Sandy soils cover a large part of upland Cambodia. High acidity is a widespread issue with many soils lacking in nutrients and organic matter, while the coarse texture means low water retention. Low pH, together with high iron or aluminium content, means that some upland soils are low in productivity and best left under natural forest. Intensive mono-cropping and cultivation intensifies the lack of nutrients although productivity can improve through liming and targeted fertilisation. A combination of shallow groundwater table, low subsoil permeability and low gradients means that much of the country's lowland areas are affected by waterlogged soils, which is well suited for rice cultivation. High rates of deforestation and forest fires have exposed the vulnerable nature of sandy Acrisols to erosion, especially in the west. Soil pollution has been linked to bauxite mining operations. Land mines buried in the soil means that some areas are unsafe for agricultural use.

China

The People's Republic of China





Region: Eastern Asia
Capital: Beijing
Population: 1 439 323 776
Climate: Varied with monsoon
Land Area: 959 696 km² (21.5% of Asia), arable soil covers 13%

Landscapes and climate

With Mongolia and the Russian Federation to the north, and the Democratic People's Republic of Korea to the northeast, China is bordered by Viet Nam, the Lao People's Democratic Republic, Myanmar, India, Bhutan, Nepal, Pakistan, Afghanistan, Tajikistan, Kyrgyzstan and Kazakhstan (from southeast to west). The Pacific Ocean marks the eastern and southeastern extent. As the largest country in Asia, China has a diverse landscape, ranging from the Gobi and Taklamakan deserts in the north to the world's highest peaks in the southwest (at 8 849 m a.s.l., Everest is the world's highest mountain – conversely, the Turpan Depression is -154 m below sea level). Steppe grasslands occupy much of the high Tibetan Plateau while subtropical forests dominate the hot and humid tropical lowhills of the southeast (annual precipitation around 2 000 mm). Like many rivers in China, the Yangtze and Yellow rivers (the world's 3rd and 6th longest) flow eastwards to the Pacific. Most of China has a monsoon climate with hot, humid summers and cool, dry winters. Cold, snowy conditions are found over the north, the mountains and Tibetan Plateau. Temperatures and precipitation in the east decrease northwards to give subarctic conditions in the northeast.

Soil characteristics

The high southwestern mountains give rise to permanently frozen Cryosols, interspersed with stony Leptosols, with Cambisols more evident at lower elevations. Fluvisols are widespread along the extensive river network, with extensive Anthrosols and Gleysols under rice cultivation. Deserts are characterised by mobile Arenosols, Calcisols (also in the loess regions), Gypsisols and Solonchaks, together with stony Regosols. Solonetz are common on the northern coast. Southeastern China has highly leached, red and yellow Acrisols, Alisols and Ferralsols that are acidic in nature and deficient in nutrients. Steppe soils (Kastanozems, Chernozems, Phaeozems) are found in a northern belt. Technosols reflect large-scale urban development and land reclamation.

Soil related issues

Long-term intensive cultivation has resulted in organic matter decline and unbalanced nutrient levels. Extensive deforestation had caused high erosion and sedimentation rates (the Loess Plateau is particularly vulnerable to soil erosion by both wind and water) but since the last two decades afforestation has dramatically restored the ecology. Risks of widespread diffuse soil pollution and contaminated sites by rapid industrialisation and population growth still remain a challenge. Coastal regions have experienced a loss of natural habitats due to land reclamation for agriculture, aquaculture and industrial development. Desertification is still a concern in the north and western regions. The "Green Wall of China" is the world's largest ecological project to halt desertification.

The Democratic People's Republic of Korea

The Democratic People's Republic of Korea





Region: Eastern Asia
Capital: Pyongyang
Population: 25 778 816
Climate: Humid continental
Land Area: 120 540 km² (> 0.27% of Asia), arable soil covers 20%

Landscapes and climate

Occupying the northern part of the Korean Peninsula, the Democratic People's Republic of Korea shares a border with China and the Russian Federation (only 18 km) to the north with the Republic of Korea to the south (the East and Yellow seas lie to the to the east and west, respectively). A wide coastal plain in the west rises inland to a rugged mountainous plateau dissected by deep and narrow valleys that extends into the Republic of Korea. Elevations increase to the north and northeast (at 2 744 m a.s.l., the active volcano of Paektu on the Chinese border is the highest point in the Democratic People's Republic of Korea, and is regarded to have been the source of one of the most violent volcanic eruptions of the past 5 000 years). The country has a humid continental climate that is modified by maritime influences. Summers are hot (generally around 25 °C, cooler with higher elevations) and humid while winters are cold (temperature generally below 0 °C) and dry. Monsoon conditions means that precipitation is around 1 000 mm annually, decreasing from south to north. Most precipitation falls as rain in the summer while snow is common in the winter, especially on the high mountains of the north.

Soil characteristics

Soils in the Democratic People's Republic of Korea generally reflect their topographic setting and the lithology of parent materials. On higher ground, the weathering and leaching of granite and metamorphic rocks results in sandy Cambisols with pockets of Podzols, both of which are highly leached with low organic matter content. Reddish Luvisols tend to be more prevalent on lower slopes, inland basins, river valleys and the limestone hills in the west. Lowland soils around the coast are deep alluvial Fluvisols, becoming saline in estuaries. Andosols can be found in the volcanic lava and ash of the Changbai Mountains, giving way to Podzols under pine forests at lower elevations.

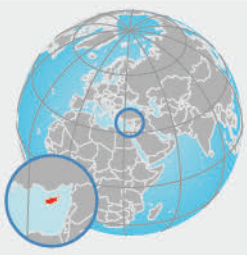
Soil related issues

The mountainous terrain over most of the country means that cultivation is confined to the coastal plains in the east and west. Intensive agricultural practices, often involving monocultures, have led to a marked drop in soil nutrient levels, increased acidification and a loss of organic matter content. High pesticide residues in soil are also reported. Widespread deforestation has resulted in significant soil erosion across the country, leading to serious flooding in the lowland areas during the rainy monsoon season. However, recently it has suffered severe drought conditions with only 50 mm of rain falling in first half of 2019.

Cyprus

The Republic of Cyprus





Region: Western Asia
Capital: Nicosia
Population: 1 189 265
Climate: Mediterranean / Arid
Land Area: 9 251 km² (0.05% of Asia), arable soil covers 9%

Landscapes and climate

Cyprus is an island in the eastern Mediterranean Sea (3rd largest), approximately 230 km long and 100 km at its widest point. Geologically, Cyprus sits on the southern margin of the Anatolian Plate, which is considered part of Asia (and therefore included in this atlas for completeness). A rugged country, mountains occupy over half the land area. The narrow Kyrenia Mountains run parallel to the northern coast while the more extensive Troodos mountain range occupies most of southwestern Cyprus. Flat land is broadly restricted to coastal strips (often quite narrow) and the low-lying Mesaoria Plain that occupies the centre of the island between the two upland areas (the islands highest point, Mount Olympus in the Troodos, reaches 1 951 m a.s.l.). Cyprus has a Mediterranean climate with well defined seasons consisting of long hot, dry summers (April to November) and cool, rainy winters. Average daily temperatures range from a maximum of 37 °C in the summer to 15 °C in the winter. From December to March, the Troodos range can experience considerable snowfall and prolonged periods of below-freezing temperatures. Average annual precipitation is 476 mm while evapotranspiration rates are 3 to 4 times higher, depending on the elevation (75% of evapotranspiration occurs from May to October).

Soil characteristics

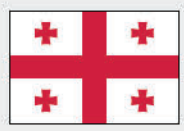
Soil development strongly reflects topography and geology. Most soils are low in organic matter. The mountains are characterised by poorly developed, stony and shallow Leptosols, Regosols and Cambisols. The limestones of the Kyrenia Range and the sediments on the western flank of the Troodos give a calcareous nature to soils (also occurring as Calcisols) while the basalt and mafic rocks of the Troodos also have a high pH. Clay-rich Vertisols, red-coloured (Chromic) Luvisols and a variety of Cambisols (calcareous, vertic, dystric) are characteristic of the lowland alluvial areas. Saline soils (Solonchaks and Solonetz) occur in small pockets across the plains. Fluvisols are not extensive but are often gravelly, denoting seasonal river channels and alluvial fans.

Soil related issues

Cyprus suffers from a shortage of water and relies heavily on precipitation to provide both domestic and irrigation needs (recently supplemented by desalination plants). While rain-fed cereal production is the major agricultural activity, around 30% of the island's arable land is irrigated. Soil sealing is an issue on the coastal plains, mostly associated with touristic developments. Salinisation of agricultural soil is increasing, especially in the north of the island, and exacerbated by increasing intrusions of seawater into aquifers. Soil pollution is associated with mining waste.

Georgia

The Republic of Georgia





Region: Western Asia
Capital: Tbilisi
Population: 3 688 600
Climate: Humid subtropical / Continental
Land Area: 69 700 km² (0.16% of Asia), arable soil covers 11.5%

Landscapes and climate

Bordered by the Russian Federation to the north, Azerbaijan to the southeast, Armenia and Türkiye to the south, and the Black Sea to the west, the crest of the Greater Caucasus Mountains in Georgia traditionally marks the boundary between Europe and Asia. Apart from the western Colchis Lowland, a few plateaus and the Alazani Plain in the east, Georgia is a mountainous country with elevations rising steeply towards the north (Mount Shkhara reaches 5 068 m a.s.l.). Much of the country is forested. The western half of the country is consistently warm (frosts are rare along the Black Sea coast) with relatively high precipitation that is distributed evenly throughout the year (the mountains are cooler and wetter, heavy snowfall occurs in the winter). While summer temperatures are higher in eastern Georgia, annual precipitation levels are about half that of the west (i.e. 500-2 000 mm).

Soil characteristics

Almost all WRB Reference Group can be found in Georgia. Elevation is a major factor leading to a broad zonal distribution of soil types. Cryosols at high altitudes give way to poorly developed, stony and shallow Leptosols, Regosols and Cambisols, with Histosols in depressions. Organic matter levels vary according to vegetation cover leading to the formation of Phaeozems in some areas. At lower elevations towards the Black Sea, soils are calcareous or waterlogged (Stagnosols, Histosols) interspersed with red Nitisols, Alisols, yellow Luvisols and leached Acrisols on slopes. The low-lying Kolkheti Region and delta areas are characterised by saturated Histosols, Stagnosols, Gleysols and Fluvisols. Cambisols are widespread throughout the country, reflecting variations in parent materials and pedogenic processes, often in combination with Chernozems and Kastanozems. Saline groundwater gives rise to pockets of Solonetz and Solonchaks on the plains in the east. Vertisols have developed in gently sloping areas of alluvial plains in the east, often in the lowest positions in the landscape.

Soil related issues

Land degradation is a major concern, with estimates that 30-40% of agricultural land affected. Human-induced soil erosion, landslides and flooding are driven by deforestation, mining and poor land management practices. Soil pollution due to poor waste management, the inappropriate use of agro-chemicals and metal pollution is widespread with concerns on human health. Increased flooding and droughts have drawn attention to climate change with predictions of higher precipitation for the western coast and mountains but decreasing on the eastern plains.

India

The Republic of India





Region: Southern Asia
Capital: New Dehli
Population: 1 324 171 354
Climate: Mostly tropical monsoon
Land Area: 3 287 263 km² (7.4% of Asia), arable soil covers 43%

Landscapes and climate

India extends into the Indian Ocean, with the Arabian Sea to the west and the Bay of Bengal to the east. Bordered by China, Nepal and Bhutan to the north, Bangladesh and Myanmar to the northeast and Pakistan to the northwest (the Andaman and Nicobar Islands have a sea border with Thailand and Indonesia). The north is dominated by the flat, low plains of the Indus, Ganges and Brahmaputra rivers, and the Himalayas (at 8 586 m a.s.l., Kangchenjunga is the world's 3rd highest peak). Southwards, the Deccan Plateau descends from around 600 m a.s.l. in the west towards the east coast. Most of India has a tropical climate with distinct wet and dry seasons. Most precipitation falls during the southwest monsoon (June to September) and is highest along the slopes of the Western Ghats (Cherrapunji, in the northeastern state of Meghalaya, recorded the world's highest average annual precipitation of 11 430 mm). The north is temperate with hot summers and cool winters. Cold, snowy conditions are found over the Himalayas while the Thar Desert is hot and dry.

Soil characteristics

India's soil types reflects the great variation in climate and the geology of the major landscape units across the country. The cold climate and the rugged terrain of the Himalayas gives rise to permanently frozen Cryosols, Leptosols, Regosols with deep Cambisols becoming more evident at lower elevations. Fluvisols are widespread, especially in the northern plains, river valleys and deltas of the east coast. Textural and chemical variations in Fluvisols denote age and flow regimes when the alluvium was deposited. The Thar Desert is characterised by Arenosols in the form of dunes, together with Regosols and Solenchaks. Much of southern India has highly leached, red and yellow, loamy Ferralsols that are generally acidic in nature and deficient in nutrients. Plinthosols with hard surface crusts are also common. Black Vertisols, that develop wide cracks when dry, are extensive on the basalt lava flows of the Deccan Plateau and associated river valleys.

Soil related issues

India has large areas of fertile soils, especially on the alluvial northern plains and the black Vertisols on the Deccan Plateau. Soils over much of the country are low in nutrients and are difficult to cultivate due to indurated layers in the soil (hardpans). Deforestation and intensive use of agricultural of land are both drivers of high soil erosion rates. Soil pollution due to poor waste management is widespread around urban and industrial areas, often affecting agricultural soils through irrigation. India's highly seasonal rainfall regime can cause water shortages for irrigation. Salinisation is common in many irrigated areas and in coastal regions.

The Islamic Republic of Iran

The Islamic Republic of Iran





Region: Western Asia
Capital: Tehran
Population: 83 992 949
Climate: Varied, large parts arid
Land Area: 1 648 195 km² (3.7% of Asia), arable soil covers 12%

Landscapes and climate

The Islamic Republic of Iran borders Armenia, Azerbaijan and Turkmenistan to the north, Afghanistan and Pakistan to the east, with Türkiye and Iraq to the west. It has coastlines on the Caspian Sea, the Arabian Gulf and the Gulf of Oman. Most of the country, is mountainous with steep slopes (the highest point, Mount Damāvand, reaching 5 670 m a.s.l., is a snow capped extinct volcano). The interior is a high, dry plateau, dissected by closed basins and hills. Along the coast, steep high escarpments back narrow plains. The Caspian Sea shore is 30 m below sea level. Climate reflects topographic, latitude and maritime influences with a distinct seasonality in the north and the west. Desert regions, extending into Afghanistan and Pakistan, have summer temperatures over 40°C. Higher elevations are cooler especially in winter, when snow can fall on high mountains. The northern coastal plain has a hot humid climate as the high Elburz Mountains block moist air from the Caspian Sea moving further inland. Annual precipitation is around 400 mm, mostly in winter, but evaporation rates are very high. The south is more arid while the Caspian Sea Plain can receive more than 1 000 mm.

Soil characteristics

Poorly developed, stony and shallow calcareous Cambisols, Leptosols and Regosols characterise the mountains, steep slopes and extensive alluvial fans. In more humid conditions, soils on steep slopes can be highly leached. Andosols are common in areas with volcanic ash and basaltic lava in the east. The plateau is mostly characterised by brown coloured, pH neutral Kastanozems. Sequences of coarse textured and poorly developed soils (Regosols and Arenosols - often in dune fields and sometimes with surface crusts), Calcisols, and saline Solonchaks in closed basins are found in drier parts of the plateau. Fine-textures Fluvisols and Gleysols are found along seasonal river channels with Gypsisols, Solonchaks and Solonetz on alluvial plains. Cambisols, red Luvisols, leached Podzols and Gleysols reflect the more humid conditions of the Caspian Sea Plain.

Soil related issues

Soils are typical of dry and hot environments, being poorly developed with low organic matter and water holding capacity. Gently sloping alluvial soils are often intensively cultivated with irrigation while extensive grazing occurs on Kastanozems. While there is high potential, general water deficit, together with salinisation, alkalinity and low nutrient status are major constraints to agricultural development. Wind and water erosion are widespread, often associated with deforestation, while landslides are common in the mountains, often triggered by earthquakes. Recent years have seen a number of major droughts, with increasing concerns in relation to desertification.

Indonesia

The Republic of Indonesia





Region: Southeast Asia
Capital: Jakarta
Population: 273 523 615
Climate: Equatorial
Land Area: 1 904 569 km² (4.27% of Asia), arable soil covers 13%

Landscapes and climate

Straddling the equator for over 5 000 km, Indonesia is the world's largest archipelago consisting of over 17 500 islands, including Sumatra, Java, Kalimantan, Sulawesi and Papua (the western part of New Guinea). A line of volcanoes extends from the northeastern tip of Sumatra to Timor-Leste marking the southern edge of the Eurasian Plate (Indonesia has more active volcanoes than any other country). Most of the islands consist of coastal plains that rise inland to high mountains (Puncak Jaya in Papua reaches 4 884 m a.s.l.). While there are some local variations, a strong equatorial climate means that most regions have constant temperatures all year (on average, 28 °C in the coastal plains to 23 °C in the mountains). Although annual precipitation and humidity are both high (around 2 000 mm and between 70-90%, respectively), Indonesia experiences a distinct dry (June to October) and wet season (November to April).

Soil characteristics

Despite the vast area covered, the major islands exhibit many similarities. Differences in soil types generally reflect local geological conditions. Deeply weathered granite and rhyolite lava give rise to Ferralsols while more fertile Andosols are found in intermediate lava flows and volcanic ash (e.g. Bali, Java, Nusa Tenggara and Sumatra). Cracking Vertisols (e.g. central Java) reflect the weathering of basaltic lava while Lixisols develop in karstic landscapes (e.g. Papua). At lower elevations, Nitisols are often the dominant soil, especially in Kalimantan (where they occur with Podzols). Consistently high temperatures and precipitation causes intense weathering and leaching of basic cations to form extensive iron-rich Ferralsols, Cambisols and Acrisols (all with low pH, nutrients and organic matter levels). Accumulations of peat (Histosols), with Gleysols, are widespread in waterlogged lowland basins, which grade to saline Fluvisols under coastal mangroves.

Soil related issues

Despite the high acidity, low water holding capacity and nutrient levels, around 30% of Indonesia is used for agriculture with extensive areas under palm oil (largest global producer), rubber plantation and rice cultivation. High population pressure, especially in Java, Sumatra, and Sulawesi, has expanded cultivation to less suitable and erosion-prone areas. Some lowland rice areas, especially in Java, have been converted for urban development, and replacements in the outer islands are not as fertile and with less dependable water supplies. Peatlands and acid sulphate soils are common on the flat coastal areas and require careful water management (drainage canals) to avoid greenhouse gas emissions and pyrite oxidation (resulting extreme low pH and toxicity).

Iraq

The Republic of Iraq





Region: Western Asia
Capital: Baghdad
Population: 41 000 000
Climate: Hot arid
Land Area: 438 317 km² (1% of Asia), arable soil covers 12%

Landscapes and climate

Located in the north of the Arabian Peninsula, Iraq borders Türkiye to the north, the Islamic Republic of Iran to the east, Kuwait and Saudi Arabia to the south, with Jordan and the Syrian Arab Republic to the west. It also has a small coastline on the Persian Gulf between Kuwait and the Islamic Republic of Iran. Most of the country is flat or gently undulating desert, dissected by the floodplains and marshes of the Euphrates and Tigris rivers. The north and west of the country are mountainous (the highest point, Cheekha Dar, reaches 3 611 m a.s.l.). Climate reflects the topographic divisions with the lowlands being characterised by hot and arid conditions where temperatures can reach 50 °C in the desert. Higher elevations give rise to lower temperatures, especially in winter when snow can fall on the mountains. Precipitation occurs mostly during the winter months and is highly variable from year to year, with around 150 mm annually (but can be two to three times higher in the northern mountains). Dust storms are common, especially with prevailing summer winds.

Soil characteristics

Soil development is most pronounced in the more humid northern mountains where organic-rich, dark-coloured Kastanozems and clay-rich Vertisols can be found among lesser developed Cambisols, Leptosols and Regosols. The desert regions (covering about 40% of the country) are characterised by coarse textured and poorly developed Arenosols (often in the form of dune fields) and Regosols. Most soils contain varying amounts and different forms of lime (Calcisols) or gypsum (Gypsisols) while saline Solonchaks and Solonetz are widespread. Gravelly Fluvisols are found along seasonal river channels while finer textured Fluvisols and poorly-draining Gleysols with higher organic matter levels have formed in the alluvial deposits along the Euphrates and Tigris rivers resulting in increased soil fertility. Histosols are found in marshes and wetlands.

