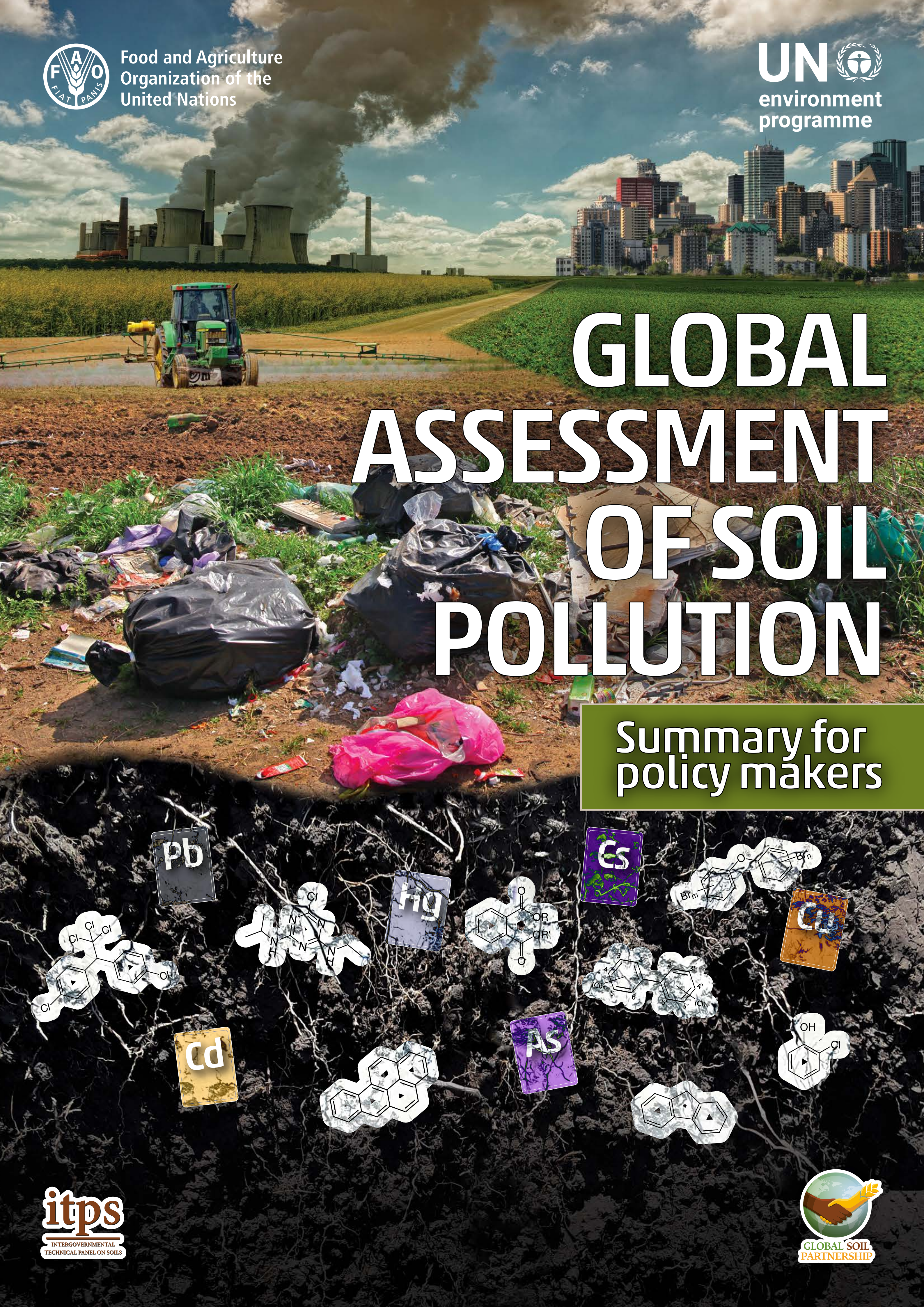
Food and Agriculture Organization of the United Nations

UN environment programme

GLOBAL ASSESSMENT OF SOIL POLLUTION

Summary for policy makers



ITPS INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

GLOBAL SOIL PARTNERSHIP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GLOBAL ASSESSMENT OF SOIL POLLUTION

Summary for policy makers

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Foreword

The Anthropocene era - the most recent period in Earth's history when human activity started to have a significant impact on the planet's climate and ecosystems - is characterized by massive global changes, including climate change, biodiversity loss, poverty, and food insecurity. The challenge for society is to adapt to and mitigate these changes while transforming our agri-food systems, making them more efficient, inclusive, resilient and sustainable, for better production, better nutrition, a better environment, and a better life, leaving no one behind. A transformative approach that is in line with the 2030 Agenda for Sustainable Development, which sets out to achieve socio-economic development, while conserving the environment.

The thin crust of the Earth's surface, the soil, supports all terrestrial life and is involved in the regulation and provision of many key ecosystem services that are essential to the environment and to human health and well-being. Soil is the foundation of the agri-food system and the medium in which nearly all food-producing crops grow - about 95 percent of the food we eat comes from the soil. After the oceans, soil is the largest active carbon store and one cubic metre of soil can store up to 600 litres of water, allowing crops to grow even during dry periods.

Biodiversity -above and below ground - is vital to ensuring healthy soils and the ecosystems upon which we depend. Soil biodiversity contributes to the cycling of nutrients and carbon, regulates the emergence of pests and diseases, and serves as a source of pharmaceuticals that contribute to boost our health. Soils also provide building materials, fuel and fibre. They are the basis for human infrastructure and preserve our cultural heritage.

However, global soils are under great pressure. The Status of the World's Soil Resources report presented in 2015 by the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Technical Panel on Soil (ITPS) identified ten major threats to the world's soils: Erosion, loss of soil organic carbon and biodiversity, pollution, acidification and sodification, salinization, nutrient imbalance, compaction, sealing and waterlogging are major pressures on soil health and limit their capacity to provide these key ecosystem services for human well-being.

Soil pollution, a chemical degradation process that consumes fertile soils, may be invisible to human eyes, but it compromises the food we eat, the water we drink and the air we breathe. Most contaminants originate from human activities and are released into the environment because of unsuitable production, consumption and disposal practices, such as unsustainable farming practices, environmentally unfriendly industrial processes and mining, as well as poor waste management. Pollution knows no borders; contaminants move through soil, air and water and enter into agri-food systems, affecting the environment and human health.

Soil pollution has been internationally recognized as a major threat to soil health and its capacity to provide ecosystems services. The United Nations Environment Assembly, at its third session in December 2017, addressed the issue and made a global call for action through Resolution 3/6 *Managing Soil Pollution to Achieve Sustainable Development*. The Assembly also requested UNEP to collaborate with relevant Organizations and entities, including the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the United Nations Convention to Combat Desertification (UNCCD) to prepare a report on the extent and future trends of soil pollution.