Soil related issues

Soils are typical of arid environments, being poorly developed with low organic matter and water holding capacity. Wind and water erosion, often linked to overgrazing, are serious concerns (the latter can be seen by the expansion of the Tigris-Euphrates Delta into the Red Sea). Salinisation, due to inefficient irrigation and rising levels of salts in groundwater, is extensive and affects around 75% of cultivated land in Iraq, where it is one of the main drivers of land abandonment. The direct loss of agricultural land is most acute around urban canters as a result of urban growth. Soil pollution associated with the oil industry, poor waste management and agrochemicals is a challenge. Organic soils have reduced dramatically in recent years due to the drainage of marshes.

Japan





Region: Eastern Asia
Capital: Tokyo
Population: 126440000
Climate: Mostly tropical monsoon
Land Area: 378000km² (0.85% of Asia), arable soil covers 12%

Landscapes and climate

A volcanic archipelago consisting of nearly 7000 islands, Japan extends over 3000km from north to south and over 1000km from east to west between the East Sea and the Pacific Ocean (only 43km of Soya Strait separates Hokkaido from the Russian Federation island of Sakhalin while the Republic of Korea is only 200km across the Tsushima Strait). Japan is a rugged country with volcanic mountains (part of the Pacific Ring of Fire) forming the core of most islands (Mount Fuji on the island of Honshū stands at 3776m a.s.l.). Lowland areas are generally more pronounced in the east, consisting of narrow coastal strips or floodplains of river valleys. The length of the country means that the climate varies from cool humid continental in the north (with distinct seasons) to warm humid subtropical in the south. Annual precipitation around 1700mm (although this can double on the higher ground of the southeast). Monsoon conditions and typhoons mean that summers are hot and humid while cold air from the northwest brings freezing temperatures and heavy snowfall to the mountain ranges facing the East China Sea (Mount Fuji is covered by snow for five months of the year).

Soil characteristics

The soils of Japan reflect the influence of climate and topography on the weathering of volcanic and igneous materials. While organic-rich Andosols are widely distributed on plateau and terraces, most of central and southern Japan are covered by acidic Cambisols that are derived from volcanic, igneous and sedimentary rocks. The subalpine zone in central and northern Japan is characterised by extensive sandy Podzols reflecting the leaching of weathered granite by high rainfall. Deeply weathered reddish Alisols in the south probably reflect warmer climatic conditions in the past. In lowland areas, Fluvisols are very extensive due to the deposition of sediments eroded from the mountains. Gleysols and Histosols are found in poorly drained basins. Anthrosols denote terraces, irrigated paddy soils and land reclaimed from the sea.

Soil related issues

Volcanic soils are considered an important resource as they are rich in organic matter and nutrients, and have high water-holding capacity. However, they require higher amounts of phosphorus than other soil types in order to be productive. Japan's mountainous topography means that the extent of agricultural land is limited. Soil pollution has been a historical problem in Japan due to contamination by metals such as cadmium, copper and arsenic from mining and ore processing activities (radioactive contamination is a critical issue after the Fukushima nuclear accident).

Kazakhstan

The Republic of Kazakhstan





Region: Western Asia
Capital: Astana
Population: 19 398 331
Climate: Continental
Land Area: 29743km² (0.1% of Asia), arable soil covers 11%

Landscapes and climate

Land-locked Kazakhstan is bordered to the north and west by the Russian Federation, with China to the east, Kyrgyzstan to the southeast, Uzbekistan and Turkmenistan to the south and the Caspian Sea to the west. As the Ural River flows through Kazakhstan, part of the country is in Europe. Around three-quarters of Kazakhstan consists of lowlands and semi-arid grassy plains while the Tian Shan range in the southeast rises dramatically to over 4000m a.s.l. (the heavily glaciated Khan Tängiri Peak is at 6995m a.s.l.). The western end of the country lies in the arid Caspian Depression, which is 25m below sea level, while the Karakum Desert surrounds the northern half of the Aral Sea. The northern third of the country is a vast region of open grassland known as the Kazakh Steppe that extends into the Russian Federation. Kazakhstan has a dry continental climate with long hot summers and cold winters (temperatures in the north range from 25°C in summer to -20°C in winter, in the south and west winters are milder). Annual precipitation is 300mm, mainly falling in the north and east.

Soil characteristics

Soils in Kazakhstan follow a distinctive zoning, reflecting differences in climate with latitude and altitude which lead to differences in organic matter content and pH. Under the extensive grasslands and forests in the humid northern third of the country, dark deep organic-rich Chernozems occupy a broad belt running west to east. In regions with higher precipitation, increased leaching gives rise to Phaeozems, and Cambisols while to the south, drier conditions are reflected by more calcareous Kastanozems. The arid south and southwest are characterised by Calcisols, Arenosols and Regosols, interspersed with Solonchaks, especially around the Aral Sea. Fluvisols are found along river valleys and on alluvial fans and in delta regions of the Aral and Caspian Sea, where Gleysols reflect the shallow water table. A similar zonal pattern of soils can be observed on mountain slopes.

Soil related issues

The steppe conditions mean that the soils in the northern part of Kazakhstan are very fertile and highly productive. Intensive agriculture is also carried out along springlines and river valleys into the desert. The main environmental issues is the shrinking of the Aral Sea, which has been reduced to less than half its size compared the early 1960s as a result of the diversion of rivers for irrigation. Soil pollution as a result of the testing of atomic weapons, industrial emissions of metals and the overuse of pesticides is widespread. Agricultural land is increasingly degraded as a result of salinisation and wind erosion.

Jordan

The Hashemite Kingdom of Jordan





Region: Western Asia
Capital: Amman
Population: 10203134
Climate: Arid / Semi-arid
Land Area: 89342km² (0.2% of Asia), arable soil covers 3%

Landscapes and climate

Essentially a land-locked country, Jordan borders the Syrian Arab Republic to the north, Iraq to the northeast, Saudi Arabia to the east and south, with Israel and the West Bank Occupied Palestinian Territory to the west (there is a 26km coast on the Gulf of Aqaba). Much of the western border is defined by the River Jordan and the Dead Sea, which at 430m below sea level is the lowest land point on the planet (it is worth reflecting that the lake is a further 304m deep). Much of the country is a hot, dry plateau that is the continuation of the Syrian Desert. The western part has more of a Mediterranean climate although the Dead Sea Basin is again arid due to the rain shadow of the Judean Mountains. A narrow ridge of mountains runs down the western edge of the country (the highest point, Jabal Umm ad Dami, reaches 1854m a.s.l. near the border with Saudi Arabia). Precipitation is generally low everywhere while the entire country tends to experience cooler winters. Western areas have a Mediterranean climate with pronounced winter rains (c. 500mm annually), which decreases (while temperatures increase) to the south and east. Precipitation in the desert is about 50mm per year. Strong hot and dry winds are characteristic of the spring and autumn.

Soil characteristics

Soils are typical of hot, arid environments, being low in organic matter and water holding capacity. Generally coarse textured, shallow depth in the west, deep sand in the south, and high levels of lime (calcium carbonate) and gypsum in the north. Sandy Arenosols cover 30% of the country, interspersed by Fluvisols along seasonal river channels (often gravelly in nature) and saline clay-rich Solonchaks in inland depressions and along the coast (locally known as sabkhas). Gypsisols are common in the west and the north. Stony or sandy Regosols form in unconsolidated deposits while desert pavements occur where fine particles have been removed by wind erosion. Thin Leptosols are found on more steeply sloping ground. Many soils are often cemented by silica, lime or gypsum - locally this is called Gatch. Arable soils (cropped area) account for around 0.83% of the total land area.

Soil related issues

Low rainfall and sparse vegetation cover mean that wind erosion is widespread and dust storms can occur throughout the year. Grazing can lead to increased wind erosion. Together with low rainfall, high aridity, water and arable land scarcity, high levels of lime and the occurrence of hardpans are limiting factors for agricultural development beyond grazing. Secondary salinisation is a feature of irrigated agriculture and along the coast. Oil pollution in the soil related to the Gulf War is an issue. There are increasing concerns on the impact of climate change, especially in relation to more extreme weather events (especially more violent precipitation), sea-level rise (resulting in a loss of land) and increased aridity.

Kuwait

The State of Kuwait





Region: Western Asia
Capital: Kuwait City
Population: 4272342
Climate: Hot arid
Land Area: 17818km² (0.4% of Asia), arable soil covers <1%

Landscapes and climate

Located on the northeastern corner of the Arabian Peninsula, Kuwait borders Iraq to the north, Saudi Arabia to the south and the Arabian Gulf to the east. Kuwait is one of the world's smallest countries and includes nine islands. Kuwait is a low-lying desert plain with small hills and depressions (the highest point of Al-Mutlaa is only 306m a.s.l.). The climate is arid and most of the country is classified as desert. Temperatures are very high in the summer, often exceeding 40°C, while winters are colder due to its latitude and onset of cold northerly winds (average minimum temperature in January can fall to 7°C). Precipitation occurs mostly in the winter and is around 105mm annually, but can vary dramatically from year to year. Sandstorms and dust storms are common. Kuwait has no permanent water bodies but depressions and intermittent channels (wadis) can fill with water after rainfall.

Soil characteristics

Soils are typical of hot, arid environments, being low in organic matter and water holding capacity. Generally coarse textured, shallow depth in the west, deep sand in the south, and high levels of lime (calcium carbonate) and gypsum in the north. Sandy Arenosols cover 30% of the country, interspersed by Fluvisols along seasonal river channels (often gravelly in nature) and saline clay-rich Solonchaks in inland depressions and along the coast (locally known as sabkhas). Gypsisols are common in the west and the north. Stony or sandy Regosols form in unconsolidated deposits while desert pavements occur where fine particles have been removed by wind erosion. Thin Leptosols are found on more steeply sloping ground. Many soils are often cemented by silica, lime or gypsum - locally this is called Gatch. Arable soils (cropped area) account for around 0.83% of the total land area.

Soil related issues

Low rainfall and sparse vegetation cover mean that wind erosion is widespread and dust storms can occur throughout the year. Grazing can lead to increased wind erosion. Together with low rainfall, high aridity, water and arable land scarcity, high levels of lime and the occurrence of hardpans are limiting factors for agricultural development beyond grazing. Secondary salinisation is a feature of irrigated agriculture and along the coast. Oil pollution in the soil related to the Gulf War is an issue. There are increasing concerns on the impact of climate change, especially in relation to more extreme weather events (especially more violent precipitation), sea-level rise (resulting in a loss of land) and increased aridity.

Kyrgyzstan

The Kyrgyz Republic





Region: Central Asia
Capital: Bishkek
Population: 6 524 195
Climate: Continental
Land Area: 199 951 km² (0.45% of Asia), arable soil covers 7%

Landscapes and climate

Land-locked Kyrgyzstan is bordered to the north by Kazakhstan, with China to the east, Tajikistan to the south, and Uzbekistan to the west. Apart from some areas on the northern border, Kyrgyzstan is a mountainous country characterised by mountain ranges and basins. Many peaks in the Tian Shan range are permanently snow covered (Jengish Chokusu on the border with China rises to 7 439 m a.s.l.). The River Naryn flows across almost the entire country into the Fergana Valley in Uzbekistan and Tajikistan. Lake Ysyk is both the world's second largest saline and mountain lake (after the Caspian Sea and Titicaca). Kyrgyzstan has a continental climate that is modified by the mountainous terrain. Most areas have long hot summers and cool winters while the centre is milder (around 30 °C in the summer and 0 °C in the winter, lower on the mountain peaks). Annual precipitation ranges from 100 mm around Lake Ysyk to 1 000 mm in the western mountains.

Soil characteristics

Soils in Kyrgyzstan follow a distinctive altitudinal zoning, reflecting changes in climate, which are modified locally by variations in the lithology of parent material and vegetation cover. The cold, unvegetated high mountain peaks are shallow stony Leptosols and Cambisols. Zones of dark Phaeozems, Chernozems and Kastanozems, reflect decreasing elevation, precipitation levels and vegetation types (forest and grassland at lower elevations). Foothills are characterised by Cambisols, often calcareous, which can grade into Calcisols and Gypsisols, interspersed with wind-blown Arenosols, stony Regosols and saline Solonchaks, on the semi-arid basins and plains between mountain ranges. Gleysols and Fluvisols occupy minor areas along river valleys and on alluvial fans. Histosols can be common at a local level.

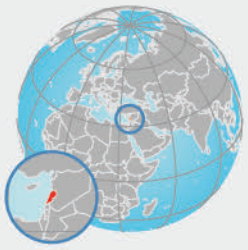
Soil related issues

The rugged landscape and dry climate mean that less than 10% of soils in Kyrgyzstan are cultivated. These are found mostly in the eastern end of the Fergana Valley and the northern lowlands around the Chu and Talas rivers. However, many mountainsides are intensively used for livestock farming. Almost 90% of agricultural land is classified as degraded (mainly due to salinisation) and are at risk of desertification. Steep slopes mean that the risk of soil erosion by water is high and widespread. Extensive mining operations have led to polluted soils at a local scale. Landslides, often triggered by earthquakes, are common. There are concerns about the reduction in the extent of glaciers due to global warming.

Lebanon

The Republic of Lebanon





Region: Western Asia
Capital: Beirut
Population: 5 000 000
Climate: Mediterranean
Land Area: 10 452 km² (0.02% of Asia), arable soil covers 13%

Landscapes and climate

One of the smallest countries in Asia, Lebanon is located on the eastern coast of the Mediterranean Sea. Beyond a wide coastal plain (narrowing in the centre), most of the country is mountainous with steep slopes (highest point is Qurnat al-Sawdā at 3 088 m a.s.l.). The broad Bekaa Valley, the tectonic extension of the Gulf of Aqaba, separates Mount Lebanon to the west and the Anti-Lebanon mountains to the east. Lebanon has a dry Mediterranean climate with pronounced seasonality. Summers are hot (often reaching 40 °C) while winters are cooler everywhere, with western areas having a pronounced winter rainy season (c. 600 mm annually), which increases gradually with altitude. The northeast and the east of the country are slightly more arid due to the effect of a rain shadow from the coastal mountains. Snow can fall on elevations above 1 200 m a.s.l. and remain for several months.

Soil characteristics

The steeply sloping terrain means that Leptosols are the dominant soil type, covering almost half the country. Soil development is most pronounced along the coastal lands and in the Bekaa Valley, where well-drained, reddish Luvisols have developed on limestone with Cambisols, Fluvisols and Vertisols in calcareous alluvial sediments. These soils are highly fertile and are intensely cultivated (the Bekaa Region is famous for wheat, potato and wine production). Shallow, lime-rich Cambisols, Calcisols, Leptosols and Regosols are characteristic of the mountainous areas. Anthrosols are extensive as a result of terracing of valley sides. Soil organic matter levels are generally low everywhere apart from on terraces and in forested lands.

Soil related issues

Arable soils are found on the coast, the Akkar Plain, in the Bekaa and on mountain terraces. Erosion by water and landslides, compounded by deforestation on steep slopes and flash flooding during torrential rainstorms, are major causes of soil loss in Lebanon. Almost all of the country is classed as medium to very high risk of erosion. Secondary salinisation is widespread as increasing areas with elevated levels of salts are found in irrigated arable land on the coast and the northeastern part of the Bekaa Valley, especially in greenhouses. Inappropriate fertiliser application gives rise to elevated levels of nitrates in groundwater and a reduction in water quality. Poorly regulated urban expansion in the coastal areas is consuming highly productive agricultural soils. Soil pollution linked to poor waste management is widespread.

The Lao People's Democratic Republic

The Lao People's Democratic Republic





Region: Southeast Asia
Capital: Vientiane
Population: 7 128 105
Climate: Tropical monsoon
Land Area: 236 800 km² (0.53% of Asia), arable soil covers 7%

Landscapes and climate

The Lao People's Democratic Republic is a landlocked country bordered by China and Myanmar to the north, Viet Nam to the east, Cambodia to the south, and Thailand to the west (much of it defined by the Mekong River). A rugged country, most of the country consists of steep terrain and narrow river valleys between mountain ranges and heavily dissected plateaus (at 2 817 m a.s.l., Phou Bia near Vientiane is the highest point). Flat land covers only about 20% of the country, which is found predominantly on the eastern floodplain of the Mekong and on the Bolovens Plateau in the south of the country (at around 1 000 m elevation). A pronounced wet season extends from May to October, which is flanked by a cool dry season from November to February where temperatures are around 20 °C, and a hot dry season from March to April (temperatures are usually over 30 °C). Higher elevations are cooler. Annual precipitation is around 2 000 mm but the southern mountains receive more than double this. Humidity is generally high. Regional droughts can cause large variations in rainfall in certain years (up to 50% reduction).

Soil characteristics

The soil-forming processes of the Lao People's Democratic Republic reflect strongly topographic settings and diverse geology of the parent materials. While the highest peaks and exposed cliffs are covered by Leptosols, most of the uplands are characterised by highly weathered, red and yellow Acrisols, which are coarse textured and acidic in nature due to high levels of aluminium and iron oxides, often occurring with Alisols and Luvisols. Highly weathered and leached Ferralsols occur in upland and plateau regions. The flat floodplain of the Mekong River consists of light-coloured sandy Fluvisols and heavier Gleysols, reflecting their formation in alluvial sediments. Nitisols have developed in the weathering products of basaltic lava, especially on the Bolovens Plateau.

Soil related issues

Extensive deforestation in the uplands has exposed the vulnerability of Acrisols to erosion unless they are protected by the dense forest canopy. Most soils are low in nutrients and have high levels of iron oxide. Studies have shown that the conversion of forest to cultivated land leads to the loss of topsoils that are rich on organic carbon and compaction of the subsoil due to the use of heavy farm machinery. Irregular rainfall distribution and droughts can affect rice yields as the highly weathered soils have low soil water holding capacity. Increasing use of pesticides due to a lack of labour in rural villages is leading to increased soil and water pollution.

Malaysia





Region: Southeast Asia
Capital: Kuala Lumpur
Population: 32 365 999
Climate: Equatorial
Land Area: 330 803 km² (0.74% of Asia), arable soil covers 3%

Landscapes and climate

West Malaysia occupies the southern end of the Malay Peninsula, where it shares a northern border with Thailand, with Singapore only 1 km off the southern tip. Eastern Malaysia covers the northern part of the island of Borneo with Indonesia the south (Brunei is an enclave on the north coast). Both parts of Malaysia consist of extensive coastal plains rising inland to hills and mountains (Mount Kinabalu in Borneo reaches 4 095 m a.s.l.). Malaysia has a strong equatorial climate that is characterised by relatively constant temperatures (generally around 27 °C), high annual precipitation (around 2 500 mm, although this can be double in the Sabah Region) and high humidity (never below 50%). Precipitation is slightly higher during the Northeast Monsoon (November to March).

Soil characteristics

The soils of large parts of Malaysia reflect intense weathering of granite under a hot and humid climate. Sandy iron-rich Ferralsols are abundant on higher ground, often found together with acidic Acrisols and Cambisols. Nitisols (and to a lesser extent Andosols) are much more evident in the non-acidic volcanic materials found in southeastern East Malaysia, especially on hills and low plateaus. Cambisols and Fluvisols define the alluvial soils of the coastal plain, grading into Gleysols and Histosols were drainage is impeded (lowland Histosols cover approximately 12% of the country with small areas of upland Histosols on the peninsula). Saline Fluvisols are found under extensive mangrove forests along the coasts. Acid sulphate soils are common in lowland areas.

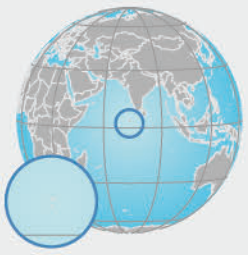
Soil related issues

Generally, soil conditions in Borneo do not differ greatly from those of the peninsula. As a result of high acidity, low water holding capacity (due to coarse texture and low organic matter content) and leaching of nutrients, the area of arable land is low (< 6%) and regular applications of fertiliser are necessary to sustain crop yields. Unless soils are saturated by water or temperatures are lower at higher elevations, organic matter is rapidly decomposed due to the constant high temperature and humidity. Malaysia is the 2nd largest exporter of palm oil in the world (covers 13% of the country). Concerns have been raised about deforestation and the draining of lowland peatlands - however a new policy sees no new planting on peat. Deforestation is a common trigger for soil erosion, especially on sloping ground. Mining during the 1970s–1990s caused large areas of land degradation (including soil pollution, erosion and deforestation). Acid sulphate soils require careful management to avoid the release of sulphuric acid into the environment which can dramatically cause crop yields to collapse.

Maldives

The Republic of Maldives





Region: Southern Asia
Capital: Malé
Population: 540544
Climate: Tropical monsoon
Land Area: 298 km² (<0.01% of Asia), arable soil covers 13%

Landscapes and climate

Maldives is a group of over 1000 islands lying in the southern part of the Arabian Sea, some 700km southwest of Sri Lanka and the southern tip of India. Maldives is made of islands, coral atolls and reefs, which mark a prominent volcanic ridge that extends for over 800km and drops over 1000m to the ocean floor. Maldives is the lowest lying country in the world with an average elevation of only 1.5m a.s.l. (the highest natural elevation is 2.4m a.s.l. on Vilingili Island in the Addu Atoll - but this is exceeded by buildings and artificial landscaping). The climate is tropical monsoon, which means that temperatures are warm all year round, varying only from 25-31 °C. Annual precipitation is around 2000mm of precipitation, mostly falling from May to September during the southwest monsoons. In contrast, the northeast monsoon (December to March) is dry.

Soil characteristics

The soils of Maldives are generally young and alkaline with pH above 8. This reflects their development from old lime-rich coral reefs and sand bars. Calcisols (often with a hard cemented horizon) and coarse textured calcareous Cambisols (often with substantial quantities of unweathered coral) dominate, together with calcareous Fluvisols and Arenosols (depending on location in the landscape). Under vegetation, a relatively thick organic surface horizon can develop on some of the older islands while mangroves can be found on the shores of many islands. Small extents of Gleysols and Histosols can be found in depressions (reflecting the naturally high water table in most islands), silted up lakes and where drainage is impeded. Anthrosols are important locally, where the soils are improved through the addition of compost and manure.

Soil related issues

Cropland in Maldives is scarce, used primarily for tropical fruits and vegetables. The highly alkaline conditions, linked to a lack of nitrogen, potassium, iron and manganese, together with low water holding capacity, severely limits agricultural production. Interestingly, soil phosphorous levels are high but in a form that is unavailable to plants. Soil pollution due to poor waste management is an issue in many inhabited islands. The entire region is threatened by sea level rise due to changes in global climate.

Myanmar

The Republic of the Union of Myanmar





Region: Southeast Asia
Capital: Nay Pyi Taw
Population: 54409800
Climate: Tropical / Subtropical
Land Area: 676578 km² (1.52% of Asia), arable soil covers 17%

Landscapes and climate

Myanmar is bordered by China to the northeast, the Lao People's Democratic Republic and Thailand to the east, India and Bangladesh to the northwest, with the Andaman Sea and the Bay of Bengal to the south and southwest. The country is characterised by a central lowland containing the Irrawaddy and Sittaung rivers, together with their deltas. To the west, the lowlands are bounded by a series of steep, parallel mountain ranges that run up to the eastern Himalayas (Hkakabo Razi at 5881m a.s.l. is located at the northern border with India and China). To the east, the deeply dissected Shan Plateau rises abruptly from the plains. A narrow strip of coastal plains, backed by steep hills runs north-south along the Thai border. Most of Myanmar experiences a tropical monsoon climate with distinct wet and dry seasons. Temperatures are generally around 27 °C, becoming lower with elevation (snow falls on the northern mountains during winter). Annual precipitation in the west is very high (>2500mm), mostly falling during May to October. The Central Lowlands are drier as a result of the rain shadow from the western mountains. Precipitation also decreases northwards to about 1000mm.

Soil characteristics

Broadly speaking, the soil-forming processes of Myanmar reflect the main topographic settings. The rugged mountain chains are mainly Leptosols and Cambisols. Forested highlands are characterised by highly leached, red and yellow Acrisols, together with pockets of Ferralsols, which are acidic in nature and deficient in nutrients. Conversely, most of the lowland areas consist of fine-grained Gleysols and Fluvisols reflecting their formation in the alluvial sediments of floodplains and deltas (clay content increases towards the coast). More gravelly variants are found in the upland river valleys where stream flow is stronger while Luvisols and Nitisols on higher terraces reflect older sediments. Soils with higher salt contents are found in coastal regions (e.g. Solonchaks).

Soil related issues

Deep alluvial soils form a vast, fertile belt in the lowland regions of Myanmar. The combination of shallow groundwater table, low subsoil permeability and low gradients means that these soils are well suited for rice cultivation. However, many agricultural soils are low in nutrients and losing organic matter as a result of improper land use practices. Salinisation and high alkalinity are widespread issues. Deforestation in the highlands exposes the vulnerable nature of Acrisols to erosion, which are normally protected by the dense forest canopy. Local soil contamination is linked to industrial sites and mining operations. During recent years, there has been a marked loss of mangroves along the coast.

Mongolia





Region: Eastern Asia
Capital: Ulaanbaatar
Population: 3256176
Climate: Cool continental / Cold semi-arid
Land Area: 1566000 km² (3.51% of Asia), arable soil covers <1%

Landscapes and climate

Land-locked Mongolia is bordered by the Russian Federation to the north, with China to the east, south and west (Kazakhstan is only 37km to the west). Apart from the Gobi Desert in the south and the forested mountains in the northern half of the country, most of Mongolia is an undulating grassy plateau that extends into China (the snow-capped Tavan Bogd Peak on the western border reaches 4374m a.s.l.). While most rivers drain internally, the Khangai Mountains are the watershed between the Arctic and Pacific Oceans. Lake Khovsgol contains 0.4% of the worlds fresh water. Mongolia has a marked continental climate with long cold winters (temperatures in the north can drop to -20 °C). Summers are short and, especially in the south, are warm with large daily variations in temperatures. With an annual average temperature of just −1.5 °C, Ulaanbaatar is the world's coldest capital city. The southern half of the country is arid with hardly any rain falling in the Gobi Desert. Precipitation increases towards the northern part of the country, with about 350mm annually in the northern mountains, mostly falling during winter as snow. Mongolia records more than 250 cloudless days each year.

Soil characteristics

Mongolia displays a broad latitudinal zoning of soil types. From the south, the Gobi Desert is characterised by gravelly and alkaline Regosols and Leptosols, with patches of Arenosols in the form of dunes. Calcisols are common. The cold and mountainous northern third of the country give rise to Cryosols (>2500m) and Leptosols, with Umbrisols and Phaeozems being more prevalent at lower altitudes, especially on the more humid forested slopes. In between these two zones, characteristic steppe soils cover over half of country. Dark coloured, loamy Kastanozems are the most prominent with some patches of Chernozems. River valleys are defined by Fluvisols, often with high salt content. Solonchaks are found in closed basins.

Soil related issues

Droughts have led to a loss of soil organic matter and increased soil erosion (over 60% of cultivated areas are highly affected). The steppe grasslands provide extensive grazing for large livestock herds. However, pasture land in the vicinity of water bodies, settlements, and along livestock driving roads are severely degraded, mostly due to overgrazing. There are concerns that rising temperatures that are causing increased desertification and the permafrost to thaw. While Mongolia has the lowest population density of any country (2 people per km²), the concentration of people and activities around Ulaanbaatar are leading to soil pollution and land degradation.

Nepal

The Federal Democratic Republic of Nepal





Region: Southern Asia
Capital: Kathmandu
Population: 29136808
Climate: Polar / Temperate / Tropical
Land Area: 147516 km² (0.33% of Asia), arable soil covers 15%

Landscapes and climate

Land-locked Nepal is bordered by China to the north, with India to the east, south and west (the narrow Siliguri Corridor separates Nepal and Bangladesh). Rising from the flat and low-lying fertile plains of the Ganges River (lying only 59m a.s.l.), through forested hills to the mountains of the Himalayas, Nepal is home to eight of the world's highest peaks (Mount Everest, the highest point on Earth, reaches 8849m a.s.l.). Several rivers (e.g. the Kosi) drain southwards towards the Ganges through deep, steep-sided valleys and gorges. The climate of Nepal reflects the range of elevations. Tropical and subtropical monsoon conditions below 1200m a.s.l. are followed by a temperate zone up to 2500m a.s.l.. Above this, temperatures fall markedly with freezing conditions and glaciers above 4400m a.s.l.. While precipitation generally decreases from east (2000mm) to west (1000mm), an arid climate (160mm annually) can be found in the northern rainshadow of the Himalayas (conversely, the slopes of Annapurna receive 5500mm). As well as blocking cold winds from Central Asia, the Himalayas form the northern limits of monsoons.

Soil characteristics

Soils in Nepal follow a distinctive altitudinal zoning, broadly reflecting changes in climate. The icy conditions on the high mountain peaks produce Cryosols and frost-shattered Leptosols that give way to shallow stony Regosols and Cambisols (the most extensive soil type in Nepal) often calcareous. Leached Umbrisols and Phaeozems are found at forested lower elevations. Fluvisols are extensive, being gravelly in the deep river valleys and on alluvial fans but are generally sandy in the lowland plains (often calcareous in nature reflecting the lithology of the watershed). Gleysols are found along the valley floors and old river channels in the plains and support rice cultivation. Luvisols are common locally, generally found on stable old slopes. Calcareous Regosols and Solonetz are found in the dry rain shadow region in the north.

Soil related issues

With 75% of the country mountainous, agricultural land is limited to valleys and the lowland plain (terracing is widespread). Many soils are shallow, highly porous and highly acidic, which affects crop yields. Micronutrient deficiencies are also problems. Deforestation, compounded by overgrazing, road construction and poor slope stability, has contributed to increases floods, soil erosion and landslides. Concentrated industrial activity has resulted in local soil pollution while the high use of pesticides is of concern. Studies report a constant retreat of glaciers due to warming climate, with concerns about the impact on the regional hydrological cycle.

Oman

The Sultanate of Oman





Region: Western Asia
Capital: Muscat
Population: 4 636 262
Climate: Hot arid / semi-arid
Land Area: 309 500 km² (0.69 % of Asia), arable soil covers 0.3 %

Landscapes and climate

Located on the southeastern coast of the Arabian Peninsula, Oman borders Saudi Arabia to the west, the United Arab Emirates to the northwest, Yemen to the southeast and the Arabian Sea to the east (a small enclave at the tip of the Musandam Peninsula is separated by the United Arab Emirates). Most of Oman is a sandy plain with mountains rising in the north and along the southeastern coast (highest point is Jebel Shams in the Al Hajar Mountain at 3 009 m a.s.l.). The climate is generally hot and arid with much of the country classified as desert. Coastal areas are hot and humid during summer while the interior is hot and dry with the exception of mountains in the southern Dhofar region, where the climate is moderated. Precipitation is around 62 mm annually (higher in the Dhofar ranges), falling in winter the north and centre of Oman. A seasonal summer monsoon occurs in the southern parts of the country causing a temperature change. Sandstorms are common.

Soil characteristics

Sandy Arenosols, covering much of the country, have been shaped by the prevailing winds to become some of the world's largest dunes, reaching elevations of over 100 m in the Sharqiya (also known as Wahiba) Sands. Western Oman is part of the Rub' al Khali desert (sometimes referred to as the Empty Quarter). Saline clay-rich Solonchaks occur in inland depressions (locally known as sebkhas and typified by the Umm al Samim). They are often associated with Calcisols and Gypsisols that reflect the evaporation of rainfall, saline groundwater or old lagoon-like features. Shallow stony Leptosols and Regosols are widespread in the mountains. Fluvisols, often gravelly in nature, are found along seasonal river channels (e.g. Wadi Shab) and on alluvial fans. Anthrosols with higher organic matter levels are located in oases.

Soil related issues

Soils are typical of arid environments, being poorly developed, low in organic matter, mostly with a coarse texture while displaying elevated levels of lime and gypsum (giving soils with a pH > 7). The fertility of most soils is naturally low although cultivation is possible on irrigated medium or fine textured soils. High salinity, indurated horizons and poor water holding capacity (as well as high temperatures and aridity) are the major constrains to agriculture. Overgrazing, coupled with lack of vegetation cover, means that soil erosion, especially by wind, is widespread. Inefficient irrigation can cause gypsum to dissolve leading to a loss of soil structure. Salinity levels are generally rising due to increased use of irrigation.

Occupied Palestinian Territory*

Occupied Palestinian Territory





Region: Western Asia
Capital: Jerusalem*
Population: 5 052 000
Climate: Hot semi-arid / Mediterranean
Land Area: 6 222 km²* (0.01 % of Asia), arable soil covers 8 %

Landscapes and climate

The Occupied Palestinian Territory consists of the Gaza Strip on the eastern coast of the Mediterranean (365 km² bordering Israel to the north and east, with Egypt to the southwest) and the landlocked West Bank (5 628 km² bordering Israel to the north, west and south, and Jordan to the east). The Gaza Strip is a relatively flat coastal plain with some low hills inland (Abu 'Awdah only reaches 105 m a.s.l.) while the West Bank is more mountainous (Mount Nabi Yunis reaches 1 030 m a.s.l.). To the east of the West Bank lies the Jordan River Valley and the Dead Sea, which at 417 m below sea level, is the lowest point on the Earth's surface. As the Jordan Valley is also the northern end of the Great Rift Valley, geologically the Occupied Palestinian Territory is located on the African tectonic plate. Summer temperatures in the Gaza Strip are around 30 °C, dropping to around 13 °C in the winter. Temperatures in the north of the West Bank are generally lower due to higher elevation but are higher around the Dead Sea. Annual precipitation in the Gaza Strip is around 300 mm while the West Bank ranges from around 600 mm in the north to less than 100 mm around the Dead Sea.

Soil characteristics

Soils in the Gaza Strip are mostly calcareous loams (Calcisols) and Arenosols, with dunes becoming more developed in the south and along the coast. Fluvisols and Vertisols with higher clay content are found in valleys and sloping ground. The soils of the West Bank are more developed, characterised by fertile reddish Luvisols, together with lime-rich Phaeozems, Cambisols and Vertisols. Calcareous Leptosols and Regosols are found on steeper slopes with Calcisols in the river valleys. Saline and gypsum rich soils (Gypsisols, Solonchaks and Solonetz) are predominant around the Dead Sea. Anthrosols are found in the oasis of the Dead Sea.

Soil related issues

Soil fertility is a key issue in the Occupied Palestinian Territory as agriculture is the main economic activity. Soils are typical of dry and hot environments, being generally poorly developed with low organic matter and water holding capacity. Alluvial soils with relatively high nutrient status are intensively cultivated (especially with irrigation) but water deficit and salinisation are major constraints to agricultural development. Recent years have seen a number of major droughts, with increasing concerns in relation to desertification. Soil erosion (by both wind and water) is severe in many places. Salinity is widespread along the Jordan Valley while soil pollution from agro-chemicals (i.e. pesticides and high use of fertilisers) are concerns for groundwater quality. Soil sealing rates are high, especially in the Gaza Strip.

*while geologically not in Asia, the Occupied Palestinian Territory is included in the atlas as it is a member of FAO's Near East and North African Soil Partnership. Both the United Nations and the European Union support the view that Jerusalem should be the future capital of both Israel and a future Palestinian state. This designation shall not be construed as recognition of the State of Palestine and is without prejudice to the individual positions of EU Member States on this issue.

Pakistan

The Islamic Republic of Pakistan





Region: Southern Asia
Capital: Islamabad
Population: 207 774 000
Climate: Tropical / Temperate / Arid
Land Area: 796 095 km² (1.78 % of Asia), arable soil covers 28 %

Landscapes and climate

With the Arabian Sea to the south, Pakistan is bordered by Afghanistan to the north, China to the northeast, India to the east, and the Islamic Republic of Iran to the west. It is separated from Tajikistan by Afghanistan's Wakhan Corridor, which is only 13 km at its narrowest. Pakistan has a varied landscape ranging from the high peaks of the Karakoram and Hindu Kush, which drop, through extensive plateaus and hills, to the flat plains of the Indus River (one of the longest rivers in Asia). The famous Khyber Pass connects to Afghanistan. Pakistan is home to five peaks over 8 000 m a.s.l. (including K2, at 8 611 m a.s.l., the 2nd highest mountain in the world). Most of Pakistan experiences a hot, dry continental climate, characterised by extreme variations in temperature and precipitation. A summer rainy season (June to September) is followed by a cold, dry winter (December to February) and a hot, dry spring (March–April). Temperatures are modified by sea breezes along the coast and with increased elevation, which sees the northern mountains snow-covered all year round (Pakistan has more glaciers than any other country outside of the Polar Regions). Annual rainfall is less than 250 mm, except on the southern slopes of the northern uplands (760 mm to 2 000 mm). The monsoon season usually brings heavy rain, which can cause severe flooding.

Soil characteristics

Soil development strongly reflects topography, the generally arid climate and predominance of lime-rich parent materials. The mountainous regions are characterised by poorly developed, stony and shallow Leptosols, Regosols and Cambisols, generally calcareous in nature with low organic matter levels. Arenosols, often in the form of dunes, with Fluvisols in valleys, are found the deserts and hills of Balochistan. The flat Indus Basin is characterised by loamy Fluvisols close to the river, becoming finer in texture away from the main channels. Saline Solonchaks and Gleysols can be found in the floodplain, especially in the delta region.

Soil related issues

Soil fertility is a major concern as agriculture is a major part of the economy (e.g. Pakistan is the world's 4th largest producer of cotton). Most soils have naturally low organic matter levels and lacking in nitrogen. Salinity, sodicity and erosion are widespread. Extreme weather events (both droughts and floods) are predicted to have significant impacts through a loss of organic matter (already low for most of the country), and increased soil erosion with a loss of nutrient-rich topsoils. Water scarcity is ubiquitous and hinders crop production in several regions of the country.

The Philippines

The Republic of the Philippines





Region: Southeast Asia
Capital: Manila
Population: 109 581 078
Climate: Tropical monsoon
Land Area: 300 000 km² (0.67 % of Asia), arable soil covers 19%

Landscapes and climate

The Philippines is an archipelago consisting of about 7 600 islands stretching out almost 2 000 km from north to south, and over 1 000 km from east to west between the Pacific Ocean to the east and the South China Sea to the west. The topography of the Philippines is varied with volcanic mountains (some still active) forming the core of the larger islands. Located on the island of Mindanao, Mount Apo is the highest point in the Philippines with an elevation of 2 954 m a.s.l.. Lowland areas are generally either narrow coastal strips or the floodplains of river valleys. The country has a tropical monsoon climate, which means that the temperature is relatively constant all year (around 27 °C) and generally with high humidity reflecting maritime influences (although humidity and temperatures drop with altitude). Although annual precipitation is high (up to 5 000 mm), the monsoon conditions give rise to a distinct dry season from December to May.

Soil characteristics

Vertisols and Cambisols are the most common soil types in the Philippines, particularly in the level ground of the paddy rice fields and alluvial plains. Vertisols are characterised by a high content of montmorillonite, a swelling clay which makes the soil heavy to work when wet but contracts to form wide cracks during the dry season. On the level ground of the broad alluvial plains poorly drained, medium textured, gray to greyish brown coloured Cambisols are found containing manganese concretions. Both types of soils have medium inherent soil fertility. With intensive use, this may lead to soil fertility decline in large parts of the country. Deep and well-drained, acidic Acrisols have formed in the weathering of basalt and andesite on undulating terraces and steep foot slopes of hills and mountains. Poorly drained, saline Arenosols and Fluvisols are common in coastal regions and river terraces that are subject to daily tidal flooding or river flow. These soils are generally planted to mangrove and used for fishponds and saltbeds.

Soil related issues

Soils in the Philippines are subjected to a series of degradation processes including soil erosion, compaction, soil fertility decline, soil salinity and soil pollution. The most common pressure in the country is from water-induced soil erosion that affects the soil's physical, chemical and biological properties. This makes the land less suitable for crop production. About 45 % of the total land area is moderately to severely eroded. Approximately 5.2 million hectares of land are considered are being severely eroded while a further 8.5 million hectares are regarded as being moderately eroded, resulting in a 30-50% reduction in soil productivity.

Qatar

The State of Qatar





Region: Western Asia
Capital: Doha
Population: 2 881 053
Climate: Arid
Land Area: 11 581 km² (0.3% of Asia), arable soil covers 1%

Landscapes and climate

Located on a small peninsula on the western shore of the Arabian Gulf (160 km long by 80 km wide), Qatar's only land border is with Saudi Arabia to the south. The island of Bahrain lies off Qatar's west coast. Qatar is a essentially a low-lying desert, with elevations rising to a central plateau that is generally no more than 50 m above sea level (highest point is Abū al-Bawl Hill at only 103 m a.s.l.). The climate is arid with hot humid summers, often exceeding 40 °C (the humidity is caused by the evaporation of the sea). Winters are cooler, averaging around 14 °C in January. Precipitation is only around 70 mm annually, falling entirely during the winter months. Sandstorms and dust storms are common. Qatar has no permanent water bodies.

Soil characteristics

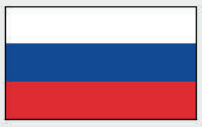
Soils are typical of an arid environment, displaying limited development with low organic matter levels. Calcareous Arenosols cover most of the country, often in the form of windblown dunes. Shallow stony Leptosols and Regosols overlie exposures of bedrock. Silty Solonchaks and Solonetz, often with gypsum crusts, are found along the coast (locally known as sebkhas). An interesting phenomenon is the formation of a calcareous loamy soil in small shallow depressions (generally no greater than 1.5 m deep). Known locally as rawdha, these soils are the basis for the country's agriculture. Extensive land reclamation into the sea around Doha (e.g. the Pearl development) gives rise to Technosols.