Furthermore, in May 2018, FAO's Global Soil Partnership together with UNEP, WHO and the Secretariat of the Rotterdam Convention, organized the *Global Symposium on Soil Pollution*, where *"Be the solution to soil pollution"* was agreed as a common way forward.

The *Global Status of Soil Pollution Report* we present today is the result of an inclusive process by scientists from all regions of the world, bringing together the science behind soil pollution. The Report, a joint effort coordinated by FAO's Global Soil Partnership and supported by UNEP, contributes to raising awareness to the threats posed by soil pollution and to the interlinkage with other global environmental pressures.

It is time to reconnect with our soils, as it is where our food begins. Soil pollution should no longer be a hidden reality. Let us all be part of *the solution to soil pollution*.

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

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Preface

Soil pollution is invisible to the human eye, but it compromises the quality of the food we eat, the water we drink and the air we breathe and puts human and environmental health at risk. Most contaminants originate from human activities such as industrial processes and mining, poor waste management, unsustainable farming practices, accidents ranging from small chemical spills to accidents at nuclear power plants, and the many effects of armed conflicts. Pollution knows no borders: contaminants are spread throughout terrestrial and aquatic ecosystems and many are distributed globally by atmospheric transport. In addition, they are redistributed through the global economy by way of food and production chains.

Soil pollution has been internationally recognized as a major threat to soil health, and it affects the soil's ability to provide ecosystems services, including the production of safe and sufficient food, compromising global food security. Soil pollution hinders the achievement of many of the United Nations Sustainable Development Goals (SDGs), including those related to poverty elimination (SDG 1), zero hunger (SDG 2) and good health and well-being (SDG 3). Soil pollution hits the most vulnerable hardest, especially children and women (SDG 5). The supply of safe drinking water is threatened by the leaching of contaminants into groundwater and runoff (SDG 6). CO_2 and N_2O emissions from unsustainably managed soils accelerate climate change (SDG 13). Soil pollution contributes to land degradation and loss of terrestrial (SDG 15) and aquatic (SDG 14) biodiversity, and decreased security and resilience of cities (SDG 11), among others (Table 1).

In response to this global and multidimensional threat, the United Nations Environment Assembly (UNEA)[1] at its third session, held in Nairobi, Kenya, from 4 to 6 December 2017, met under the theme "Towards a pollution-free planet" (UNEP, 2017). As a result, UNEA Resolution 3/6, requested "the Executive Director to present a report on the extent and future trends of soil pollution [...] in collaboration with the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), the Global Soil Partnership (GSP) and its Intergovernmental Technical Panel on Soils (ITPS), and other relevant UN organizations by the fifth session of the United Nations Environment Assembly". This report is the response to that request.

The Status of the World's Soil Resources report prepared by FAO's Intergovernmental Technical Panel on Soils identified 10 global soil threats that put the provision of key soil ecosystem services at risk (FAO and ITPS, 2015). Soil pollution was identified as one of the most worrying threats to soil health and functioning. In 2018, FAO's Global Soil Partnership organized the Global Symposium on Soil Pollution (GSOP18). The symposium, co-organized by the GSP and the ITPS, UNEP, the Secretariat of the Basel, Rotterdam and Stockholm Conventions, and WHO, was the first attempt to build an international network of experts, academia, industry, and remediation businesses, to gather existing information and identify gaps and options for priority actions (FAO, 2018b).

Following the successful organisation of the GSOP18, multiple events were organised throughout the year to raise awareness of soil pollution targeting different stakeholders, from academics and technical experts to policy makers, and concluded with the celebration of World Soil Day on December 5th 2018 under the motto "*Be the solution to soil pollution*".

Based on the outcome document of the GSOP18 "Be the solution to soil pollution" (FAO, 2018a) and an intensive consultation and literature assessment, this report has been developed by the GSP in close consultation with UNEP, WHO and a wide range of experts and stakeholders to meet the UNEA-3 request. The report addresses the extent and trends of soil pollution, considering both point source and diffuse soil pollution, and describes the risks and impacts of soil pollution on health, the environment and food security – including land degradation and the burden of disease resulting from exposure to polluted soil. The process to develop the report involved in-depth regional assessments of soil pollution, and the regional chapters provide an overview of soil pollution issues at the global scale that is long overdue (Figure 1). The Editorial Board comprised over 30 international experts representing the ITPS, the Regional Soil Partnerships, relevant international fora and expert groups, and the private sector.

The Summary for Policy makers presents the main findings of the report, together with options for action to facilitate global policy considerations in the UNEA process. The main report is a comprehensive publication which is available on the FAO website.

1 The UNEA is the world's highest-level decision-making body on the environment. Created in June 2012 at the United Nations Conference on Sustainable Development (Rio+20), the Assembly convenes all 193 UN Member States to tackle our most critical global environmental challenges. Through its resolutions and calls to action, it provides the global leadership and inter-governmental action so critical to the health of our planet.

Table 1. Relationships between the Sustainable Development Goals and soil pollution

Links between S

Targets releva

1 NO POVERTY	2 ZERO HUNGER	3 GOOD HEALTH AND WELL-BEING
1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day	**2.4** By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	**3.4** By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being **3.9** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
About 79 per cent of people living in extreme poverty live in rural areas and depend heavily on natural resources for their livelihoods, mostly through agriculture. Soil pollution reduces crop yields and quality, leading to reduced incomes for rural populations and exacerbating the burden of contaminants.	Soil pollution affects soil security by reducing crop yields, hampering the quantity and the quality of the food produced. Soil pollution also degrades soil structure and organic carbon content, thereby reducing the resilience of terrestrial landscapes to flooding and drought, and ability to contribute to climate change adaptation and mitigation.	Soil pollution is closely linked to a great variety of diseases. WHO estimates that about sixteen percent of total global mortality is attributed to environmental pollution-related diseases (including water, air and soil pollution). However, the burden of disease attributed solely to soil pollution and soil-borne diseases remains largely unknown and may be greatly underestimated.

5.5 Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix

8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead

nt to soil pollution

Around 45 per cent of the world's women work in vulnerable jobs (World Bank, 2020), many in marginal agricultural areas, or as scavengers, and they tend to have less access to education and therefore have fewer resources and solutions to reduce their exposure to soil pollution.

Improvement and protection of water quality can only be achieved if all forms of pollution, including soil pollution, are addressed. On the one hand, water pollution leads to soil pollution through practices such as irrigation with polluted water or the discharge of wastewater. On the other hand, soil pollution leads to water pollution through contaminant leaching, surface runoff and soil erosion.
Open defecation is responsible for a higher burden of soil pollution and transmission of soil-borne diseases.