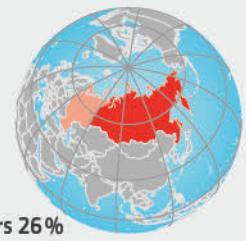
Soil related issues

Water scarcity, high temperatures and the prevalence of sandy soils, means that the organic matter content of most soils is naturally low (<1%). Agriculture can only be carried out with irrigation and cultivated soils occupy only 3% of the country. A lack of vegetation cover, coupled with strong sea breezes, means that wind erosion is widespread. Secondary salinisation due to irrigation is an increasing concern in agricultural soils. Sea water intrusions into aquifers is compounding the issue. Significant urban expansion means that soil sealing is common around Doha. There are concerns on the impact of climate change, especially in relation to more extreme weather events (both in terms of temperature and precipitation), sea-level rise (resulting in a loss of land) and increased aridity (increased wind erosion and dust storms).

Russian Federation (asian part)

The Russian Federation





Region: Northern Asia
Capital: Moscow
Population (Asia)*: 31 790 000 [*total 143.4 million]
Climate: Continental / Polar
Land Area (Asia)*: 12 823 684 km² (29 % of Asia) [*total 17.1 million km²], **arable soil covers 26%**

Landscapes and climate

The asian part of the Russian Federation borders the Democratic People's Republic of Korea, China, Mongolia and Kazakhstan to the south, with the Urals marking the western edge (the north and east face the Arctic and Pacific Oceans). Cape Dezhnev, the eastern most point of Asia, is only 82 km from the western most point of North America. Between the Urals and the Yenisey River, a low flat marshy plain, generally not exceeding 150 m above sea level is drained by three of the world's longest rivers (the Ob and the Lena also flow across the region to the Arctic Ocean). To the east, a series of wet lowlands and plateaus increase in elevation to merge with the East Siberian Mountains and the volcanoes of the Kamchatka Peninsula (at 4 750 m a.s.l. Klyuchevskaya Sopka is the highest point although Mount Elbrus in the Western Caucasus reaches 5 642 m a.s.l.). A continental climate gives short summers while the proximity of the Arctic means that winters are long and very cold (below -25 °C is not uncommon). Apart from Kamchatka and the East Sea coast, precipitation is generally below 500 mm, often falling as snow.

Soil characteristics

The soils of the asian part of the Russian Federation generally occur in a series of broad latitudinal belts, mostly reflecting very low winter temperatures. East of the Yenisey River, Cryosols are widespread in the permafrost of the tundra and forest tundra of the north. With warmer and more humid conditions to the south and along the Pacific coast, extensive Podzols have developed in sandy parent materials under coniferous forests (taiga), grading southwards into a belt of Albeluvisols under open mixed-forest areas. The vast low-lying and flat West Siberian Plain is one of the world's largest expanses of Histosols. Beyond the forest and swamp zones, Chernozems, Phaeozems and Kastanozems are found in loess deposits under drier and warmer steppe grasslands. In the mountains along the southern border, elevation dictates soil patterns with Regosols and Leptosols giving way to Cambisols and steppe soils on lower slopes. Andosols are widespread along the Pacific coast.

Soil related issues

Agricultural land is mostly concentrated in south of Western Siberia. There are concerns that rising temperatures as a result of global warming is thawing the permafrost, which can lead to increased emissions of methane into the atmosphere. The lack of steep slopes and cultivated land means that water erosion is generally low although deforestation along the border with China is responsible for higher rates. Overgrazing in southern regions has resulted in increased incidences of wind erosion. Although population densities are low, local soil pollution can be found in the vicinity of large mining operations.

The Republic of Korea

Republic of South Korea





Region: Southern Asia
Capital: Seoul
Population: 51 269 185
Climate: Temperate
Land Area: 99 000 km² (0.23% of Asia), arable soil covers 22%

Landscapes and climate

The Republic of Korea is a peninsula that extends into the Yellow, East China, and East Seas. It is bordered by the Democratic People's Republic of Korea to the north and separated from Japan to the southeast by the Korea Strait. A narrow coastal plain (wider in the west and southwest) rises inland to a rugged backbone of mountains that increase in elevation to the northeast (but not exceeding 2 000 m a.s.l.), that extends into the Democratic People's Republic of Korea (although at 1 950 m a.s.l., the extinct volcano of Mount Halla on Jeju Island is the highest point in the Republic of Korea). Most of the lowlands are river floodplains. the Republic of Korea has a temperate climate with distinct seasons. Winters are long, dry and cold (average temperature in January is below 0 °C except along the south coast). Summers are short, hot and humid (July averages around 25 °C). Summer monsoons (June-September) bring about 1 500 mm of precipitation in the west, reducing to half on the east coast. Most precipitation falls as rain in the summer while snow is common in the winter. Occasional typhoons in late summer bring heavy rains, occasionally causing extensive damage to crops.

Soil characteristics

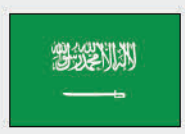
Soils of the Korean Peninsula generally reflect the weathering of granite and metamorphic rocks. Soils tend to have low organic matter content due to accelerated decomposition as a result of the climate. High rainfall results in the leaching of cations causing low pH, especially on sloping ground. As a result, sandy Cambisols and Podzols are evident in the uplands. Luvisols tend to be more prevalent on lower slopes, with Gleysols in inland basins, river valleys and floodplains (reflecting the movement of clay particles to low-lying areas). Lowland areas around the coast are deep alluvial Fluvisols, becoming saline in estuaries. The basaltic lava and ash of Jeju Island give rise to Andosols and Vertisols.

Soil related issues

A growing population has driven drastic changes in land use and soil management practices that have caused significant deterioration in soil and environmental quality. Rapid urban and industrial development, together with an emphasis on food production, has led to deforestation, the conversion of natural land to intensive cultivation, the drainage of lowland wetlands, soil sealing, and local soil pollution. Deforestation means that soils on slopes are prone to erosion, while soils in the lowlands (especially valley bottoms) are prone to flooding. A high nutrient balance in agriculture results from the intensive use of manure from livestock breeding. There are concerns that climate change will bring even more pressure to bear on soils.

Saudi Arabia

The Kingdom of Saudi Arabia





Region: Western Asia
Capital: Riyadh
Population: 34 813 871
Climate: Hot arid
Land Area: 2 149 690 km² (4.8% of Asia), arable soil covers 1.6%

Landscapes and climate

The largest country of Western Asia, Saudi Arabia borders Jordan, Iraq and Kuwait to the north, the United Arab Emirates and Oman to the southeast, Yemen to the south, Bahrain, Qatar and the Arabian Gulf to the east, and the Red Sea and Gulf of Aqaba to the west. The eastern part of the country is flat or gently undulating and dominated by the Arabian Desert. Elevation increases towards the west where a rugged escarpment that runs parallel to the Red Sea coast marks the end of the central plateau (the highest point, Mount Sawdā at 3 015 m a.s.l.). Apart from the highlands in the south, most of the country experiences hot and arid summers with relatively cooler winters. Temperatures can reach 50 °C in the desert. Precipitation is highly seasonal (around 75 mm annually in winter). Generally, rainfall levels can vary greatly from year to year but no rain at all can be recorded in the southeastern deserts for several consecutive years. Dust storms are common.

Soil characteristics

Sandy deserts mean that Arenosols are widespread (e.g. extending over 650 000 km², the Rub' al-Khali is the largest expanse of sand in the world). Dunes can reach heights of over 100 m (especially in the east) while the valleys between dune ridges can be several kilometres wide. Saline clay-rich Solonchaks (locally known as sebkhas and typified by the Matti Salf Flats on the border with the UAE) develop in inland depressions (often marking the end of river systems), between dune ridges or along the Red Sea coast. Shallow and gravelly Leptosols and Regosols are extensive on the central plateau and western mountains. Fluvisols, also gravelly in nature, are found along seasonal river channels (e.g. Wadi Al-Hamd). Volcanic soils can be observed in lava flows and cones in the western highlands (e.g. Harrat Khaybar). Anthrosols with higher organic matter levels can be found in oases.

Soil related issues

Soils are typical of arid environments being poorly developed, low in organic matter, mostly with a coarse texture and low water retention properties, while often displaying elevated levels of lime and gypsum (giving rise to alkaline soils with a pH > 7). However, agriculture through irrigation is an important economic sector in Saudi Arabia. Distinctive circular pivot irrigation systems support wheat cultivation in otherwise unvegetated areas while the Al Jouf region contains the world's largest olive plantation. There are concerns on the over-exploitation of fossil ground water reserves and increasing soil salinity levels. Infrastructure deformity due to soil instability (often related to high salt levels) is a problem in many areas.

Singapore

The Republic of Singapore





Region: Southeast Asia
Capital: Singapore
Population: 5 850 342
Climate: Tropical rainforest
Land Area: 725.7 km² (> 0.01 % of Asia), arable soil covers < 1 %

Landscapes and climate

The smallest country in Asia, the island state of Singapore is located at the southern tip of the Malay Peninsula (consisting of 63 islands in total, most of them are uninhabited). The main island is separated from Malaysia by the narrow Straits of Johor (about 1 km wide), and from Indonesia by the Straits of Singapore (about 16 km wide). A low-lying country, elevations do not generally exceed 15 m above sea level (Bukit Timah only reaches 164 m a.s.l. in the centre of the main island). The northwestern part is more undulating while the east is a low dissected plateau. Singapore has no natural lakes and only a few short rivers. Lying on the equator, the tropical rainforest climate is characterised by relatively constant temperatures (generally between 25 °C and 33 °C), high annual precipitation (around 2 400 mm, usually rain falls every day) and high humidity (never below 50 %). Precipitation is slightly higher during the Northeast Monsoon (November to March). The eastern side of Singapore is drier and slightly hotter than the west due to a micro rain shadow caused by Bukit Timah Hill.

Soil characteristics

The high density urban fabric means that soils are not so visible and most of those that remain are highly eroded. As the surface area of Singapore has increased by 25 % since the 1960s, Technosols are widespread around the coastal regions reflecting extensive land reclamation projects (mangroves on the north coast give rise to saline Fluvisols). Reddish Acrisols in the centre denote the weathering of igneous rocks, while the undulating topography of the northwest gives rise to a mosaic of Acrisols and Ferralsols while Cambisols in east reflected soil development in highly eroded soils. Plinthosols with hardened horizons can be found on flat land while Histosols can be found along undeveloped coasts and in depressions.

Soil related issues

Deforestation has affected virtually all of Singapore with significant habitat loss (only 0.25% of the land area is considered as having natural vegetation). Large parts of the main islands are sealed with impermeable materials necessitating extensive drainage and water management systems to avoid flooding. Extensive coastal developments have seen a marked reduction in the extent of mangroves. Reclamation projects are projected to add another 56 km² of land by 2030. Rising sea levels and increased storm events due to climate change are concerns given its low-lying coastal setting.

The Syrian Arab Republic

The Syrian Arab Republic





Region: Western Asia
Capital: Damascus
Population: 21 124 000
Climate: Temperate/Arid Mediterranean
Land Area: 185 180 km² (0.42 % of Asia), arable soil covers 25%

Landscapes and climate

The Syrian Arab Republic borders Türkiye to the north, Iraq to the east, Jordan to the south, the Occupied Palestinian Territory to the southwest, with Lebanon and around 200 km of the Mediterranean Sea to the west. Much of the country is a hot, dry plateau of the Syrian Desert that becomes cooler and more humid towards the coast. The west of the country is mountainous (the highest point, Mount Hermon or Jabal al-Shaykh, reaches 2 814 m a.s.l. on the Lebanese border). The Euphrates River runs through the desert region and represents over 80% of the country's water resources. Southern and eastern parts of the Syrian Arab Republic are characterised by hot and arid conditions where winter precipitation is less than 100 mm annually and summer temperatures can reach 40 °C. To the north and west, slightly cooler temperatures (30 °C in the summer, just above 0 °C in winter) and higher precipitation (c. 200 mm annually) supports a semi-arid grassland zone. The Mediterranean coast is cooler again (especially in winter) and more humid as winter precipitation can be around 1 400 mm annually.

Soil characteristics

Soil development is most pronounced in the alluvial sediments of the more humid western areas. Along the Mediterranean coast, dark-coloured Chernozems and clay-rich Vertisols can be found among Cambisols, Leptosols and Regosols. Eastwards, the desert and mountain regions are characterised by coarse textured and poorly developed Cambisols, Leptosols and Regosols (sand dunes are largely absent). Many soils contain varying amounts and forms of lime (Calcisols) or gypsum (Gypsisols), often as hard layers. Saline Solonchaks and Solonetz are found in seasonally-flooded basins to give extensive salt flats (e.g. Sabkhat al-Jabbul). Fine-grained Fluvisols with higher organic matter levels have formed in fluvial deposits along the Euphrates and Orontes Rivers, which combined with irrigation, has resulted in increased soil fertility in the desert region.

Soil related issues

Soils with moderate levels of organic matter content only occupy about 2% of the country and are used to cultivate citrus fruits and vegetables on the Mediterranean coastal strip. Poorly developed shallow, arid soils, with low organic matter and water holding capacity, cover more than half of the country. Salinisation, including elevated levels of lime and gypsum, is found in cultivated land and can limit agriculture. Access to water resources is a concern, especially in the context of climate change. Wind and water erosion, often linked to deforestation, overgrazing and desertification, are widespread. Soil erosion by wind results in extensive dust and sandstorms. Dealing with soil pollution associated with industry and poor waste management is an increasing challenge.

Sri Lanka

The Democratic Socialist Republic of Sri Lanka





Region: Southern Asia
Capital: Colombo
Population: 21 803 000
Climate: Tropical monsoon
Land Area: 65 625 km² (0.15 % of Asia), arable soil covers 45 %

Landscapes and climate

Sri Lanka is an island in the southern Indian Ocean, situated only 27 km off the southeastern tip of India. Low-lying coastal plains extend inland to flat or gently rolling terrain and central mountainous mass with an elevation of 2 524 m a.s.l.. Rivers flow radially from the central highlands to the sea. Mangroves are extensive along the coast. The climate is tropical monsoonal with distinct wet and dry seasons. The average annual temperature in lowlands is 27 °C (lower in the central highlands), with a daily range of about 6 °C. Precipitation is driven by monsoon winds from the Bay of Bengal and Indian Ocean (northeast monsoon: December to January, southwest monsoon; May to September). Annual precipitation ranges from 900 mm in the southeastern lowlands to around 5 550 mm on the slopes of the central highlands, giving rise to a dry zone (< 1 750 mm annual rainfall with a distinct dry season from May to September), a wet zone (> 2 500 mm annual rainfall without a pronounced dry spell) and an intermediate zone.

Soil characteristics

Dark red Luvisols dominate the drier lowland plains, interspersed mainly with Arenosols and Leptosols. Deeply weathered, acidic, red and yellow Acrisols, together with Plinthosols occur where precipitation is high. The intermediate zone displays a transition from Luvisols to Acrisols, with slightly acidic Cambisols on the steeper slopes. Variable textured Fluvisols and heavy Vertisols (reflecting the deposition of weathered clay-rich sediments from the uplands) are found in the alluvial deposits of river valleys and flood plains and are an important soil resource for paddy cultivation. Solonetz and Solonchaks are found along the drier coasts, often grading to saline Fluvisols in the tidal mangrove areas.

Soil related issues

Inherently low fertility and soil degradation due to deforestation and inappropriate agricultural practices are the key issues. Soil erosion is a major concern, especially in the central highlands with very high rates observed during intense monsoon rains. Fertility decline has adversely affected agricultural productivity in the wet and intermediate zones. Acidic soils in the wet zone require considerable management effort to maintain the agricultural productivity. The lowering of soil pH caused by inappropriate agricultural practices has further aggravated this problem. Excessive application of phosphatic fertilisers has triggered the eutrophication of surface water bodies adjacent to vegetable cultivated soils in the central highlands. The areas of mangrove forests have been constantly reducing due to an increase in aquaculture and other anthropogenic activities.

Tajikistan

The Republic of Tajikistan





Region: Central Asia
Capital: Dushanbe
Population: 9 101 000
Climate: Mediterranean/Semi-arid continental/Cold desert
Land Area: 143 100 km² (0.32 % of Asia), arable soil covers 5 %

Landscapes and climate

Land-locked Tajikistan is bordered by Kyrgyzstan, China, Afghanistan and Uzbekistan. Around 93% of Tajikistan is mountainous, with more than half the country lying over 3 000 m a.s.l.. Many of the peaks of the Pamir-Alay Mountain are permanently covered in snow and ice (the Ismoil Somoni Peak in the Pamir reaches 7 495 m a.s.l. while the Syr Darya River on the Uzbekistan border is only 300 m above sea level. Tajikistan has a relatively arid continental climate that is modified by the enormous elevation gradients. The western lowland areas have hot dry summers and cool winter (averaging 25 °C and 0 °C respectively). Temperatures are higher in the southwest lowlands but winter temperatures in the eastern mountains can drop to below -20 °C. Annual precipitation for the eastern part of the country and the lowland areas is less than 200 mm but the central mountains can receive over 1 000 mm, falling as heavy snow in the winter.

Soil characteristics

Soils in Tajikistan follow a distinctive altitudinal zoning, reflecting changes in climate and modified locally by variations in parent material and vegetation cover. The Vakhsh and Fergana valleys are dominated by Calcisols and Cambisols that have formed in thick loess deposits covering the valleys and foothills. Large areas have been transformed into Anthrosols as a result of long-term sediment accumulation through flood irrigation. Salt-affected Solonchak, Solonetz, and Planosols, occur in the dry lowlands with desert and semi-desert vegetation. The foothills of the Pamir and Alay are mostly red Cambisols. Higher elevations are dominated by Umbrisols, interspersed with Leptosols under grasslands, which extend to the glacier edges.

Soil related issues

The rugged landscape and dry climate mean that less than 10% of soils in Tajikistan are cultivated. These are found mostly in the Fergana, Kofarnihon and Vakhsh valleys. Almost all agricultural land is classified as degraded, predominantly due to high levels of pesticide residues from the cultivation of cotton, salinisation (natural salinity aggravated by irrigation) and erosion, especially by gullies along river banks caused by deforestation for firewood. Forest soils are rich in organic matter and have high fertility status with wooded river valleys being intensively cultivated for food production or used for extensive grazing. Erosion due to overgrazing of high-mountain grasslands by sheep is a serious problem. This can lead to the formation of bare compacted terracettes under sheep trails, which leads to landslips and greater soil loss. Fluvisols of high-lying valleys are often cultivated for vegetable production.

Thailand

The Kingdom of Thailand





Region: Southeast Asia
Capital: Bangkok
Population: 66 500 000
Climate: Tropical savannah / Monsoon
Land Area: 513 115 km² (1.15% of Asia), arable soil covers 48%

Landscapes and climate

Thailand is bordered by the Lao People's Democratic Republic to the northeast and east, Cambodia to the southeast, Malaysia and the Gulf of Thailand to the south with Myanmar to the west and northwest. Most of northern and western Thailand is mountainous (Mount Inthanon at 2585 m a.s.l. is located near the northern border with Myanmar) while the Khorat Plateau in the northeast consists of low hills. The centre is a lowland plain that is drained by the Chao Phraya River. Much of northeast Thailand drains into the Mekong River system. The southwest of the country consists of a peninsula with a mountainous spine flanked by coastal plains with mangroves. The climate is dominated by monsoon winds that bring distinct wet and dry seasons. Temperatures are generally constant all year (around 28 °C), but can reach 40 °C during March to May in the north (conversely October to March can be much cooler on high mountains). Most of Thailand has a pronounced dry season with annual precipitation around 1 340 mm, mostly falling from May to October in the south. The mountains on the Malaysian border receive 4 500 mm of precipitation annually.

Soil characteristics

Broadly speaking, the soil-forming processes in Thailand reflect the main topographic settings. Forested highlands are characterised by highly leached, red and yellow Acrisols that are acidic and deficient in nutrients. Pockets of Nitisols reflect changes in topography. The Khorat Plateau is a large expanse of sandy Acrisols with pockets of Cambisols. Luvisols are widespread in northern and central regions with Plinthosols in the northeast. Most of the lowland areas consist of fine-grained Fluvisols reflecting their formation in the alluvial sediments of floodplains, deltas and under mangroves (clay content is higher in the delta and tidal flats). Gleysols are widespread, especially in the central plain and the delta region.

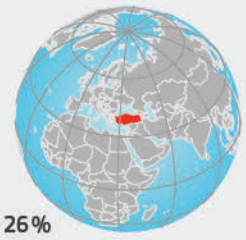
Soil related issues

The combination of shallow groundwater table and low permeability means that the central part of the country is flat lowland areas that are well suited for rice cultivation. Soils with acid conditions are widespread in upland areas with many soils lacking in nutrients and organic matter. Soils can become productive through liming and targeted use of fertilisers. Soils on steep slopes (> 35%) are considered unsuitable for agriculture due to erosional hazards and other environmental problems. To support the demands of farmers for increased access to arable land, the Thai government has a programme for optimum management practices for soils with limitations for crop cultivation (e.g. acid sulphate soil, high salinity, stoney, organic soil, sandy soils).

Türkiye (asian part)

The Republic of Türkiye





Region: Western Asia
Capital: Ankara
Population (Asia)*: 71 598 276 [*total 84 869 541]
Climate: Mostly Mediterranean
Land Area (Asia)*: 744 272 km² (0.2% of Asia) [*total 783 562 km²], **arable soil covers 26%**

Landscapes and climate

The westernmost part of Asia (Cape Baba is at 26°03'50"E), the Anatolian part of Türkiye is bordered by the Black Sea to the north, Georgia and Armenia to the northeast, Azerbaijan and the Islamic Republic of Iran to the east, Iraq and the Syrian Arab Republic to the southeast, with the Mediterranean Sea to the south and the Aegean in the west. The Asian and European parts of Türkiye are separated by the Turkish Straits that link the Aegean and Black seas (only 700 m wide in the Bosporus). Apart from a largely continuous narrow coastal plain, the Asian part of Türkiye is predominantly mountainous with high peaks, steep slopes, deep valleys and plateaus (the dormant volcano of Mount Ağrı (Ararat) reaches 5 137 m a.s.l.). Earthquakes are common. Elevations rise significantly towards the east where the average altitude is 2 200 m a.s.l. (both the Euphrates and Tigris rivers have their sources in eastern Türkiye). While the coast has a Mediterranean climate, most of Türkiye's interior experiences a dry continental climate with very hot summers and very cold winters, especially in the east (temperatures can range from >40 °C to <30 °C, respectively). Precipitation is more pronounced along the coasts, highest in the eastern Black Sea (>2 000 mm annually) dropping to around 500 mm in the Mediterranean). Heavy snow fall can be expected on the mountains.

Soil characteristics

Soil development largely reflects variations in topography and climate. Leptosols, Regosols and Cambisols predominate throughout the interior and reflect the active tectonic nature of the region. Many soils are calcareous reflecting lime-rich parent materials while higher vegetation levels, leaching and eluviation in more humid regions (mostly along the coasts) gives rise to calcaric Cambisols, Phaeozems and red clayey Luvisols. Fluvisols and Chromic Vertisols are mostly found along river valleys and around lakes in the western half of the country, often forming deltas at the coast. Pockets of Vertisols and Andosols in the east reflect the weathering of volcanic deposits.

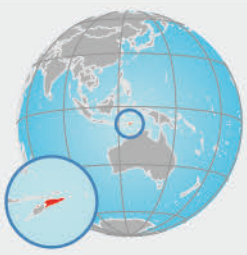
Soil related issues

As a result of the mountainous nature of the country (only 20% of the country lies below 500 m a.s.l.), fluvial soils along river valleys are used to cultivate rain-fed cereals and irrigated cash crops. Land degradation is a major concern, especially in agricultural areas where overgrazing and the excessive use of agro-chemicals are putting pressures on soil health. Around three-quarters of the land surface experiences soil erosion. Increased summer temperatures and changes in precipitation patterns as a result of climate change are predicted for much of the country. Türkiye is committed to a major reforestation programme.

Timor-Leste

The Democratic Republic of Timor-Leste





Region: Southeast Asia
Capital: Dili
Population: 1 318 445
Climate: Tropical savannah
Land Area: 15 007 km² (<0.1% of Asia), arable soil covers <1%

Landscapes and climate

The only Asian country entirely in the southern hemisphere, Timor-Leste occupies the eastern part of Timor Island in the southeastern part of the Malay Archipelago, with a land border to Indonesia to the west (the enclave of Ambeno lies on the northwestern coast of Timor). A narrow coastal plain rises inland to a rugged backbone of steep limestone hills and mountains that are cut by narrow valleys. Elevation increases towards the west (close to the western border, Mount Tatamailau reaches 2 986 m a.s.l.). A tropical savannah climate means that temperatures are relatively constant throughout the year (generally between 25-27°C along the coast, becoming cooler with altitude). Annual precipitation is relatively low (around 1 400 mm), with a distinct wet (December to March) and dry (June to September) season.

Soil characteristics

Timor-Leste displays a broad zonal distribution of soil type, predominantly reflecting topography and underlying geology. The steep terrain means that most soils are relatively thin and low in organic matter content. Along the central mountain chain, the intense weathering of old coral reefs gives rise to calcareous Regosols, Cambisols and Calcisols. On lower slopes, clay-rich Lixisols, Luvisols and dark Vertisols (that crack when dry), becoming more pronounced although the high rainfall can result in carbonates being leached out thus lowering the pH. Red Ferralsols and small pockets of Andosols reflect the weathering of metamorphic rocks and volcanic materials, respectively. The lowlands are characterised by deep Fluvisols, with clay-rich Stagnosols and Gleysols denoting waterlogging at some stage of the year. Saline Fluvisols under mangroves are more abundant along the south coast than the north.

Soil related issues

The steep mountainous terrain means that most soils are shallow with low water holding capacity and levels of organic matter. Widespread deforestation has resulted in extensive soil erosion, which is compounded by overgrazing, leading to marked reduction in soil fertility. Steeply uplifted bedrock means that landslides and rockfalls are common. On the gently sloping coastal plains, alluvial soils are used for annual crops while the impeded drainage supports rice paddies. The generally high pH means that many soils can be deficient in zinc and iron.

Turkmenistan





Region: Central Asia
Capital: Ashgabat
Population: 6 031 200
Climate: Cold arid
Land Area: 491 210 km² (1.1% of Asia), arable soil covers 4%

Landscapes and climate

Turkmenistan is bordered by Kazakhstan to the north, Uzbekistan to the northeast, Afghanistan to the southeast, the Islamic Republic of Iran to the south, and the Caspian Sea to the west. Turkmenistan is essentially a low-lying (average elevation is below 200 m a.s.l.), flat or gently undulating country, covered almost entirely by the Karakum Desert (Mount Aýrybaba in the extreme east reaches 3 138 m a.s.l. while the Kopet Dag Range on the Iranian border also reaches 3 000 m a.s.l.). The Caspian Sea coast is -28 m below sea level while Lake Sarygamysh on the Uzbekistan border drops to -100 m below sea level. Turkmenistan has a cold desert climate with long hot summers (averaging 35 °C, often hotter) and mild winters (although temperatures can drop to below -25 °C in the winter in the mountains on the border with Afghanistan). The arid climate means that the maximum annual precipitation is only around 300 mm (on the highlands of the Kopet Dag), which decreases markedly over the rest of the country.

Soil characteristics

Soils are typical of arid environments. Soil profile development is limited, being typically low in organic matter content and generally alkaline. Arenosols in the form of enormous dunes dominate the Karakum, one of the world's largest sand deserts, interspersed with poorly developed Leptosols and Regosols. Calcisols are the dominant soil type along the southern border of the country. Solonchaks in depressions reflect the evaporation of saline groundwater. Leptosols and Regosols are also widespread in the upland areas. Fluvisols are found along seasonal river channels and on alluvial fans. Anthrosols with higher organic matter levels are found in oasis along the foothills of the Kopet Dag Range and the Darya river.

Soil related issues

The excessive or improper use of fertiliser and pesticides, such as DDT for cotton production, has resulted in extensive soil pollution in cultivated lands, which also affects groundwater supplies through leaching or runoff into irrigation channels. Desertification, overgrazing and inefficient irrigation is driving land degradation, which results in increased wind erosion, salinisation and a loss of biodiversity. The diversion of water to irrigation is contributing to the continued drying and reduction of the Aral Sea.

The United Arab Emirates

The United Arab Emirates





Region: Western Asia
Capital: Abu Dhabi
Population: 9366829
Climate: Hot arid
Land Area: 83600km² (0.19% of Asia), arable soil covers <1%

Landscapes and climate

Located on the northeastern coast of the Arabian Peninsula, the United Arab Emirates borders Oman and the Arabian Gulf to the east, with Saudi Arabia to the south and west. The United Arab Emirates is a low-lying hot sandy desert with the Hajar Mountains in the east providing the main elevation (highest point is Jebel Jais at 1 892 m a.s.l.). Marshes and mangroves occur on the coast. The climate is arid with high temperatures all year, exceeding 40° C in the summer although conditions can be cooler at higher altitudes and in winter (January is around 18 °C). Precipitation is around 80 mm annually, but can be higher in the mountains. Precipitation is often torrential causing temporary flows in otherwise dry river channels (wadis). Sandstorms and dust storms are common. The United Arab Emirates has no permanent water bodies.

Soil characteristics

Soils are typical of arid environments. Almost all soils are low in organic matter. Sandy Arenosols, covering over 80% of the country, extend to the Rub' al Khali desert and have been shaped by the prevailing winds to become some of the world's largest dunes (e.g. Al-Liwā). Mobile dune systems can also lead to buried soils. Saline clay-rich Solonchaks are associated with shallow groundwater tables and are characteristically found in inland depressions and along the coast (locally known as sabkhas and typified by the Matti Salt Flat). They are often associated with Calcisols and Gypsisols that reflect the evaporation of rainfall, groundwater or old lagoon-like features, often with shallow hardpans. Stony Leptosols and Regosols are widespread in the mountains. Fluvisols, often gravelly in nature, are found along seasonal river channels (e.g. Wadi Wurayah) and on alluvial fans. Anthrosols with higher organic matter levels are found in oases. Arable soils account for less than 1% of total land area, mostly as permanent crops in oasis.

Soil related issues

Low precipitation, high temperatures and the prevalence of sandy soils, means that the organic matter content of most soils is naturally low (< 1 %). A lack of vegetation cover, coupled with strong winds, means that wind erosion is widespread. Significant urban expansion and land reclamation shows that soil sealing (e.g. such as the Palm Islands of Dubai) and Technosols are common in cities such as Abu Dhabi and Dubai. Furthermore, there are concerns on the impact of climate change, especially in relation to more extreme weather events (in terms of both temperature and precipitation), sea-level rise and increased aridity (leading to increased wind erosion and dust storms).

Viet Nam

The Socialist Republic of Viet Nam





Region: Southeast Asia
Capital: Ha Noi
Population: 96208984
Climate: Tropical / Subtropical
Land Area: 331235km² (0.74% of Asia), arable soil covers 23%

Landscapes and climate

Located on the east coast of the Indochina Peninsula, Viet Nam borders Cambodia and the Lao People's Democratic Republic to the west, China to the north and the South China Sea to the south and east. Viet Nam is a hilly country with mountains occupying almost three-quarters of the land area (highest point is Fan Si Pan at 3147 m a.s.l.). Two large deltas at the mouths of the Mekong and the Red Rivers provide large expanses of flat fertile land that are only a few metres above sea-level (rising in Tibet, the Mekong is over 4350km long). The climate is tropical and monsoonal, but with increasing seasonality and colder winters in the north. Mean annual temperatures range from 21-27 °C. Annual precipitation is generally between 1500 to 2000mm and falls mainly in a single rainy season. Precipitation increases with latitude and elevation.

Soil characteristics

Deeply weathered, highly leached, red and yellow Acrisols or Ferralsols cover more than half of the country, especially on sloping ground or hilly terrain. Ferralsols become more apparent in the south. Extensive alluvial Fluvisols, together with poorly drained Gleysols and organic Histosols (generally as swamp forests), are found along rivers valleys and the deltas of the Mekong and Red Rivers. Acid sulphate conditions are found in the deltas of the Mekong and Red Rivers. Arenosols and Regosols are found on coastal dunes and weathered bedrock while Plinthic Acrisols are found on old river terraces and old alluvial deposits. Saline soils are associated with mangroves along the coast.

Soil related issues

Ferralsols and Acrisols are low in available plant nutrients, as a result of the chemical depletion through weathering or leaching, and due to the fixation of phosphorous by iron and aluminium oxides. They are both susceptible to erosion by water. Acrisols can suffer from impeded drainage due to higher clay levels in the subsoils, but this also makes them ideal for rice cultivation. Acid sulphate soils are estimated to occupy around 2 million hectares, where the exposure of the mineral jarosite to oxygen causes it to turn to sulphuric acid that kills all plants. The high rainfall and heavy soils can result in a high water table and stagnating water. This requires extensive drainage but with the risk that jarosite will become exposed. Saline groundwater and sea water contamination of coastal aquifers is driving up secondary salinisation in some areas. Liming is used on Ferralsols and Acrisols to raise pH and improve agricultural production. Luvisols may suffer from insufficient root depth for perennial crops.

Uzbekistan

The Republic of Uzbekistan





Region: Central Asia
Capital: Tashkent
Population: 33469203
Climate: Arid continental
Land Area: 448978km² (1.01% of Asia), arable soil covers 10%

Landscapes and climate

A land-locked country, Uzbekistan is bordered by Kazakhstan to the north and west, Kyrgyzstan to the northeast, Tajikistan to the southeast, Afghanistan to the south, and Turkmenistan to the southwest. Uzbekistan is dominated by the Kyzylkum Desert, an arid plain (average elevation around 300m a.s.l.) with salt flats and a few hills. To the southeast, the mountainous western end of the Tian Shan range rise dramatically to over 4000m a.s.l. (Khazret Sultan rises to 4643m a.s.l. on the border with Tajikistan while Lake Sarygamysh on the Uzbekistan border is -100m below sea level). The broad Fergana Valley contains numerous oasis and irrigated cropland. The southern half of the Aral Sea lies in Uzbekistan. With an arid continental climate often reaching over 40°C in the summer and cooler winters (averaging around -5°C) in the winter), annual precipitation is only 200mm, highly seasonal, with much less falling on the desert regions and more on the high mountains.

Soil characteristics

Soils over more than 75% of the country are typical of arid environments with elevation providing some additional zonal development. Soil profile development is limited in many regions, being typically low in organic matter content. Arenosols, often in the form of dunes, dominate the centre of the country while Gypsisols and poorly developed calcareous Leptosols and Regosols occupy the west and the south. Towards the southeast, Calcisols become the main soil type while in the west, Cambisols with sodic features are the dominant soil group. Solonchaks are widespread, but more extensive around the Aral Sea. Leptosols and Regosols are also widespread in the upland areas. Higher rainfall and vegetation gives rise to Kastanozems on loess deposits on the mountain slopes. Fluvisols are found along seasonal river channels, on alluvial fans and in delta regions of the Aral Sea, where Gleysols reflect the shallow water table. Anthrosols with higher organic matter levels are found in oasis in the Fergana Valley.

Soil related issues

Land degradation, desertification and an increase in the number of droughts, are the main environmental challenges facing Uzbekistan, especially in areas with cultivated soils which have seen a reduction in area and yields. Salinisation has been noted in more that 50% of irrigated areas (the level can be much higher locally). The excessive or improper use of fertiliser and pesticides for cotton production has resulted in extensive soil pollution in cultivated lands, which also affects groundwater supplies through leaching or runoff into irrigation channels. The diversion of water to irrigation is contributing to the continued drying of the Aral Sea.

Yemen

The Republic of Yemen





Region: Western Asia
Capital: Sana'a
Population: 30000000
Climate: Arid and semi-arid
Land Area: 445500km² (1% of Asia), arable soil covers 8%

Landscapes and climate

Located on the southern coast of the Arabian Peninsula, Yemen borders Saudi Arabia to the north, Oman to the east with the Red Sea and the Gulf of Aden to the west and south. Beyond a narrow coastal plain, much of Yemen is hilly or mountainous (the highest point is Jabal An-Nabi Shu'ayb at 3760m a.s.l.). Temperatures are high at lower elevations all year round and can exceed 40°C in the summer, although conditions are cooler at higher altitudes. The climate is arid or semi-arid. Precipitation is around 130mm annually, but can be three or four times higher on the western and southern mountains. Levels in the east are much lower or even absent. Most rainfall is associated with southwesterly monsoons. Sandstorms and dust storms are common.

Soil characteristics

Soils are typical of arid environments, being low in organic matter and alkaline. Soil profile development is limited in many areas. Sandy Arenosols, as typified by the Rub' al Khali desert, cover the northern and eastern parts of the country. Calcisols and Gypsisols with high pH reflect the evaporation of old shallow lakes that existed several thousand years ago when the climate was significantly more humid. Many islands and the inland mountainous areas exhibit volcanic (basaltic) rocks that weather to clay-rich Andosols. Shallow stony Leptosols and Regosols are widespread in the upland areas. Fluvisols are found along seasonal river channels and on alluvial deposits. Anthrosols with moderate organic matter levels are found on terraces, which are common in the mountains to conserve water and to provide land for cultivation on steep slopes. Arable soils (predominantly on alluvial soils and terraces but also on volcanic deposits) account for about 7% of the total land area but only a small proportion is planted with permanent crops.

Soil related issues

Low rainfall, high temperatures, and prevalence of sandy and loamy soils, mean that the organic matter content of most soils is naturally low (< 1%). Arable land is found on alluvial soils in the intermountain plains and volcanic materials. Many terraces, where soils have been enriched by compost for hundreds of years, have fallen into disrepair due to socio-economic factors and vulnerable to collapse and erosion by water. A lack of vegetation cover, coupled with overgrazing and deforestation, means that water and wind erosion are widespread. Desertification (especially water scarcity) affects more than half the land surface of Yemen. There is considerable interest in the reintroduction of indigenous agricultural practices to combat land degradation. Reliable and current data on soil conditions in Yemen are lacking.

Solutions for heathy soils

Soil is the critical and dynamic regulatory centre of the majority of ecosystem processes. Soils, and the organisms that live in them, contribute to a range of ecosystem services that are essential to the sustainable functioning of natural and managed ecosystems. Certain management practices may help preserve soils and ensure the provision of the various ecosystem services that our lives depend on. A significant and increasing proportion of land on Earth is covered by croplands and rangelands. Conservation of soil in agricultural landscapes is thus intrinsically linked to land use and management systems that conserve and promote soil protection. In this section, we will explore different ways in which soil can be managed to protect and restore soils and sustain soil-mediated ecosystem functions and services.

How can shifting cultivation avert desertification?

Traditionally, a simple but effective farming system that took note of soil constraints, known as shifting cultivation, was practiced widely throughout many parts of southern and southeastern Asia. Under shifting cultivation, natural vegetation was cut at shoulder height to allow it to regenerate quickly. The cut branches were burned and the ash was added to the soil as a source of nutrients. In addition, a type of zero tillage was practiced as crops were planted in small holes, pits or furrows. A plot of land would be cropped for about three or four years at the most and allowed to revert to a 'natural' state before the soil showed signs of degeneration. The soil would remain fallow for about twenty years before it was considered ready for another cycle of cropping.

Shifting cultivation is commonly perceived as a primitive agricultural practice, economically unviable and a cause of tropical deforestation and environmental degradation. Growing scientific evidence to the contrary shows that it is a sustainable agricultural practice that maximises soil fertility, minimises erosion and weeding and reduces the risk of crop failure. The soil was seen as a precious resource that should not be over-exploited. Land ownership issues today mean that the practice is limited and yields are unable to meet the needs of an exploding population.

Conservation agriculture

In conventional intensive agriculture, continuous ploughing and harrowing, the removal or burning of crop residues, mono-cropping and the excessive use of agro-chemicals can lead to a loss of soil fertility and decreasing yields, soil erosion, increased vulnerability to drought and floods and a loss of soil biodiversity. In response, low-cost and low-tech conservation tillage systems have been developed to protect the soil and reduce erosion. The goal of conservation agriculture is to maintain and improve crop yields and resilience against drought and other hazards, while at the same time protecting and stimulating essential soil functions. [130]

The two essential features of conservation agriculture are no- or low-tillage and the maintenance of a cover on the soil surface from live or dead plant remains. Crops are seeded or planted through this cover. The soil cover inhibits the germination of many weeds thus maximising nutrient and water availability to the crop. Conservation agriculture also involves inter-cropping and crop rotation.

Experience has shown that conservation agriculture systems achieve yield levels as high as comparable conventional agricultural systems but with less fluctuations due to natural disasters such as drought and storms. Therefore, conservation agriculture contributes to local and regional food security, reduces health risks (well nourished people are better able to recover from illness and diseases such as malaria) and reduces the burden on the State (e.g. less road and waterway maintenance, less emergency assistance).

Conservation agriculture (CA) and the improved management of soil also contribute to wider environmental benefits such as less flooding, less erosion (and reduced siltation), more constant flow in the rivers, better recharge of groundwater resources, increased carbon sequestration, less carbon release (less fuel used) and increased biodiversity through diversification.