Around 65 percent of the world's energy production comes from the combustion of fossil fuels (coal, natural gas and oil), which are a major source of environmental contaminants.

Poorly managed stockpiles and diffusion of chemicals into the environment resulting from industrial activities are major sources of soil pollution, both on the industrial site, and also more widely through the transport of particles via air and water.

DG and soil pollution

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

Links between SDG

Targ to

10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average

Soil pollution will lead to the reduction of productive agricultural land, crop yields and quality, which will ultimately result in lower incomes for rural populations that already face extreme poverty. Human health impacts that disproportionately affect poorer populations/communities due to soil pollution reduce human capacity to improve their economic circumstances.

10 REDUCED INEQUALITIES

11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons

11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

Transport and poor waste management are two of the main causes of soil pollution in urban areas. By promoting sustainable systems for all and reducing the environmental impact of cities, soil pollution in cities can be reduced and a healthier environment created.
Urban green spaces present great opportunities for personal and social development, and human health and well-being, but if polluted they will be a further route for contaminants to enter the body.

11 SUSTAINABLE CITIES AND COMMUNITIES

12.2 By 2030, achieve the sustainable management and efficient use of natural resources

12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment

12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

Modern production and consumption patterns based on the rapid obsolescence of products have led to an incessant production of waste and the excessive extraction of raw materials. The world produces more than 2 billion tonnes of solid waste annually. While some of this waste is stored, recycled and reused, much of it is not properly managed and often ends up polluting the environment, including the soil. With rapid population growth and urbanization, annual waste generation is projected to increase to 3.4 billion tonnes in 2050. Unsustainable waste management represents the main source of soil pollution in some countries, especially in the Global South.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

Unsustainable agriculture is one of the main causes of soil pollution and also has a major impact on climate change. Some 109 million tonnes of synthetic nitrogen fertilisers were applied worldwide in 2018. The excess nitrogen alters biological cycles in soil and is released into the atmosphere in the form of N_2O, resulting in emissions of 700 000 CO_2 equivalents. In 2017, agriculture emissions accounted for 20 percent of all human activities.

13 CLIMATE ACTION

14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

15.3 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally

16.3 Promote the rule of law at the national and international levels and ensure equal access to justice for all

16.7 Ensure responsive, inclusive, participatory and representative decision -making at all levels

17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed

17.9 Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the sustainable development goals, including through North-South, South-South and triangular cooperation

ets relevant soil pollution

About 80 percent of marine pollution comes from land-based activities. Erosion of polluted soils contributes plastics, nutrients and organic chemicals which are contaminants of concern in marine ecosystems.

Soil pollution causes a chain reaction in terrestrial ecosystems, starting with the contamination of plants growing in the polluted soil, and then continuing through the food chain to humans, resulting in contamination of entire ecosystems. Heavily polluted soils also result in soil degradation, increasing susceptibility to erosion and thinning of forest cover.

Minority ethnic groups and the poorest and most vulnerable are most affected by soil pollution. These groups have less access to justice and often suffer discrimination and multiple forms of racism. Environmental inequalities exist in both developing and developed countries and are fostered by a lack of information and data on the state of the environment, which limits the capacity of affected populations to react, act and decide.

Developed countries are more advanced in the development of technologies to detect emerging contaminants, innovative environmentally friendly industrial production and soil pollution remediation technologies, and therefore need to actively collaborate in the transfer of knowledge.

G and soil pollution

14 LIFE BELOW WATER

15 LIFE ON LAND

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

17 PARTNERSHIPS FOR THE GOALS

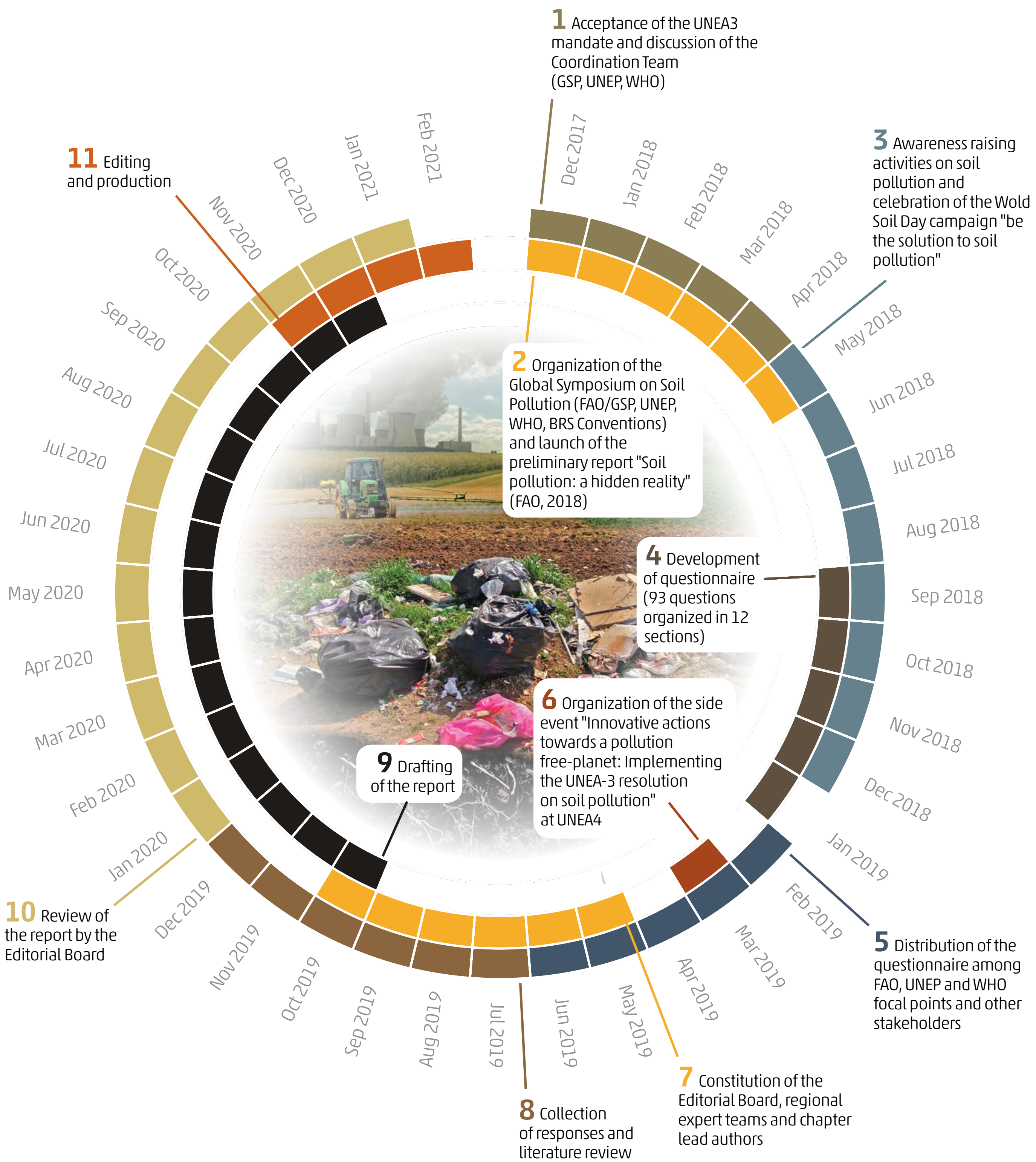

Figure 1. Timeline and main milestones of the development of the Global Assessment of Soil Pollution report