For more information and documentation on CA in Asia, please visit the FAO Conservation Agriculture Portal [130].

Preventing soil compaction

The risk of soil compaction can be lessened by:

- avoiding heavy pressures on land, especially when the soil is wet;
- reducing stocking densities of animals;
- use of low-pressure tyres or higher number of axles on farm machinery;
- use of minimum-tillage technology;
- addition of organic matter.

Soil compaction can be remediated by tillage or ripping the soil.

Subsoil compaction can only be countered by deep tillage which breaks through plough pans. However, the effects of deep tillage are usually short lived unless management strategies are adopted to avoid further compaction.



A next-generation subsoil crusher capable of breaking the hard pan layer formed by compaction. This will improve drainage and expand root zone. (SFM)

Contaminated sites: an alternative view!

While the remediation of polluted sites should be the priority, some contaminated land may support habitats and species of high conservation value. Many sites may also have cultural and archaeological importance and may need to be protected for these purposes.

However, much care must be taken to minimise any eventual impact on human health and the environment.

Preventing salinisation

The primary methods of controlling soil salinity are:

- to use excess water to flush the salts from the soil. In most areas where salinisation is a problem, this must inevitably be done with high quality or scarce irrigation water;
- to limit the use of saline or brackish water in irrigation;
- to minimise evaporation, do not over-water and do not irrigate in full sun.

Preventing soil sealing

Soil sealing must be addressed nationally and at a local level by managing urban development and through the inclusion of mitigation measures [132]. Maintaining key functions such as the natural drainage and filtering capacity of soils to slow the passage of water to rivers, thereby reducing pollution and flooding risk, should be a priority for urban planners. In particular, specific attention should be placed on:

- raising awareness of politicians, decision-makers, planners and residents about the value of soil in general and especially in an urban context;
- the development of planning guidelines where a preference is given for urban redevelopment (this is also referred to as brownfield development) rather than consumption of agricultural or environmentally productive soils;
- using permeable materials for walkways and parking zones (e.g. gravel, concrete or plastic grids, block surfaces with drainage holes) instead of creating an impermeable surface made out of cement or asphalt.

Organic farming

Organic farming is a form of agriculture based on more natural production techniques, such as crop rotation, reduced tillage, biological pest control, and manure or compost application. It excludes, or strictly limits, the use of mineral fertilisers and pesticides.

Organic farming relies heavily on the natural decomposition of organic matter by soil organisms, especially bacteria and fungi, to replace nutrients taken from the soil by previous crops.

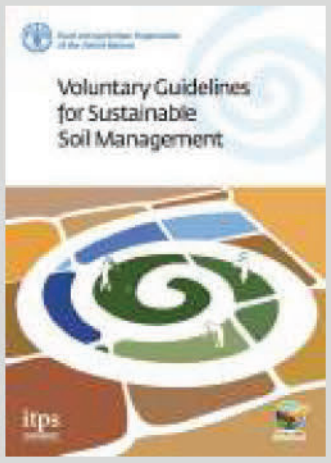
This biological process has been referred to as 'feeding the soil to feed the plant'.

Voluntary Guidelines for Sustainable Soil Management

Through an inclusive process within the framework of the Global Soil Partnership (GSP), FAO has developed and published a set of Voluntary Guidelines for Sustainable Soil Management (VGSSM) [131]. These guidelines aim to provide general technical and policy recommendations on sustainable soil management for a range of stakeholders.

Within the VGSSM, 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. Sustainable soil management is associated with the following:

1. Minimal rates of soil erosion by water and wind;
2. The soil structure is not degraded (e.g. soil compaction) and provides a stable physical context for movement of air, water, and heat, as well as root growth;
3. Sufficient surface cover (e.g. from growing plants, plant residues, etc.) is present to protect the soil;
4. The store of soil organic matter is stable or increasing and ideally close to the optimal level for the local environment;
5. Availability and flows of nutrients are appropriate to maintain or improve soil fertility and productivity, and to reduce their losses to the environment;
6. Soil salinisation, sodification and alkalinisation are minimal;
7. Water (e.g. from precipitation and supplementary water sources such as irrigation) is efficiently infiltrated and stored to meet the requirements of plants and ensure the drainage of any excess;
8. Contaminants are below toxic levels, i.e. those which would cause harm to plants, animals, humans and the environment;
9. Soil biodiversity provides a full range of biological functions;
10. The soil management systems for producing food, feed, fuel, timber, and fibre rely on optimised and safe use of inputs;
11. Soil sealing is minimised through responsible land use planning.



The Voluntary Guidelines for Sustainable Soil Management provide technical and policy recommendations on how sustainable soil management can be achieved. (FAO) [131]



When managed sustainably, soils play an important role in climate change adaptation and mitigation. (FAO)

Preventing soil erosion

Preventing soil erosion requires a combination of political, economic and technical considerations.

Politicians and decision-makers need to address how soil is used on a national level and to identify areas that are at risk or vulnerable to erosion. Schemes could be established to offer incentives to farmers to manage their soil in a sustainable manner and implement practical measures to control soil erosion.

Technically, such measures could include:

- the use of contour ploughing (i.e. cultivating the land so that the plough furrows run at right angles to the slope) to restrict the initiation of rills and gullies;
- planting of hedges or tree belts that act as shelter belts and to reduce ground wind speeds;
- the use of terraces on sloping land;
- minimising the removal of natural vegetation, especially on slopes or even on flat terrain if wind erosion is an issue;
- strip cultivation - leaving unploughed vegetated strips between tilled land or allowing buffer zones of indigenous plants to grow along river banks;
- ensuring adequate plant cover in rainy, dry or windy periods, especially in the period immediately after ploughing;
- making sure that organic matter levels are maintained. Organic matter binds soil particles together and plays an important part in preventing erosion;
- avoiding overgrazing and the over-cultivation of crop lands.



Wind erosion is a major degradational process in many parts of Asia. In the Tarim Desert, nets are being assembled across dunes as physical barriers that limit the movement of sand grains. (MK)

Soil and climate: a way forward?

A more sustainable approach to land management could see soils playing a significant role in reducing the impact of climate change by taking carbon out of the atmosphere and storing it in soil. A priority should be given to protect soils with the highest carbon content – namely peat soils and carbon-rich permanent pastures and forests.

Improvements in soil-management practices can have considerable impact on carbon stocks. Changes to agriculture techniques can minimise carbon losses. Of particular relevance are the management of crop residues, which ensure that soils are protected against erosion through increased vegetation cover, together with less-intrusive soil tillage techniques. The widespread adoption of such practices could avoid the release of carbon from soils, but would help sequester millions of tonnes of carbon per year.

- On cropland, soil carbon stocks can be increased by return of biomass to the soil, tillage and residue management, water management and agro-forestry.
- On grassland, soil carbon stocks are affected by grazing intensity, grassland productivity and species management.
- On forest lands, soil carbon stocks can be increased by species selection, stand management (e.g. avoiding clear cuts, low-impact logging) appropriate site preparation, undergrowth control, fire management, protection against disturbances and the prevention of harvest residue removal.
- On cultivated peat soils, the loss of soil carbon can be reduced by maintaining higher groundwater tables or reduction of drainage.
- On unmanaged peatlands, soil carbon stocks are affected by maintaining water table and reducing burning or grazing pressures.

Land sparing versus land sharing

Conserving biodiversity within networks of reserves from which intensive human activity is excluded is part of a strategy referred to as 'land sparing'. Consequently, agricultural land is presumably farmed more intensively for a higher yield, to reduce the area needed for production. [133]

'Land sharing' means adopting wildlife-friendly practices to conserve biodiversity within a matrix of land uses, such as different levels of agricultural intensification, forestry, grazing and human settlements. Given that not all land can be taken out of production, systematic conservation planning focuses on 'sparing' areas that contain the greatest concentration and broadest representation possible of species, and which can be maintained as conservation reserves over the long-term.

Conservation planners often use vascular plants, mammals or birds as indicators of terrestrial biodiversity, as these are the taxa for which most data are available. Despite the fact that soil is likely to harbour the greatest concentration of terrestrial biodiversity, soil microorganisms and fauna have been almost completely ignored in conservation planning. Conservation research is systematically biased toward vertebrates, even though invertebrates represent nearly 80% of known species.

Agroforestry, afforestation and reforestation

Agroforestry is a land use practice that combines trees with crops and/or animals, arranged in space or following a temporal sequence, and benefits from ecological interactions between trees and agricultural components. Agroforestry has been increasingly recognised and practiced as a land management option that can simultaneously contribute to income, food security and the conservation of biodiversity and ecosystem services. Furthermore, it is also considered a climate change mitigation and adaptation tool for agriculture.

Afforestation and reforestation both refer to establishment of trees on land without trees. Reforestation refers to establishment of forest on land that had recent tree cover, whereas afforestation refers to land that has been without forest for much longer. These practices are used by landholders who want to plant and maintain a forest on their land to, for example, minimise erosion, reduce salinity or improve water quality.

Both agroforestry and afforestation/reforestation can be considered as effective measures to counter deforestation and the consequent loss of aboveground biodiversity that negatively impacts soil life.



Planting trees and shrubs can give farmers healthier soils and higher yields while supporting biodiversity. (ICRAF)

Biochar

Biochar is the solid matter that remains after the pyrolisis (heating in low or no oxygen environment) of organic materials, such as agricultural wastes and animal manures, wastewater sludge, paper mill wastes, as well as trees or other plants. Wood charcoal, as used on barbecues, is produced through a similar process. Many people believe that biochar has beneficial value as a soil amendment and can help mitigate climate change. [134]

The idea behind biochar as a soil amendment comes from Terra Preta; a type of carbon rich soil found in the Amazon Basin and attributed to early pre-Columbian activities, which is highly fertile compared to the surrounding soils. Furthermore, evidence suggests that the carbon within Terra Preta soils has remained there for a long time, from centuries to millennia. It is thought that Terra Preta soils were established over extended periods of time through the addition of charcoal and other waste materials. The idea is that adding biochar to soils, as well as helping mitigate climate change, may also lead to other Terra Preta-like properties, such as increased fertility.

Bioremediation

Without doubt, the best way of managing soil pollution is to prevent it from happening and to regulate the management of waste and the use of pesticides. Over the past decades, growing awareness of environmental impacts has led to regulations on the use of old, often dangerous, substances and the development of new pesticides based on thorough testing of their side-effects on soil life (especially earthworms, enchytraeids and collembolans.

In the unfortunate cases where soil pollution occurs, soil biodiversity can be of great help through the cleaning services it provides in the form of bioremediation agents. Notably of organic compounds can be degraded through the use of specific species of soil bacteria and fungi. These species can be inoculated into the polluted areas or, if they are already present in the soil, their activity can be stimulated. For example, the capacity of the wood decomposer fungus *Pleurotus ostreatus* (also commercially known as the oyster mushroom) to remove polycyclic aromatic hydrocarbons (PAHs) from a highly contaminated soil was tested. After a 12-week treatment period, a reduction in PAHs of 50% up to about 90% was observed, demonstrating the PAH-removal potential of the oyster mushroom.

When bioremediation is carried out by plants (phytoremediation), specific groups of soil bacteria and fungi can help to increase speed and/or efficiency. For example, the bacterium *Ralstonia metallidurans* carries out bioremediation of heavy metals in soil. The mechanisms by which soil bacteria and fungi help plants through bioremediation are dependent on the species of bacteria and fungi and their metabolic potential. There are two pathways for phytoremediation; the first considers less direct action by soil organisms, whereas the second is more based on soil biota.

The first mechanism, known as 'phytoextraction', in which plants play the main role, involves the use of metal-accumulating species to remove metals from soil by concentrating them in the harvestable parts of the plant. However, in order to be accumulated by plants, heavy metals must be made available. Soil organisms act at this stage by increasing the solubility of heavy metals and, thus, their uptake by plants. Once plants have absorbed the pollutants, they can be harvested. The plant material may need further treatment to concentrate and possibly recycle the pollutants, otherwise it can be incinerated.

The second mechanism is known as 'phytostabilisation'. Phytostabilisation is the most successful and well acknowledged process of phytoremediation. In this case, plants provide a suitable zone around their roots where the pollutants can be stabilised and immobilised by soil organisms. Consequently, in this process the contribution of soil biota is more evident. In particular, heavy metals are rendered harmless by soil microorganisms through different mechanisms, such as the production of specific substances (e.g. glomalin produced by arbuscular mycorrhizal fungi) that immobilise metals, the direct absorption by microbial cells and the direct reduction of heavy metal.

The process that facilitates identification of species suitable for bioremediation often requires a long time and several experiments to test the efficiency and applicability of the selected organisms at large scale. Nonetheless, current scientific knowledge shows that the use of soil organisms for bioremediation is feasible and recommended.

Fire management

Fire can threaten soils both directly due to heat and combustion or indirectly through post-fire soil erosion and degradation.

Over time, some plants have evolved to adapt to fire. One of the best known adaptations is pyriscence, which occurs when a plant releases its seed in response to fire, in an ecosystem with relatively short fire return intervals and where post-fire conditions offer improved seed germination and seedling survival. In addition to the physical opening of the seed pod, the heat from the fire can also stimulate or inhibit the germination of seeds in the soil. For example, thermal cracking of the seed coat of jelly bean tree seeds has been observed after being exposed to 200°C for one minute and eight minutes. The resulting fracture pattern after one minute is thought to be indicative of having overcome seed coat-enforced dormancy. The deeper fracturing after eight minutes heating exposes internal parts of the seed, thereby killing it. Research has also revealed that the smoke from a fire can promote seed germination, without any thermal effect. Smoke has been observed to produce a chemical scarification on the seed surface and an increase in the permeability of the internal cuticle, both of which significantly increase the rate of germination.

Conclusions







The soils of Asia are diverse. They range from bare and dry sandy dunes the Arabian Peninsula to fertile, life-sustaining soils on the Mekong Delta. The economies of many Asian countries are highly dependent on their soil base, while rural populations often depend on the fertility of the soil for their survival. While soil degradation is a major concern across Asia, especially in relation to human health, food security, rural poverty and loss of biodiversity, careful management and sustainable use of soils will help combat these issues. In fact, in many parts of Asia, land restoration project are making significant progress.

Clockwise from top left: Rehabilitation of collapsed terraces in the Utomah District of Yemen (MHAM); Soil quality monitoring in a palm plantation in Abu Dhabi - up-to-date data on the condition of soils are critical to ensure that land management practices are sustainable from a soil perspective (BA); A striking panorama showing the typical landscape of the mountainous region of Viet Nam, where rice is cultivated on the terraces of high and steep mountain slopes, together with other crops such as maize, cassava, tea and fruits trees (orange, mango). The numerous scars highlight that the soils are prone to erosion due to a lack of soil conservation techniques. (VMQ)

Soil is defined as the top layer of the Earth's crust. It is a natural substance composed of weathered rock particles (minerals), organic matter, water and air. A typical sample of mineral soil comprises 45% minerals, 25% water, 25% air and 5% organic matter – however, these proportions can vary.

Soil is a habitat and gene pool, it serves as a platform for human activities, landscape and heritage, and acts as a provider of raw materials. A healthy, fertile soil is at the heart of food security. Its functions are worthy of protection because of their socio-economic as well as environmental importance.

Soil-forming processes tend to be slow and occur over long periods — typical rates of soil formation under permanent grasslands in temperate climates are in the order of only 1-2 cm per 100 years.

Soil that is lost due to degradation processes (e.g. erosion, pollution) needs hundreds or thousands of years to recover naturally. Compared to the lifespan of human beings, soil loss is not recoverable which means that soil must be regarded as a non-renewable resource.

The soil resources of Asia are diverse. However, many soils are inherently fragile, being low in nutrients and organic matter. A lack of water is a major constraint to their use in agriculture.

Despite technological advances, soil will always be necessary for humans to grow most of their food, fodder, fuel and fibre. More than 95% of the food consumed in Asia comes from the land as does fuel wood for cooking and heating.

FAO has estimated that some countries in Asia will need to increase their food production by up to 77% to meet their food requirements as the population of Asia is projected to reach 2.4 billion by 2050. On the one hand, this represents a profound challenge for the Asian agricultural community. However, it is also a great opportunity for the development of sustainable soil management practices to meet the increasing food demand. Through a sound understanding of the natural soil processes and the interactions of the soil with water, air, biota and humans, it should be possible to optimise the productivity of the soil, while ensuring ecological and environmental conservation.

The unsustainable use and management of land are leading to increased soil degradation and the loss of a key resource that is fundamental to life on the continent of Asia. Notable issues are a loss of nutrients and soil organic matter, contamination, erosion, landslides, salinisation, biodiversity decline, compaction and sealing through urbanisation and infrastructure development. These are being exacerbated by climate change and lead to further degradation.

The degradation of land resources has a negative impact on rural and urban livelihoods. For instance, over production and an absence of nutrient management has led to exhausted or infertile soils. This state, coupled with increasing aridity gives rise to desertification which is known to have increased the level of poverty in rural areas. In turn this leads to population migration in to cities and increasing rates of poverty.

Planners, decision-makers and users of the land need to be more aware that agricultural production depends on the productivity of soils and the sustenance of production depends on proper utilisation of the soil resources. This is because land is not an infinite resource. Indeed, competition for the same piece of land for different uses (e.g. roads, buildings, forests and agriculture) has, for the past years, overtaxed the resilience of natural processes, thereby causing severe land degradation and a decline in soil productivity. Therefore, strategies for intensification of agricultural production should aim to achieve high yields per unit area while at the same time improving soil health and conserving water resources and environmental vitality. This can be achieved when land users are informed of the potential and management requirements of a given area of land identified for a specific purpose.

Improved knowledge base

Up-to date, relevant knowledge on the state of soils is critical to facilitate effective policies and decision-making that ensure their protection, restoration and sustainable use. This knowledge is obtained traditionally through soil surveys and related land resource inventories. However, increasing data flows from satellites, precision agriculture and even citizen science initiatives are helping us to understand better the condition of our soils. In combination with socio-economic data, our understanding of soil properties can be analysed and interpreted to evaluation the suitability of different tracts of land for various uses.

Such information is used as a baseline for monitoring changes in the state of soils. In this context, the development of comprehensive national soil monitoring programmes is essential. At the time of writing, there is generally a lack of timely, consistent and comparable data on soil resources and trends across Asia. National soil survey programmes and monitoring systems are nonexistent or have been suspended in many countries. The data that exist are sometimes decades old and often have limited applicability to contemporary needs (e.g. soil biodiversity, diffuse pollution). There is little coherence between countries, which makes the quantitative evaluation of changes in soil state and functions impossible. The lack of data also hampers efforts to develop indicators to measure the situation, especially in relation to the main threats to soil that have been described in this atlas.

FAO's Global Soil Laboratory Network (GLOSOLAN) was established in 2017 to build and strengthen the capacity of laboratories in soil analysis and to respond to the need for harmonizing soil analytical data to form the basis for focused collection of soil data [135]. In turn, GLOSOLAN feeds into other technical initiatives [136], such as the International Network on Soil Biodiversity (NETSOB), the International Network on Soil Pollution (INSOP) and the International Network on Fertilizer Analysis (INFA), to provide better analysis and improve quality standards.









Along with water, soil is one of the most important resources for supporting life on the planet yet it is greatly undervalued. Significant areas of soil are being lost to non-agricultural uses or to degradation as a result of soil erosion by water or wind, salinisation, waterlogging, depletion of plant nutrients, deterioration of soil structure, desertification and pollution. Since humanity's existence depends on population migration, civil unrest, urban flooding and the silting up of dams and ports. New data collection and monitoring, together with education and awareness raising of the importance and value of soil are critical considerations.

Clockwise from upper left: Cryosols in East Khangai, Mongolia exposed through freeze/thaw cycles – warming of high latitudes and elevations are causing permafrosts to thaw, which in turn releases methane, a powerful greenhouse gas (OB); rice cultivation in paddy fields is synonymous with large parts of Southern and Eastern Asia (LDDT); even in the harshest conditions, soils can sustain life – this solitary tree in not far from Abu Dhabi survives by sending long roots to deep groundwater while the lower branches provides grazing opportunities for camels (PZ); forest soils contain larger carbon stocks than the trees that grow in them – they are teeming with life, support aboveground biodiversity and are essential part of a sustainable circular bioeconomy (EM).

Policy approaches

In recent years, there has been an increasing appreciation of the value of soil to society and a realisation that soil needs at least the same level of attention and protection as air and water. In fact, many social crises in Asia are triggered largely by inadequate soil and water management policies and practices.

In 1982, FAO adopted a World Soil Charter detailing some basic principles and guidelines for sustainable soil management and soil protection to be followed by governments, international organisations and users of the land. In light of new learning gained over the past 30 years, especially with respect to issues such as soil pollution, climate change adaptation and mitigation, and urban sprawl, an updated Charter was published in 2015 to promote and institutionalise sustainable soil management at all levels [137].

However, in many parts of Asia, it is clear that the principles of the Charter are not being applied fully. The Asia and the Pacific SDG Progress Report 2023 shows that progress towards all 17 SDGs in the Asia-Pacific region has been slow, with only 14.4% of the progress needed to meet the 17 Sustainable Development Goals being achieved at the midway point [138]. Consequently, the region will miss the 2030 target by several decades. Politicians and policymakers should take note of the importance of soil in meeting many SDG targets and reflect how it is being utilised across their territories.

Long term and large-scale measures are needed in order to build greater resilience to soil degradation and reduce human vulnerability to disaster events. Key to this goal is the enhancement of capability and capacity for soil survey and monitoring, with a particular focus on assessments of soil productivity, soil carbon and soil biodiversity in light of soil, and water, conservation.

A common approach to the soils of Asia?

At present, there is no common pan-Asian framework to ensure the sustainable use of soil and preserve its essential functions. This hinders a collective approach to a vital common good. To ensure healthy soils across the Asian continent, national authorities could initiate:

- an assessment of the state of soils and associated threats to identify areas at risk of diverse degradational processes such as erosion, decline in nutrients and organic matter, salinisation, acidification, compaction or landslides. This could be combined with an inventory of contaminated sites;
- preventative measures to assess the impacts of current policies and land use practices on soil health in areas such as agriculture, waste management, urban development or mining, and to ensure that the sustainable use of soil and its functions becomes the new norm;
- actions to deal with the main issues of local concern, along with remediation strategies for degraded and contaminated soils;
- the collection of harmonised soil information;
- the maintenance and development of soil education components at all levels – without a trained scientific base, the collection of relevant soil information will be impossible.

At the heart of such a framework should be support to facilitate the networking of soil scientists and land use experts from all parts of Asia. Such a move would help improve information exchange and develop a more comprehensive knowledge base to underpin sustainable soil use policy development and practices. Awareness raising must be coupled with a supportive policy environment and technical solutions that lead to the effective protection and management of soils.

Last word



As shown by this scene from Bangladesh, sustainable soil management is a local issue. It requires a personal commitment to ensure that soils are used within their limits and that degraded soils can be restored to a healthy state. (FAO/BSJ)

Soils are amazing! There is a growing realisation that knowledge of soil, a fragile but vital resource that is not easily renewed on a human scale, is vitally important for our understanding of the environment.

In Asia, the lack of easily accessible reference books means that the discovery of soil, and the role that it plays in our lives, is limited to universities or narrow scientific domains. This atlas aims to provide a simple introduction that will help people from all walks of life to discover and use soils sustainably.

A more balanced and considered use of land, through the adoption of sustainable soil management practices, will ensure that the soils of Asia will become healthier and more able to provide the myriad of ecosystem services on which we all depend.



Soil conservation practices on tealands in Sri Lanka sustains soil health! (UV)

Ancillary information

Glossary

This page explains some of the more technical words and phrases used in the atlas. Readers can avail themselves of additional explanations from the many comprehensive glossaries that can be found on the Internet. For example:

Technical definitions of soil terms from the ASSS:

https://www.soils.org/publications/soils-glossary

Soil terms explained for children/general public:

http://www.soil-net.com

Definitions

acid: a substance which reacts with a **base**, denoted by **pH** < 7. Substances having the property of an acid are said to be acidic.

active layer: part of ground that is subject to annual **thawing** and **freezing** in areas underlain by **permafrost**.

adsorption: process by which atoms, molecules or ions are retained on the surfaces of solids by chemical or physical binding.

aeolian: relating to wind, sediments comprising wind-blown material (usually sands).

aggregate: soil particles bound together by water, organic films or biological activity. Classified by size, shape (e.g. platy) and grade (e.g. strong).

agriculture: the production of animals and plants for food, fibre and fuel, also called farming.

agriculture, conservation: farming system that aims to minimise loss of soil and water and increase **organic matter** levels, involves **zero- or minimal tillage** while leaving **crop** residues on the surface to protect the soil.

agriculture, subsistence: farming system where the focus is on producing enough food to maintain a specific group of people. Shifting cultivation and nomadic pastures are the main examples.

alkalines: any of various bases, the hydroxides of the alkali metals and of ammonium, that neutralise acids to form salts.

alluvium: deposit made by a river or running water, often very productive agricultural soil.

anaerobic: conditions where very little oxygen is present (e.g. the waterlogged soil in a bog).

anion: particle with a negative charge. See also **ion, cation**.

anthropogenic: generated by humans.

arable land: land that is cultivated by **ploughing**.

base: a substance that can accept hydrogen ions, opposite to acid.

biofuel: liquid fuels produced from **biomass** (e.g. maize).

biomass: the total amount of living plants above and below ground in an area at a given time.

biome: areas of the Earth's surface with distinct climate-flora/fauna relationships (**e.g. tropical rainforest**).

bog: wetland without any significant inflows or outflows.

buffering capacity: ability of the soil to reduce high alkalinity or acidity levels (e.g. calcareous soils can neutralise acids).

bulk density: dry mass of soil per unit volume (kg m^{-3}).

carbon: non-metallic chemical element with symbol C and atomic number 6, essential building block of all living matter. Occurs in variety of forms (e.g. coal, diamond). Constituent of fossil fuel and **carbon dioxide**.

carbon cycle: transformation of carbon dioxide to organic forms by photosynthesis, recycled through the biosphere (with partial incorporation into sediments) and ultimately returned to its original state through respiration or combustion.

carbon dioxide: naturally occurring chemical compound composed of two oxygen atoms bonded to a single carbon atom (CO_2). A gas at standard conditions. In photosynthesis, plants absorb carbon dioxide to produce carbohydrate energy. Also produced by combustion of hydrocarbons (e.g. petrol), the fermentation of liquids and the breathing of mammals. A **greenhouse gas**.

carbon sink: a medium that absorbs or takes up released carbon from another part of the **carbon** cycle, nominally the atmosphere, terrestrial biosphere (including soil), oceans and geological sediments (including fossil fuels).

carbon sequestration: the fixation of atmospheric carbon dioxide in a carbon sink through biological or physical processes, for example, as organic carbon in soils.

cation: particle with positive charge.

cation exchange: interchange between a cation in solution and another cation in the boundary layer between the solution and the surface of negatively charged material (e.g. clay or organic matter). Main process behind uptake of soil nutrients by plants.

cation exchange capacity: the ability of soil to hold **nutrients** for plant use, also referred to as CEC.

clay: soil particle smaller than 0.002 mm or 2 µm.

clay minerals: clay-sized silicates having a large interlayer space that can hold significant amounts of water and other substances (e.g. montmorillonite, smectite, kaolinite).

climate: commonly defined as the weather averaged over a long period, classically 30 years.

coating: thin layer of a substance completely or partly covering a surface; soil coatings can comprise clay, calcite, gypsum, iron, organic material, salt, etc.

colluvium: unconsolidated, unsorted material associated with transportation and/or deposition by mass movement and local, unconcentrated runoff on slopes and/or at the base of slopes.

coniferous: trees, such as spruces, hemlocks, pines and firs. The leaves of these trees are needle-like and most stay green all year round (evergreen). The larch is a coniferous tree which loses its leaves in autumn. All conifers are softwoods and are able to thrive on acidic soils.

contaminant: an unwanted constituent in a substance, usually degrades the receiving material. Can cause damage or harm (e.g. pesticide in water) but not always (e.g. water in wine). See **pollution**.

crop: plants cultivated for food, fibre or fuel. Often undertaken on a large scale. Major crops include maize, wheat, rice, cassava, potatoes and cotton.

cuirasses: indurated horizons rich in iron and or aluminium compounds (oxides, hydroxides). Often referred to as ferruginous or ferralitic crusts.

deforestation: the removal of trees from forested land.

electrical conductivity: measure of how well a soil conducts an electrical charge, determines salinity.

eluviation: the movement of dissolved or suspended material within soil, generally downwards.

emissions: releases of gases to the atmosphere, can be natural or man-made (e.g. the release of carbon dioxide during fuel combustion or burning of **biomass**).

erosion: the wearing away of land or soil through one or more processes. Wind and water are the main processes affecting soil. Can be triggered by poor land management such as overgrazing or deforestation.

fallow: practice of leaving land either uncropped or with regenerative vegetation during at least one period when a crop would normally be grown, with a view to restoring plant nutrients.

fen: flat and swampy land, usually at low altitude.

fertilisation: application of **fertiliser** in order to improve specific soil properties and increase soil fertility.

fertiliser: any material which is added to the soil to supply plant nutrients. Organic fertilisers are derived on the remains of plants or animal excretion (e.g. decomposed crop residues, manure) while inorganic fertilisers are either mined or chemically synthesised in laboratories. Fertilisers typically provide a range of soil **macronutrients** and **micronutrients**. Main components are nitrogen (N), phosphorus (P) and potassium (K), in varying proportions.

field capacity: soil moisture state after heavy rain when all downward movement of water has ceased.

fluvial: relating to a river or rivers.

freezing: change of phase from water to ice. Occurs at 0°C.

forest: an area with a high density of trees (woodland).

function: a service, role or task that meets specific objectives.

geology: scientific field concerning the study of rocks, also used to denote solid material from which most soil is formed, characterised by the horizon symbol 'R'.

geomorphology: science which studies landforms.

glaciers: large masses of ice that form by the compaction and recrystallisation of snow under freezing conditions; move downslope under their own weight.

grazing: the regular consumption of part of one organism by another organism without killing it (e.g. cattle feeding on grasslands).

gully: channel resulting from the concentrated but intermittent flow of water during and immediately following heavy rain.

greenhouse gas: a gas in the atmosphere which prevents heat (longwave infrared radiation) from being radiated into space. A driver of global climate change.

groundwater: water below the surface of the ground. See also **water table**.

habitat: the native environment in which a given animal or plant naturally lives or grows.

harvest: the process of gathering mature crops which marks the end of the growing cycle for the harvested crop. The removal of **organic matter** through harvesting and subsequent transfer to market is one of the main causes of **nutrient losses** in soil. Heavy loads during harvest cause **soil compaction**. The harvesting of cereal crops is referred to as reaping.

hectare: metric unit of land area defined as 10 000 m^2 (i.e. 100 m by 100 m). Abbreviated to ha.

horizon: layer of soil or soil material approximately parallel to the surface and differing from adjacent genetically related layers in physical, chemical and biological properties or characteristics such as colour, structure, texture, acidity, etc.

humification: process whereby the carbon of organic residues is transformed and converted to **humic** substances through biochemical processes.

humus: organic compounds in soil, exclusive of undecayed plant and animal tissues, their partial decomposition products, and the soil biomass; humus possesses an amorphous structure, low specific weight and high surface area. Humus is important for soil fertility and helps to bind soil particles and aggregates.

hydrogen: chemical element with symbol H and atomic number 1. A colourless, odourless, tasteless, non-toxic, highly combustible gas with the formula H_2 at standard conditions, hydrogen is the most abundant chemical substance in the Universe. Present in the water molecule and in most organic compounds. Hydrogen plays a particularly important role in acid-base chemistry (see cation exchange).

hydraulic conductivity: a quantitative measure of how easily water flows through soil (see **infiltration** and **permeability**).

hydromorphic soils: formed under conditions of poor drainage in marshes, swamps, seepage areas or flats.

ice: water in the solid state.

illuviation: the accumulation in one layer of soil of materials that have been leached out of another layer.

infiltration: movement of water from the surface into the soil.

ion: electrically charged atom or group of atoms.

jarosite: ochre-yellow or brown hydrous iron sulphate mineral ($KFe_3(SO_4)2(OH)_6$).

jungle: Sanskrit word to describe an area of dense or impenetrable vegetation, nowadays associated with the tropical rainforest biome.

karst: topography with sinkholes, caves and underground drainage that is formed by the dissolution of limestone or gypsum.

landslide: the gravitational movement of a mass of rock, debris or soil down a slope. Landslides occur when the condition of a slope changes from being stable to being unstable.

leaching: process by which soluble materials (including **nutrients** and **salts**) in the soil are washed down the soil profile by water.

loess: predominantly silt-sized sediment transported and deposited by wind.

mangrove: family of plants (Rhizophoraceae) that grow in saline coastal **sediments** in the **tropics** and subtropics, also applied to the habitat irrespective of species (e.g. mangrove **swamp**).

marsh: transition zone between water and land, usually covered by grass.

mica: silicate (rich in silica and oxygen) crystalline mineral formed in igneous rocks, constituent of granite.

mineral: an inorganic component derived from rocks.

mineral soil: soil containing less than 20% organic carbon.

monoculture: **agricultural** system that grows a single **crop** over a wide area, often over many years. Highly mechanised, produces large **harvests** and is characterised by large fields. Monocultures are susceptible to spread of diseases. Off-site processing means that residues are not returned to the soil and inorganic **fertilisers** must be applied to maintain soil nutrient levels. Opposite system is polyculture.

mycorrhiza: fungal hyphae that makes a symbiotic association with plant roots, acting as an extension of root system and thus aiding plant development and soil condition.

nitrate: ion with the formula NO_3^-, base of nitric acid. Combines to form highly soluble salts (e.g. sodium nitrate, $NaNO_3$). Occurs in urine and also produced by a certain bacteria. Key constituent of fertilisers. Synthetically produced nitrates are key ingredients of fertilisers and pollutants responsible for eutrophication of water bodies.

nitrogen: chemical element with symbol N and atomic number 7. Colourless, odourless inert gas at standard conditions. Basis for many compounds (e.g. ammonia, nitric acid, nitrous oxide, urea). Occurs in all living organisms in amino acids.

no till: a procedure whereby a crop is planted directly into the soil without **ploughing** after the harvest of the previous **crop**. A special planter is necessary to prepare a narrow, shallow seedbed immediately surrounding the seed being planted. Protects soil from **erosion** and increases **organic matter** levels. Also known as **zero tillage**. Used in **conservation agriculture**.

nutrient: essential element needed by plants and animals to build biomass. Classed as macronutrients if needed in large quantities (primarily **nitrogen**, **phosphorus**, **potassium**, calcium, magnesium and sulphur) or micronutrients if needed in very low quantities (primarily boron, chlorine, copper, iron, manganese, molybdenum and zinc).

organic: relating to an organism, living material.

overland flow: water that travels across the surface of the soil, either when soil is **saturated** or rainfall exceeds **infiltration** rate. Also known as **runoff**.

oxide: chemical compound that contains at least one **oxygen** atom and one other element (e.g. NO nitrous oxide, CO_2 carbon dioxide). Most metal ore deposits are actually oxides (e.g. the iron ore haematite, Fe_2O_3).

oxidation: the addition of oxygen, removal of hydrogen or the removal of electrons from an element or compound. Soil organic matter is oxidised to more stable substances. Opposite of **reduction**. Oxidation of iron is referred to as rusting.

pan: a well-defined, hardened layer in the soil. **Plough** pan builds up just below the depth of **tillage** while iron pan forms by the accumulation of iron **oxide**. Can impede the passage of water through the soil.

parent material: mineral or rock material on and/or from which soils are formed.

pasture: grassland used for grazing animals.

peat: organic soil consisting of decayed or partially decayed humified plant remains in swampy or water-logged areas, where oxygen is absent. Peat-covered terrain is often referred to as **peatland**.

ped: an individual natural soil aggregate.

pedogenesis: process of soil formation and development.

pedology: the scientific study of soil.

pedon: three-dimensional body of soil with lateral dimensions (1 to 10 m^2) large enough to permit the study of shapes and relations of horizons.

permanent grassland: natural or agricultural land with grass cover, not ploughed.

ploughing: mechanical cultivation of soils by the plough to different depths, creating arable land.

permafrost: ground (soil or rock and included ice and organic material) that remains at or below 0 °C for at least two consecutive years.

permeability: a measure of the ease with which fluids, gases or plant roots can travel through soil.

pH: a measure of acidity, measured from 1 (acid) through 7 (neutral) to 14 (alkaline). Most soils fall in a range between pH 4 to 8.

phosphorus: a highly reactive, non-metalic element with symbol P and atomic number 15. Phosphorus is never found as a free element on Earth. Essential for life as it is a component of DNA and cell membranes. Low phosphate levels limit growth in plants. Major component of fertilisers as it is needed to replace the phosphorus removed from the soil by harvested plants and boost **yields**. Highly bound to some soils, especially in tropics. Also used in pesticides.

photosynthesis: process by which plant cells use the sun's energy to join carbon dioxide and water to make sugar, the food of green plants.

pollution: introduction of contaminants into the natural environment that cause undesirable changes, causes stress to organic systems and can result in death of organisms depending on susceptibility or dose. Can affect human health and soil functions.

pore: the space between soil **aggregates** or soil particles. Also referred to as pore space.

porosity: a measure of the volume of **pores** in a soil, expressed as a fraction for a given volume of soil.

potassium: chemical element with symbol K and atomic number 19. Essential for life and occurs in high concentrations in plants and fruits. Intensive crop production rapidly depletes soils of potassium. **Agricultural fertilisers** account for almost all global production of potassium.

precipitation: water reaching the ground in the form of rainfall, snow or hail.

pyrite: commonly occurring, pale-bronze or brass-yellow mineral, iron sulphate (FeS_2): also known as 'fool's gold'.

quartz: resistant crystalline mineral consisting of silicon and oxygen (SiO_2). Second most abundant mineral in the Earth's crust. Major component of granite, sand (Arenosols), many tropical soils (e.g. Ferralsols) and many sedimentary deposits.

quaternary: a geological time period extending from 1.8 million years ago to present time; incorporates both the Pleistocene and Holocene epochs.

rainforest: **forest** characterised by high rainfall, normally >2 000 mm, can be **tropical** or **temperate**.

reduction: the addition of **hydrogen**, removal of oxygen or the addition of electrons to an element or compound. Under anaerobic conditions (such as in waterlogged soils), sulphur compounds are reduced to odour-producing hydrogen sulphide (H_2S). Reduction is the opposite of oxidation.

regolith: unconsolidated mantle of weathered rock and soil material on the Earth's surface.

rhizosphere: zone immediately adjacent to plant roots in which levels of microorganisms can be significantly higher than that of the soil body.

root exudates: carbohydrates, organic acids, vitamins and other substances released from roots.

runoff: see **overland flow**.

saline soil: soil containing sufficient soluble salt to adversely affect the growth of most crop plants.

saturation: when soil pore space is completely full of water, may give rise to **overland flow**.

sand: soil particles between 0.05 mm and 2 mm.

sediment: mineral or organic material that has been transported by wind or deposited in water (such as lakes or the sea). Basis for sedimentary rocks such as sandstone, chalk and shale. See **alluvium**.

shifting cultivation: form of **agriculture** in which cultivated area is abandoned after a few years to allow soil properties to recover under natural re-growth.

silica: name for chemical compound silicon dioxide, (SiO_2). Silica is a resistant substance and is most commonly found in nature as sand or quartz

smectite: a 2:1 type **clay mineral** with a high **cation exchange capacity**.

sodic soil: soil with excess of sodium (pH is usually in the range 8-10) that are not used for agriculture.

sodium: a chemical element with symbol Na and atomic number 11. A soft, silvery-white, highly reactive alkali metal. Sixth most abundant element in the Earth's crust and component of numerous minerals (e.g. feldspars, rock salt). Produces highly soluble salts that are easily leached in soil.

soil compaction: a decrease in the volume of pore space between soil particles or aggregates. Severely compacted soil can become impermeable.

soil degradation: process that leads to a deterioration of soil properties and functions, often accelerated by human activities.

soil depth: depth of soil profile from the top to parent material or bedrock or to the layer of obstacles to roots.

soil fertility: measure of the ability of soil to provide a sufficient amount of nutrients, water and a suitable medium for healthy plant growth.

soil function: any service, role or task that soil performs, especially sustaining biological activity (agriculture); regulating and partitioning water and solute flow; filtering, buffering, degrading and detoxifying pollutants; storing and cycling of nutrients; providing support for buildings and other structures; protecting cultural heritage.

soil microorganisms: very small life-forms, represented by protozoa, viruses, bacteria, fungi and algae.

soil organic matter: **carbon**-containing compounds of the soil exclusive of undecayed plant and animal residues. See **humus**.

soil productivity: the capacity of a soil to produce a certain **yield** of a **crop** under a specified farming system.

soil profile: vertical section through soil, often from parent material, showing the arrangement of horizons.

soil quality: quantitative or qualitative measure used to estimate the capacity of a soil to deliver a specific **function**, often expressed in biological, chemical or physical terms.

soil sealing: covering or destruction of soil by urban fabric or artificial material which may be impermeable to water (e.g. asphalt or concrete). Soil sealing can cause rapid **overland flow** after **precipitation** where water cannot soak away, leading to potential flooding.

soil structure: the aggregation of soil particles into units separated from each other by surfaces of weakness.

soil texture: numerical proportion of sand, silt and clay in a soil. Texture can be coarse (sand particles predominate), medium (silt particles predominate) or fine (clay particles predominate).

sorption: a physical or chemical process by which one substance becomes attached to another

swamp: seasonally flooded low land. Similar to **marsh**, but with more woody plants and to **bog** but with better drainage.

swelling and shrinking: swelling – increase of soil volume, shrinking – decrease of soil volume. Processes influenced by water content and the nature of clay minerals.

silt: soil particles between 0.002 mm and 0.05 mm.

tertiary: a period of time between sixty five and three million years ago, prior to the **quaternary** period.

temperature: describes the warmth or coldness of an object.

thawing: melting of the ice as a result of a rise in temperature.

tillage: see ploughing.

topsoil: dark-coloured surface layer of soil containing decomposing organic matter, usually high in nutrients.

tropic: line that marks the northernmost and southernmost latitudes (23° 26' 16") at which the sun may be seen directly overhead (Tropic of Cancer and Capricorn respectively).

tropics: area of land around the Equator bounded by the Tropics of Cancer and Capricorn, often associated with climate that is warm to hot and moist all year round, although this is not always the case.

tropical: relating to the tropics, often with the sense of lush vegetation and a hot, humid climate.

temperate: climatic zone that lies between the **tropics** and the polar regions characterised by moderate temperatures and precipitation, can become more extreme with distance from the ocean. Limited in Asia to northern and southern coastal areas.

vermiculite: highly charged 2:1 clay mineral, formed from mica.

wasteland: land not capable of, or suitable for, producing materials or services of value (e.g. **crops**).

water capacity, available (AWC): amount of water available for plants to use. Volume of water released from soil between the time the soil is at field capacity until the time it is at the wilting point. Loamy soils and soils high in organic matter have the highest AWC.

water capacity, retention (WHC): ability of soil to hold water for a period that is longer than infiltration, also known as water holding capacity.

water table: upper level of groundwater.

waterlogging: soil that is very wet, most pore spaces are filled with water (saturation). The opposite is an aerated soil.

weathering: breakdown of rocks by a combination of biological, chemical, and physical agents.

weed: vague term to define unwanted plants in human-controlled settings where it may be in competition with other plants (i.e. crops) for water and nutrients, or may interfere with harvests. Often denotes plants that grow and reproduce aggressively and invasively.

wetland: land that is normally inundated or saturated by groundwater (e.g. bog, swamp, marsh). Characterised by distinctive vegetation communities that can tolerate wet conditions and peaty or gleyic soils.

wilting point: occurs when water is held too tightly in soil for plants to extract.

yield: the amount of a specified crop (e.g. maize, coffee beans) produced per unit area. Usually expressed in kg or tonnes per hectare.

zero tillage: See no-till.