Abbreviations and acronyms

AAFC	Agriculture and Agri-Food Canada
ACAP	Arctic Council Action Plan
ASEAN	Association of Southeast Asian Nations
ASP	Asian Soil Partnership
ATSDR	United States Agency for Toxic Substances and Disease Registry
BPA	Bisphenol A
BTEX	Compounds of benzene, toluene, ethyl benzene and xylenes
DDT	Dichlorodiphenyltrichloroethane
DNA	Deoxyribonucleic acid
ECLAC	Economic Commission for Latin America and the Caribbean
EFSA	European Food Safety Authority
EIONET	European Environment Information and Observation Network
EOL	End-of-life
EPA	Environment Protection Agency
ESP	European Soil Partnership
EU	European Union
EUR	Euro
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
GSOP	Global Symposium on Soil Pollution
GSP	Global Soil Partnership
HCH	Hexachlorocyclohexane
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
INI	*International Nitrogen Initiative*
IPCC	Intergovernmental Panel on Climate Change
IQ	Intelligence quotient
ISO	International Organization for Standardization
ITPS	Intergovernmental Technical Panel on Soils
ITRC	Interstate Technology Regulatory Council
IUPAC	International Union of Pure and Applied Chemistry
JRC	Joint Research Centre, European Commission
LAC	Latin America and the Caribbean Soil Partnership
MNM	Manufactured nanomaterials
MSW	Municipal solid waste
NENA	Near East and North Africa Soil Partnership
NICOLE	Network for Industrially Co-ordinated Sustainable Land Management in Europe
NPRI	Canadian National Pollutant Release Inventory
OCPs	Organochlorine pesticides
OPs	Obsolete pesticides
PAE	Phthalate ester
PAHs	Polycyclic aromatic hydrocarbons
PBDDs	Polybrominated dibenzo-p-dioxins
PBDEs	Polybrominated diphenyl ethers
PBDFs	Polybrominated dibenzofurans
PCBs	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PFAS	Perfluoroalkyl and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctanesulfonic acid
POPs	Persistent organic pollutants
PPCP	Pharmaceuticals and personal care products
RDX	1,3,5-trinitroperhydro-1,3,5-triazine
SDG	Sustainable Development Goals
SSM	Sustainable soil management
SSV	Soil screening value
TNT	Trinitrotoluene
TRI	United States Toxics Release Inventory
TSIP	Toxic Sites Identification Program
UAE	United Arab Emirates
UN	United Nations
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US	United States of America
USD	United States Dollar
VGSSM	Voluntary Guidelines for Sustainable Soil Management
VOCs	Volatile organic compounds
WHO	World Health Organization

Executive summary

1. Global environmental degradation due to pressures from the growing demands of agri-food and industrial systems, responding to a rising world population, is one of the major global challenges facing humanity.

2. Thousands of different synthetic chemical compounds and naturally existing elements with potential toxicity have been released into the environment by human activities since ancient times. These contaminants can have residence times in the environment in the order of hundreds to thousands of years and are distributed throughout the planet.

3. Pollution is a global problem that knows no borders. Contaminants are found in every continent even in their most remote areas, and are readily transported from one country to another.

4. Soil is one of the main recipient of contaminants. Soil pollution is one of the main threats to soil health but its impacts go far beyond the soil dimension and soil contaminants can have irreparable consequences on human and ecosystem health.

5. Polluted soil can act as a source of contaminants for all environmental compartments, including water, air, food, and organisms, including humans. Ecosystem and human health are interconnected, as the Planetary Health and One Health initiatives emphasize, yet neither can be effectively addressed without tackling soil pollution.

6. Soil pollution can result in the loss of ecosystem services, and cause severe economic losses and social inequities, all of which jeopardise the achievement of the 2030 Agenda on Sustainable Development.

7. The main sources of contaminants contributing to soil pollution (in order of importance) are industrial activities, mining, waste treatment, agriculture, fossil fuels extraction and processing, and transport emissions. There is, however, no concrete and comparable data on the actual emissions of each sector.

8. With the exception of agrochemical inputs, most contaminant releases to soil are not easily quantified and, as a result, remain highly uncertain. Industrial contaminants are released into the environment throughout their life cycle, from manufacturing to the production of the contaminant-containing materials, their transport, use and disposal.

9. Since the beginning of the XXI century, the global annual production of industrial chemicals has doubled to approximately 2.3 billion tonnes and is projected to increase by 85 percent by 2030. Soil and environmental pollution is therefore expected to increase unless there is a rapid shift in production and consumption patterns and a political commitment towards a real sustainable management where nature is fully respected.

10. Despite decades of research, inventorying and monitoring of point-source polluted soils in a number of countries, there are still significant knowledge gaps and uncertainty about the number and extent of areas affected, which is compounded by the emergence of new contaminants. The knowledge gap on soils affected by diffuse pollution and its impact on other environmental compartments is even greater.

11. The proliferation of organic contaminants and emerging contaminants such as pharmaceuticals, antimicrobials that result in resistant bacteria, industrial chemicals, and plastic residues is a growing societal concern. In the current global pandemic situation caused by COVID-19, the pressure on the environment has increased with an intensified release of waste.

12. Given the large amount of contaminants, the variety of their physical-chemical characteristics and their multiple interactions with the soil (which determine the fate of contaminants) estimating the load of contaminants is complex. Scientific knowledge on the fate of emerging contaminants is yet lacking. This makes establishing distribution models at a global level very difficult in the absence of regular systematic analysis in soil laboratories (which are more focused on the agronomic part of soils) and monitoring systems in many countries of the world.

13. Identification and assessment of risk at potentially polluted sites is the essential first step in the management of soil pollution. If contamination at a given site is at levels that can cause harm to organisms, information about that site should be collected at the appropriate governmental level and made available to the public, and remediation or risk minimization actions taken accordingly, especially if the site is used for food production or as a water reservoir for human consumption.

14. The identification of the site also allows the tracing of ownership of the site to occur, which is fundamental to the "polluter pays" principle. Although many countries have effective processes in place to identify and assess polluted sites, this fundamental step of identifying the liable part (polluter) is still lacking in many states.

15. Management and remediation of polluted sites is required to protect human health and that of the environment. The regional chapters in the main report show that in every region there are examples of successful approaches to managing polluted sites; sharing of expertise at the regional level would greatly facilitate progress in addressing soil pollution.

16. Clear channels of communication are required between academia, policy makers, and society to ensure that timely, science-based information on the potential threats posed by contaminants is available to policy makers and other stakeholders.

17. Remediation of soil pollution is a technically complex and costly undertaking, ranging from tens of thousands to hundreds of millions of USD per year. The cost of remediation varies from site to site depending on the characteristics of the site, the type of contaminants and their concentration, the environmental compartments affected (e.g. topsoil, groundwater, surface water), the protective measures to be taken to protect the population during the remediation work, and the post-remediation land use, as well as the technology chosen.

18. The production, use, transport, and disposal of the most harmful soil contaminants are regulated by global conventions (the Stockholm, Basel, Rotterdam and Minamata Conventions). In some regions, these global agreements are extended by regional agreements such as the Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa. Countries that are not parties to these conventions should be strongly encouraged to bring them into force.

19. In the current scenario of a worsening global trend in soil pollution, greater political, business, and social commitment is needed to seek alternative solutions to the use of highly toxic contaminants and increased investment in research, prevention and remediation.

20. Enhanced cooperation and partnership are essential to ensure the availability of knowledge, the sharing of successful experiences, and universal access to clean and sustainable technologies, leaving no one behind.


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Soil contaminants: properties, sources and health effects

Chemicals that act as environmental contaminants in soil and which potentially cause risks on human health and the environment, are either inorganic or organic compounds. Figure 2 introduces a systematic categorization of some of the most common contaminants in soils according to their chemical properties. As emerging contaminants can fall into a wide range of categorisations they are not included in the figure. The fate in the soil (Figure 3), including retention or mobility to other environmental compartments and effects on living organisms is determined by the intrinsic characteristics of the contaminant and by the local soil properties. Identifying the sources of trace elements in the environment is of key importance to understanding their pollution patterns and for making decisions concerning pollution remediation.

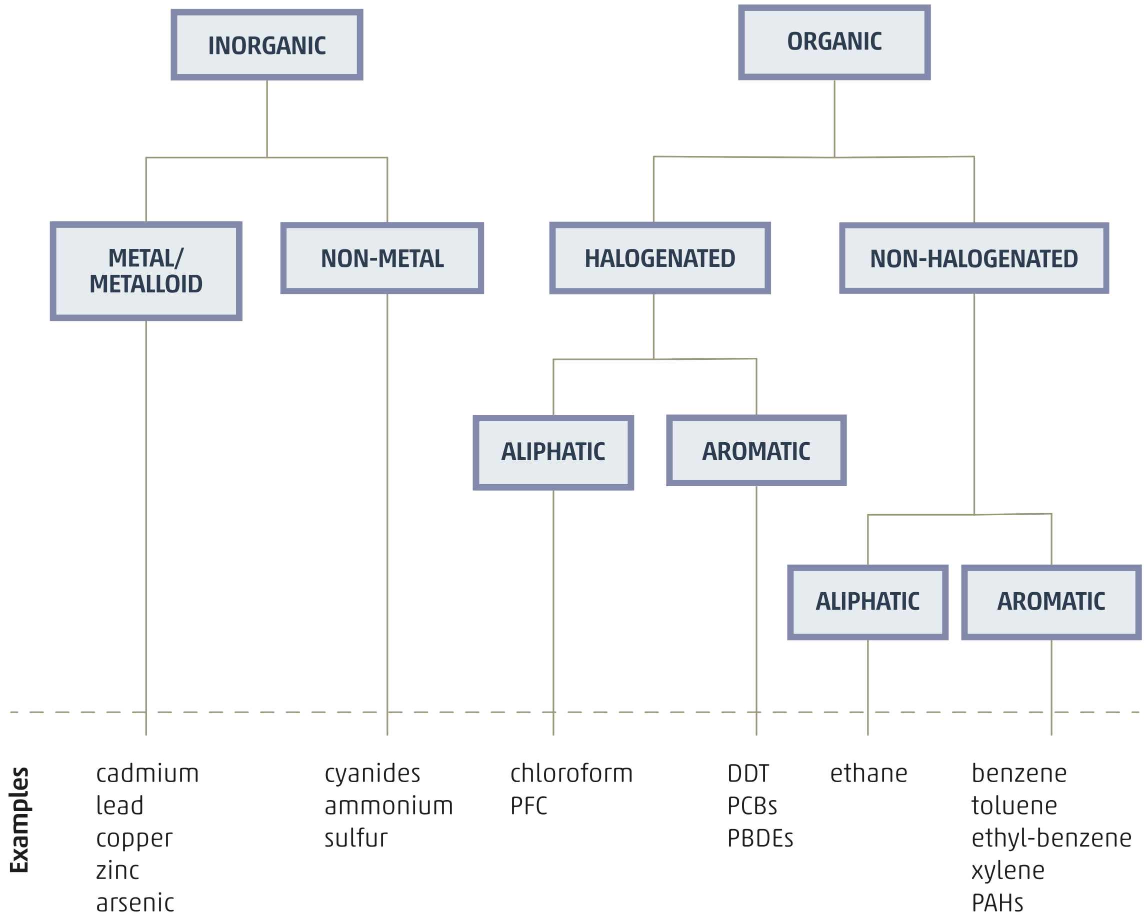


Figure 2. Systematic categorization of the main pollutants in soils according to IUPAC (Nič *et al.*, 2009). Halogenated compounds comprise fluorinated, chlorinated, and brominated compounds