Further reading

If you want to learn more about soil, then we would suggest investing in a general textbook (see #7, 7a below). If you are interested in obtaining more information on the material presented in the Atlas, then the following sources are proposed. The numbers of the references listed below refer to the bracketed numbers in the text of the Atlas (e.g. [6]). All urls were checked in June 2023.

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Contacts

Soil contacts in specific countries

If you are interested in learning more about the soil of a specific country, a list of contact persons and organisations is available on the GSP and JRC Web Page for the Soil Atlas of Asia:

https://esdac.jrc.ec.europa.eu/content/soil-atlas-asia

Afghanistan
FAO Afghanistan
https://www.fao.org/afghanistan/en/

Armenia
The Republic of Armenia Ministry of Agriculture
http://old.minagro.am/en/

Azerbaijan
Institute of Soil Science and Agrochemistry (NAS)
https://tai.az/en

Bangladesh
Central Laboratory, Soil Resource Development Institute (SRDI), Ministry of Agriculture, Bangladesh
http://www.srdi.gov.bd/

Bhutan
National Soil Service Centre (NSSC)
Department of Agriculture, Ministry of Agriculture and Livestock
https://www.nssc.gov.bt/

Cambodia
Department of Agricultural Land Resources Management, General Directorate of Agriculture

China
Ministry of Agriculture and Rural Affairs
http://english.moa.gov.cn/

Institute of Soil Science, Chinese Academy of Sciences
http://english.issas.cas.cn/

Cyprus
Ministry of Agriculture, Natural Resources and Environment
https://moa.gov.cy/?lang=en

Georgia
Soil Fertility Research Service
https://srca.gov.ge/en/

India
Indian Council of Agricultural Research
https://icar.org.in/

Indonesia
National Research and Innovation Agency (BRIN), Research Center for Geospatial
https://www.brin.go.id/en

The Islamic Republic of Iran
Soil & Water Research Institute
http://www.swri.ir/en-US/DouranPortal/1/page/Home

Iraq
Soil and Water Management Department, Directorate of Planning and Follow-up

Japan
Institute for Agro-Environmental Sciences, NARO (NIAES)
https://www.naro.go.jp/english/

Jordan
Ministry of Agriculture - Amman
https://moa.gov.jo/Default/EN

Kazakhstan
Kazakh Research Institute of Soil Science and Agrochemistry

Kuwait
Kuwait Institute for Scientific Research
https://www.kisr.edu.kw/en/

Kyrgyzstan
Kyrgyz Soil Science Society
Kyrgyz Research Institute of Irrigation (KRII)
Republican Soil-Agrochemical Station

The Lao People's Democratic Republic
ASEAN Hydroinformatics Data Center (AHC)
https://www.aseanwater.net/

Department of Agricultural Land Management (DALaM)
Ministry of Agriculture & Forestry (MAF)
https://www.maf.gov.la/

Lebanon
CNRS
http://www.cnrs.edu.lb/site/SubPage.aspx?pageid=111

Malaysia
Soil Resource Management and Conservation Division
Department of Agriculture Malaysia
http://www.doa.gov.my/

Maldives
Ministry of Environment, Climate Change and Technology
http://www.environment.gov.mv/v2/en/

Mongolia
Institute of Plant and Agriculture Sciences, Darkhan-Uul
http://ipas.edu.mn/en/about-us/brief-introduction/

Myanmar
FAO Myanmar
https://www.fao.org/myanmar/fr/

Nepal
Subtropical Horticulture Center, Kirtipur, Kathmandu
https://ncfd.gov.np/en

Department of Agriculture, Ministry of Agriculture and Livestock Development
https://moald.gov.np/

Oman
Soil and Water Research Center
https://www.squ.edu.om/agriculture/Academic-Department/Soils-Water-and-Agricultural-Engineering/Description

Pakistan
National Centre of Excellence in Geology, University of Peshawar, Peshawar
http://nceg.uop.edu.pk/

Occupied Palestinian Territory
Ministry of Agriculture, Soil and Land Classification Department
https://www.moa.pna.ps/
FAO Office in West Bank & Gaza Strip

Philippines
Bureau of Soils and Water Management
http://bswm.da.gov.ph/

Republic of Korea
National Institute of Agricultural Sciences, Rural Development Administration
https://www.naas.go.kr/english/index.do

Russian Federation
M. V. Lomonosov, Moscow State University
https://soil.msu.ru/eng

Singapore
International Biodiversity Conservation, National Parks Board
https://www.nparks.gov.sg/biodiversity/our-international-and-regional-links/international

Sri Lanka
Natural Resources Management Centre
https://doa.gov.lk/nrmc/

Soil Science Society of Sri Lanka
https://www.ssssl.org

The Syrian Arab Republic
General Commission for Scientific Agricultural Research
https://gcsar.gov.sy/en/

Tajikistan
Republic of Tajikistan Institute of Soil Science and Agrochemistry by the Academy of Agricultural Science
http://www.khokshinos.tj/en

Thailand
Land Development Department
http://www1.ldd.go.th/ldd_en/

Timor-Leste
Soil Department, Ministry of Agriculture and Fisheries
https://customs.gov.tl/enquiry-point/other-govermment-agencies/ministry-of-agriculture-and-fisheries/

Türkiye
General Directorate of Agrarian Reform, Ministry of Agriculture and Forestry
https://www.tarimorman.gov.tr/TRGM

United Arab Emirates
Environment Agency - Abu Dhabi
https://www.ead.gov.ae/en

Uzbekistan
Design and Research UZGIP institute

Viet Nam
Soils and Fertilizers Institute
https://en.sfri.org.vn/

Yemen
Renewable Natural Resources Research Center (RNRRC) in Agricultural Research and Extension Authority (AREA)

EU and FAO representations

In addition to their headquarters in Brussels and Rome, both the EU (through its External Action Service) and FAO have an extensive network country representations as well as Regional and Subregional offices. Further details are available through the following links:

EU:

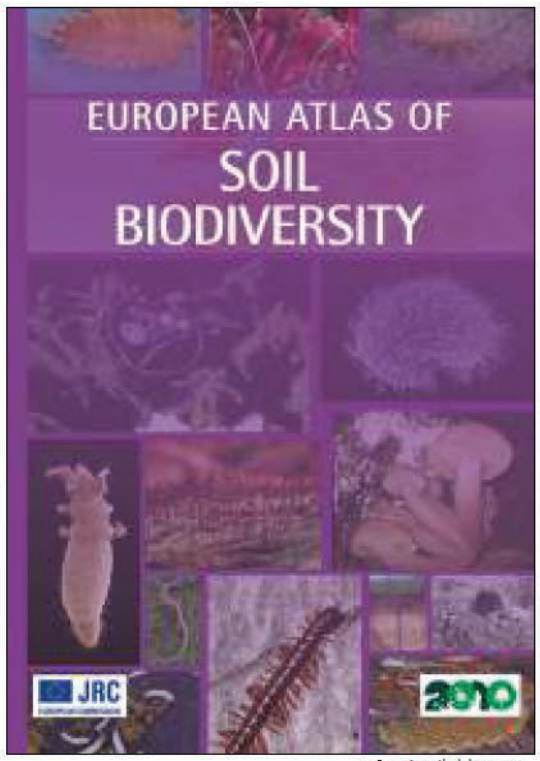
https://www.eeas.europa.eu/eeas/eu-world-0_en

FAO:

https://www.fao.org/about/who-we-are/worldwide-offices/en/

JRC Soil Atlas Series

The European Commission's Joint Research Centre collaborates with soil scientists and researchers from all over the world to develop a series of soil-related atlases. To obtain a copy or for further information, please consult the Publications Office of the European Union (**http://publications.europa.eu/**) or the JRC SOIL Action's website (**http://eusoils.jrc.ec.europa.eu**).



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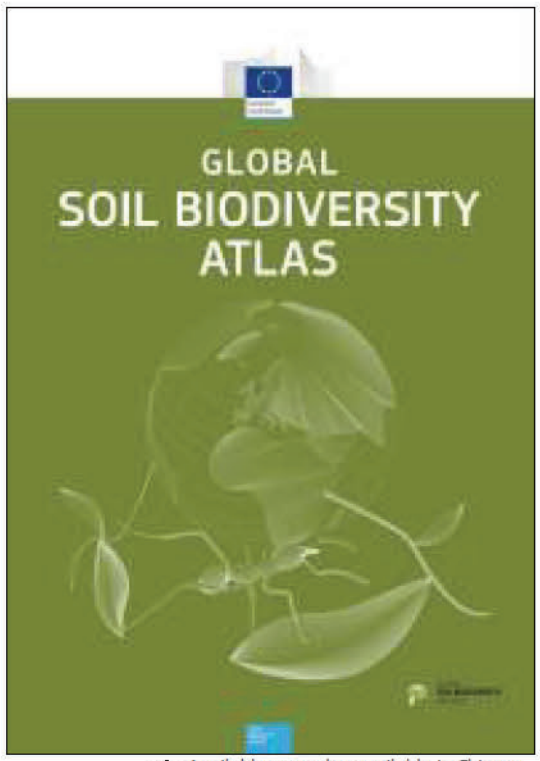

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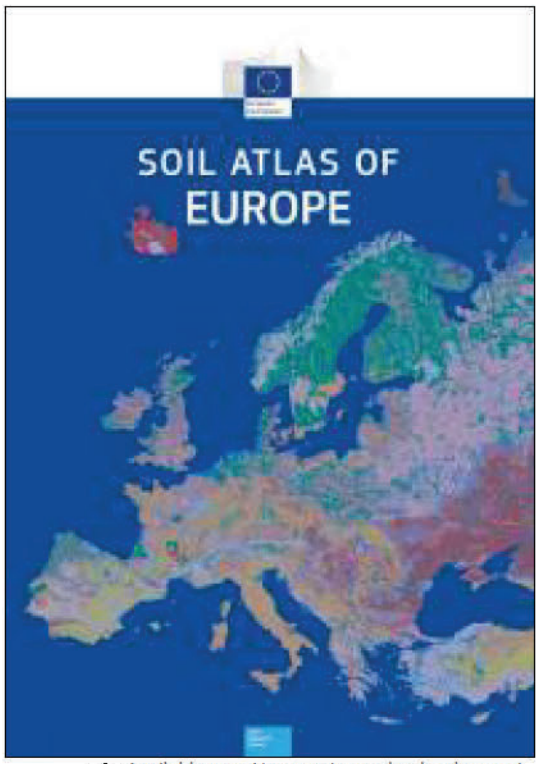

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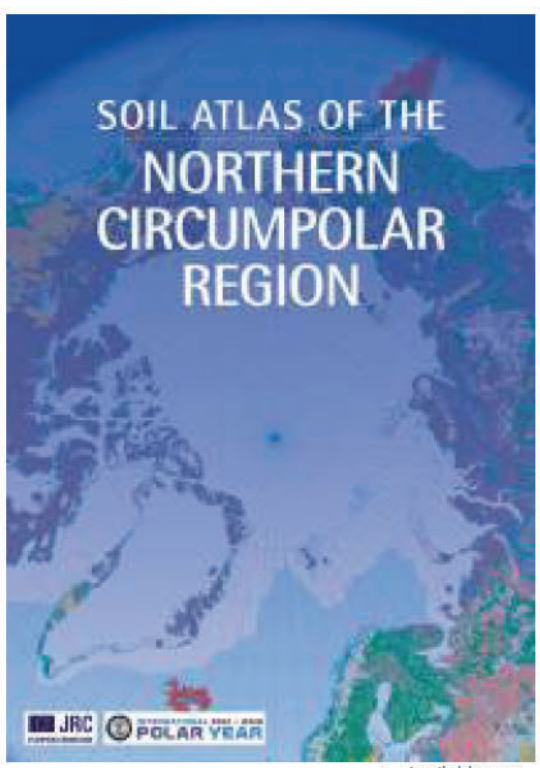

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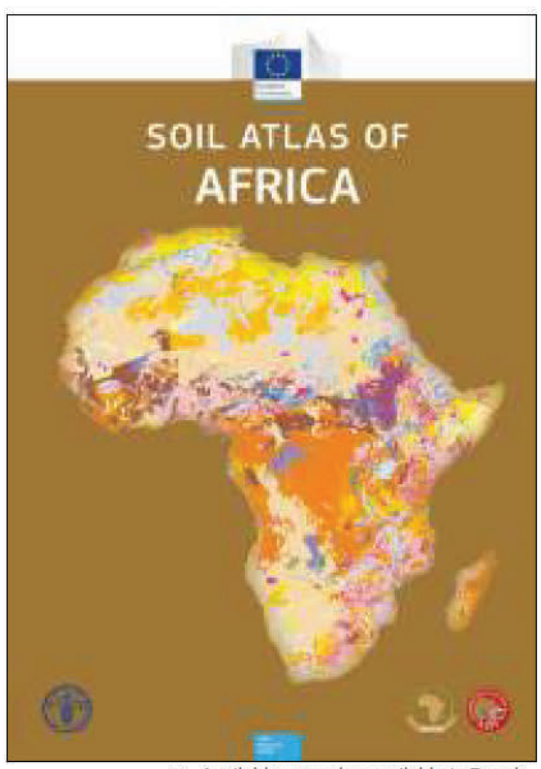

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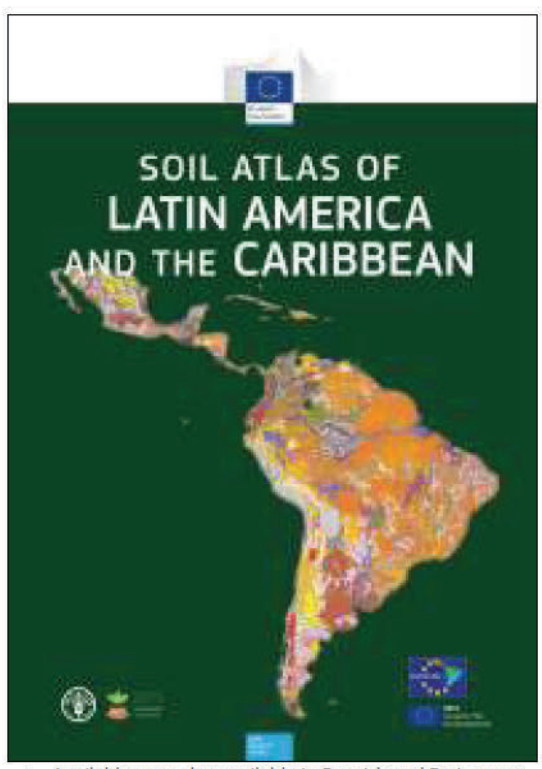

Available now; also available in Spanish and Portuguese.

Publications Office of the European Union

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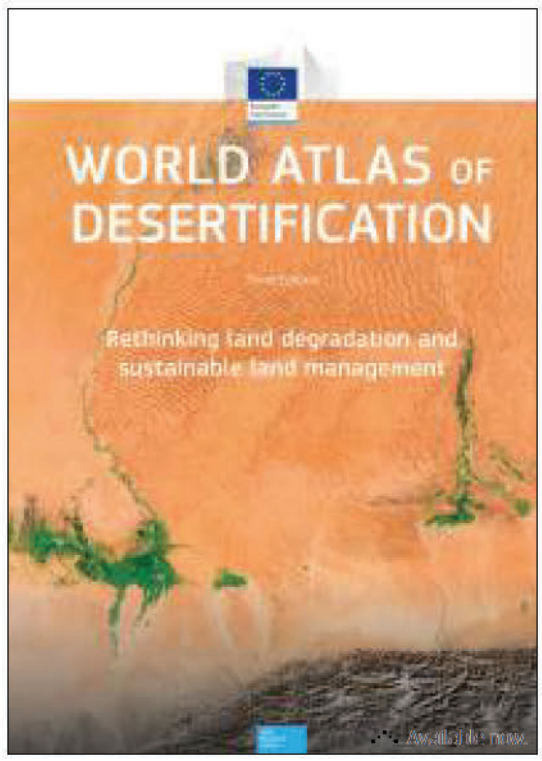

The first ever SOIL ATLAS OF ASIA uses striking maps, informative texts and stunning photographs to show the changing nature of soil across this vast continent. It explains the factors that control the origins of soil and their evolution over time, the functions and ecosystem services that they support and their relevance to local and global issues, and in particular the way that we live our lives.

The SOIL ATLAS OF ASIA also discusses the main threats to soil across different parts of Asia and the steps being taken to protect them, presenting an interpretation of an often neglected but vital natural resource that surrounds and affect us all.

Scientists from both Asia and Europe have collaborated over several years to produce this unique document.

The SOIL ATLAS OF ASIA is an essential reference to a non-renewable resource that is fundamental for life on this planet.

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The characteristics of soil vary tremendously from region to region. Soils under equatorial rain forests become vulnerable to erosion and nutrient depletion if the tree cover is removed. Oases in deserts show how seemingly infertile soils can be cultivated in the presence of water. The wetlands of Indonesia, Malaysia and Siberia, together with the grassland soils of the steppe regions, are major stores of organic carbon, which is a key factor in mitigating the impact of climate change. The black, clay-rich soils of the Decan Plateau in India are full of nutrients but are difficult to cultivate when very wet or very dry. Soils with high levels of salt are not suitable for the cultivation of most crops but they may support a unique plant community and biodiversity.

The atlas aims to help you understand the reasons for the soils that you have where you live, their strengths, weaknesses and opportunities for the future.

Plants are dependent on soils for the supply of water, nutrients and a medium within which to grow. Soils store, filter, buffer and transform substances - this includes the remains of vegetation but also contaminants and water. This capability is crucial in protecting water supplies from pollution, regulating flood events and the emissions of greenhouse gases from soil. Soil is a provider of raw materials, including pharmaceuticals. Soil is an incredible habitat in its own right and underpins all other terrestrial ecosystems. Soil is a fundamentally important component of our cultural heritage and who we are.

Yet despite all of this, we treat soils terribly! We overuse, overfeed, poison and starve them. We allow them to be washed and blown away or crush and cover them in concrete.

This atlas aims to make you better understand the importance of healthy soils in your life.

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