Source: adapted from Swartjes, 2011

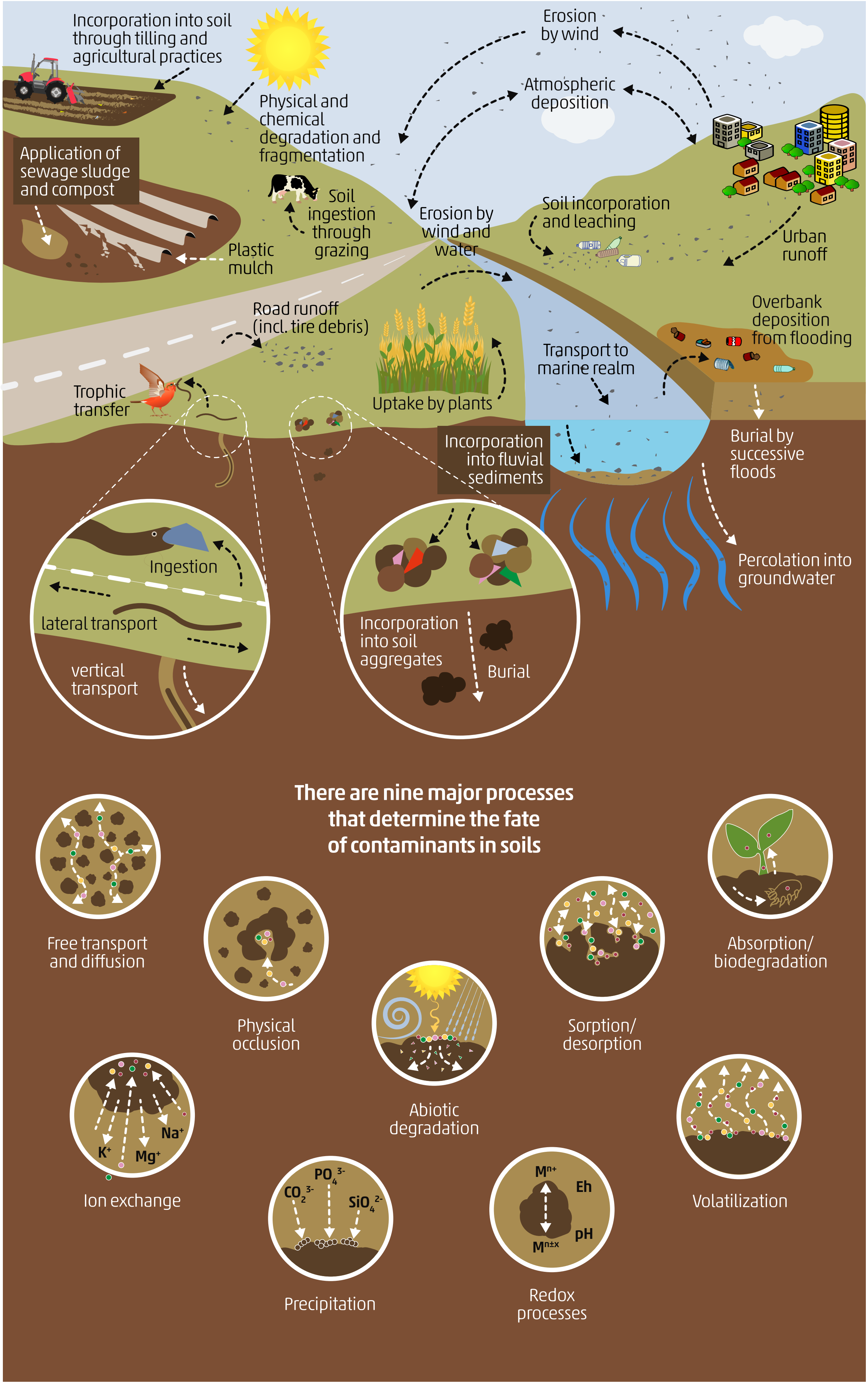


Figure 3. Routes of entrance and fate of contaminants in soils

Source: adapted from Hurley and Nizzetto, 2018

Soil pollution often has a long-term impact on human health (Figure 4) and many variables determine the relationship between exposure to soil pollution and disease, such as:

- Contaminant(s) and concentrations > humans are exposed to multiple contaminants at specific times and throughout their lives. The mixtures of contaminants to which we are exposed vary throughout our lives and can have synergistic, antagonistic or additive effects.
- Routes of exposure > there are three main routes of exposure (inhalation, ingestion, and dermal absorption), which are often combined and occur simultaneously.
- Source media of exposure > soil contaminants can reach humans through soil, dust, air, water or food. All can occur separately or simultaneously.
- Individual vulnerabilities and community specificity > people with pre-existing illnesses, or more vulnerable individuals such as foetuses, neonates and children will be more sensitive than healthy adults. Certain communities are at higher risk of exposure because of their traditions and food culture (e.g. geophagists), socio-economic status and proximity to pollution sources.

Inorganic contaminants

This group of contaminants includes elements or compounds that occur naturally in parent rock or that have an anthropogenic origin. The major inorganic contaminants (trace elements, radionuclides, and asbestos) are described below.

Trace elements [2]

The term "trace elements" refers to a group of ubiquitous elements that normally occur at very low levels in the environment and which can be toxic to organisms. Trace elements include heavy metals (that is, those metals with high atomic mass) such as lead (Pb), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), mercury (Hg), tin (Sn), nickel (Ni) and zinc (Zn). Non-metals that are regarded as trace elements include arsenic (As), antimony (Sb) and selenium (Se).

Trace elements are persistent and cannot be degraded by metabolic processes. Trace elements can occur in many different forms such as salts, oxides, sulphides, organo-metallic complexes, or may be present in the form of ions dissolved in soil solution. The partitioning among air, water and soil is driven by chemical processes such as adsorption to particles or pH-dependent dissolution in water (Alloway, 2012).

Trace elements have a geogenic (natural) origin, as many rocks contain high concentrations of trace elements that are released into the environment through weathering or anthropogenic action. Many soils have a natural background trace element concentration that originates from the soil parent material, which must be established if the human-induced increases in concentration are to be assessed. Soil pollution by trace elements occurs from point sources such as industrial areas, mines, landfills with disposal of trace element-containing wastes, paints, coal combustion residues, spillage of petrochemicals, and, to a decreasing extent, the deposition of exhaust gases emitted by leaded gasoline cars. Diffuse sources of trace element-pollution include fertiliser and pesticide application, land application of animal manures and sewage sludge, wastewater irrigation and atmospheric deposition (as polluted dust).

Trace elements accumulate in the tissues of living organisms. Some trace elements are essential micronutrients for organisms, including; iron, copper, zinc, manganese, nickel, boron, selenium and molybdenum. However at high concentrations they may be toxic. Among trace elements zinc, nickel, cobalt and copper are relatively more toxic to plants, and arsenic, cadmium, lead, chromium and mercury are relatively more toxic to higher animals including humans.

The human health consequences of specific trace elements such as arsenic, cadmium, lead, and mercury are well-known (Landrigan *et al.*, 2018). A wide range of organs and systems are affected by trace elements, causing cardiovascular disease, neuro-developmental alterations, haematological and immunological disorders, reproductive complications and cancer. The following provides information on three of the trace elements of most concern to health and the environment, although there are other trace elements also responsible for soil pollution (see the full report for more details on other trace elements).

Chronic exposure to arsenic can cause skin lesions such as hyperpigmentation, keratosis and ulceration; respiratory system problems; cardiovascular disease; neurological and developmental alterations; haematological and immunological disorders; reproductive complications; and cancer (WHO, 2020). The major source of arsenic is contaminated water, although food irrigated with arsenic-contaminated water or grown on polluted soil can also be a significant contributor of arsenic dietary exposures.

2 Elements that are generally found in soil at low concentrations, less than 100 mg/kg, that are biologically significant in some fashion. Biological significance would include elements that are essential or toxic to any organism where some elements can be both, depending on their concentration. Many of the trace elements of importance are metals, while others are metalloids, non-metals, actinoids, and halogens occurring a variety of chemical states (elemental, cations, anions, oxy-anions, methylated, etc.).

Lead is highly toxic to humans. The Lancet Commission estimates that nearly 2 percent of annual global deaths are due to lead as indicated in the Global Burden of Disease study; 82 percent of these deaths occur in low- and middle-income countries (Prüss-Ustün *et al.*, 2016). Lead causes increases in blood pressure, renal failure, strokes and other cardiovascular diseases in adults. In children, neurodevelopmental toxicity (including cognitive impairment) is the most important consequence of lead toxicity.

Mercury has numerous, well-known, health effects in humans, including cardiovascular, reproductive, and developmental toxicity, neurotoxicity, nephrotoxicity, immunotoxicity, and carcinogenicity, and as such is considered by WHO as one of the top ten contaminants of health concern (WHO, 2017). Babies are especially vulnerable as they can be exposed both by transfer through the placenta during pregnancy and through breast milk, leading to reduced and impaired development of the foetal and neonatal brain.

Radionuclides

Radionuclides are contaminants that produce ionising radiation during the decay of active atoms and, as such, pose a high risk to the environment and organisms. Soil pollution by radionuclides originates either from natural processes such as parent rock weathering and volcanic eruptions or from anthropogenic activities such as historical refinement of radium (for cancer treatment) and uranium, the use of radioactive phosphate and cobalt-ores, nuclear weapon tests or nuclear accidents.

Radionuclides in the soil are taken up by plants, and thereby becoming available for further redistribution within the food chain. Humans are exposed to ionizing radiation through inhalation and ingestion of contaminated food and soil particles. Ionizing radiation causes alterations in DNA, which leads to mutations and alterations of cells. Exposure to ionizing radiation has a long-term effect on the risk of cancers, including thyroid, leukaemia, salivary gland, lung, bone, oesophagus, stomach, colon, rectum, skin, breast, kidney, bladder, and brain cancer. The effects may only become apparent after several years or several decades of exposure (UNSCEAR, 2011).

Asbestos

Asbestos is a generic term for a wide range of naturally occurring hydrated mineral silicate fibres belonging to the serpentine and amphibole groups of rock-forming minerals. Asbestos has been widely used in a variety of construction materials. All types of asbestos fibres are potentially harmful to human health but effects depend on the type of asbestos material, its use, condition, location and exposure (WHO, 2019). Due to the high toxicity, 67 countries, as reported by the International Ban Asbestos Secretariat, have banned use of asbestos and asbestos containing materials. However major consumers of asbestos still exist, including India, China, Russia, Brazil and Indonesia (Kazan-Allen, 2019).

Although particularly important for occupational exposure, asbestos fibres can also be inhaled by people in areas surrounding mining sites or by accidental exposure during gardening and recreation activities due to erosion or weathering of soils and rocks containing asbestos. Inhaled asbestos is responsible for 80 percent of mesothelioma cases worldwide, a malignant tumour that affects lungs, abdomen or pericardium. Larynx cancer and ovarian cancer are also related to exposure to asbestos.

Organic contaminants

Organic contaminants are carbon-based molecules, many of which are anthropogenic in origin, but also to a minor extent compounds derived from natural processes such as wildfires or volcanic eruptions. Synthetic organic contaminants may be produced for specific uses, such as pesticides or as industrial chemicals or intermediate chemicals, such as polychlorinated biphenyls (PCBs) or other halogenated organics and volatile organic compounds. Organic contaminants may also be produced unintentionally as by-products such as industrial emissions, frequently from mining and petroleum industries, that release polycyclic aromatic hydrocarbons (PAHs).

Compared to metals and radionuclides, knowledge about the overall footprint of soils polluted by organic contaminants is lower. The diversity of organic contaminants is enormous and many studies have highlighted concerns about the unknown effects of mixtures of organic contaminants in soils and on ecosystems and human health. Organic contaminant-polluted soils are mainly localized around industrial or urban centres, although some organic contaminants have a ubiquitous distribution due to their potential for long-range transport and their persistence in the environment. Organic contaminants cause contamination of the food chain and pose a threat to human health.

Polycyclic aromatic hydrocarbons

PAHs are compounds containing only carbon and hydrogen. There are several thousand possible PAHs, released by natural events like volcano eruptions or forest fires or through a wide range of past and current anthropogenic activities such as production and combustion of petroleum and fossil fuels, open burning of municipal solid waste and incinerators, and creosote production. PAHs are ubiquitous contaminants in soils present in decreasing concentration in industrial, urban, agricultural and forestry soils (Zeng *et al.*, 2019).

Many PAHs, specifically the larger molecules, are carcinogenic, mutagenic and/or toxic for reproduction, the most toxic of which is benzo(a)pyrene. PAHs are highly lipophilic and can be absorbed from the lungs, gut and skin, and are able to pass the placental barrier affecting the foetal neurodevelopment. They have chronic consequences in adulthood, contributing to heart disease, obesity, and immunosuppression (Drwal, Rak and Gregoraszczuk, 2019).

Volatile organic compounds

The volatile organic compounds (VOCs) encompass a range of chemical classes that exist primarily as liquids that are highly volatile (that is, they readily change state from liquid to gaseous form) at room temperature. The VOCs most commonly encountered in soils are the BTEX compounds (benzene, toluene, ethyl benzene and xylenes), which are easily biodegraded. VOCs are mainly released from natural sources such as forest fires. Anthropogenic sources are becoming more relevant as activities such as the extraction and combustion of oil and natural gas, petrochemical activities and their use in industrial products such as paints, lubricants, adhesives, and other oil products. Their volatility makes quantitative determination of concentration in soil difficult, but VOCs are among the most significant categories of contaminants found at polluted industrial sites.

Due to their volatile nature, humans are mainly exposed to VOCs through inhalation, both in indoor air by diffusion of soil gas and outdoors (ATSDR, 2004). Ingestion and dermal contact are also possible but normally limited to occupational exposure. VOCs have a range of toxic effects, with some promoting carcinogenic, mutagenic and teratogenic responses. Hematologic effects, acute myelogenous leukaemia and myelodysplastic syndrome are the main diseases attributed to BTEX acute exposure supported by stronger evidence (Galbraith, Gross and Paustenbach, 2010).

Phenols, chlorobenzenes and chlorophenols

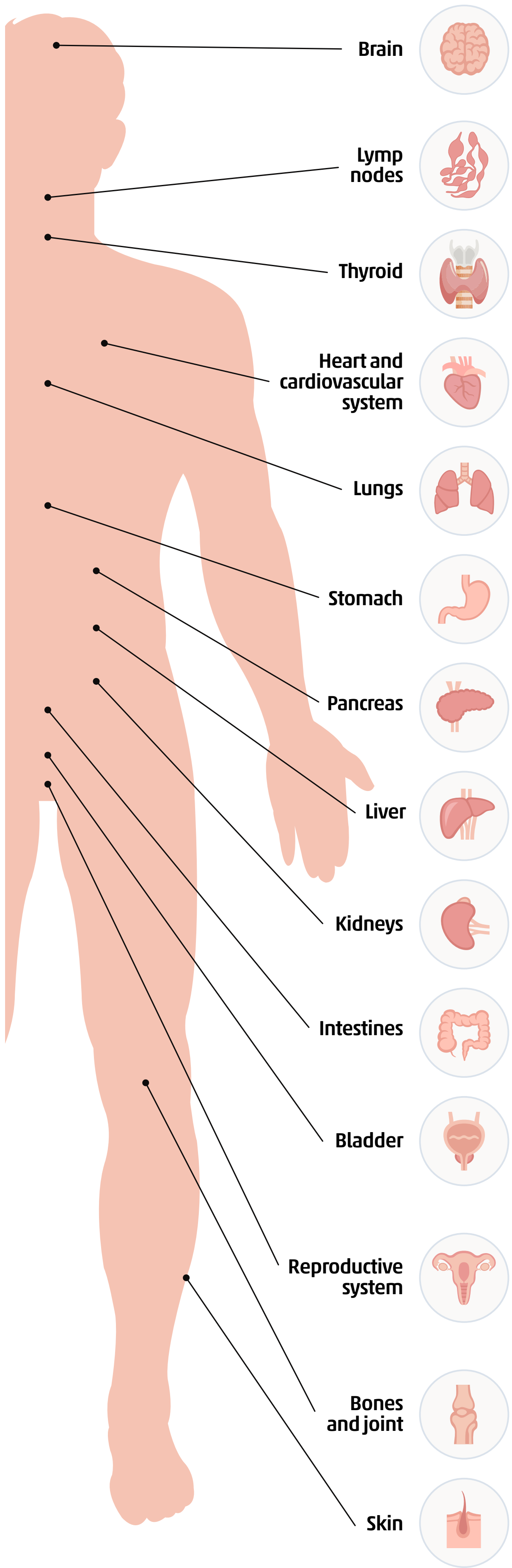
Phenols, chlorobenzenes and chlorophenols are chlorinated derivatives of benzene and phenol. Phenol and related compounds can occur naturally in soil via synthesis by plants and fungi, release by decomposition of organic matter, or chlorination by microorganisms of mono and polyaromatic compounds in soil and water. Industrial activities are important anthropogenic sources, such as the production of dyes, polymers, resins, pharmaceuticals, pesticides, fertilisers, disinfectants, and organic preservatives. They can be released during production, use and disposal of phenol-containing products, as well as in the generation of industrial and municipal wastewater, and reach the soil through wastewater, sewage sludge and direct release.

Human-made phenol-containing compounds are contaminants of priority concern due to their ubiquitous distribution in the environment, persistence and toxicity (ECB-JRC, 2006). Phenolic compounds can easily be absorbed by the skin and respiratory and gastrointestinal track, and once in the body, they go through metabolic degradation in liver, gut and kidneys that lead to the formation of more reactive species. They are potent neurotoxins. Chlorophenols are considered as potential carcinogenic to humans. Endocrine disrupting activity has also been reported in animals and humans. Although the environmental exposure to these contaminants is low, few or no studies are available on the effects of acute or chronic exposure to this category of contaminants in humans (ATSDR, 2020).

Explosives

Although explosives are not as widely distributed in the soil as other organic contaminants, there are still many polluted areas inherited from the First and Second World Wars, from civil wars, and from military sites scattered around the planet. Production facilities and training ranges are the most common sites polluted with explosives. Soil pollution mostly comes from the use of nitro aromatic explosive compounds (such as trinitrotoluene (TNT), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) and 1,3,5-trinitroperhydro-1,3,5-triazine (RDX)), for which the United States of America EPA has recommended concentration restrictions because of their toxicity for the environment and human health (Chatterjee *et al.*, 2017).

The population may be exposed to these contaminants by ingestion of polluted soil or food produced in polluted soil and neighbouring areas, as well as by accidental inhalation or direct dermal contact with the contaminant or polluted soil. Ecotoxicological effects have been observed in bacteria, aquatic and terrestrial organisms and crops, and thus similar mechanisms could be expected in humans. However, health outcomes of exposure to explosives have scarcely been studied and controversy exists on some of the results (Lima *et al.*, 2011).



Lead, manganese, mercury, tin, PBDEs, PAHs, PCBs
Neurodevelopmental impairment, reduction of intelligence quotient, behavioural disorder, Parkinson-type syndrome, headache

BTEX, lead, PFAS, PCBs
Altered immune response, reduced response to vaccines in children

Cadmium, PCBs, PBDEs
Altered metabolism and reproductive hormone levels, reduced thyroid hormones, altered growth

Benzene, lead, mercury, organochlorine pesticides, PAHs, PFAS, PCBs, microplastics
Hypertension, haemolysis, anaemia, cardiovascular disease, elevated leucocyte count, leukaemia

Arsenic, asbestos, cadmium, chromium, copper, mercury, radon
Pulmonary emphysema, asthma, chemical pneumonia, lung cancer, mesothelioma

Nitrogen and ionizing radiation
Stomach cancer

Phthalates, PCBs
Altered insulin metabolism and adipogenesis, diabetes

DDT, chromium, copper, mercury, PAHs, PCBs, PFAS, phthalates
Increased cholesterol levels, liver cancer, elevated hepatic enzyme levels, necrosis

Cadmium, lead, mercury, PAHs, PFAS
Renal tubular dysfunction, kidney weight changes, progressive nephropathy, chronic inflammation, kidney cancer

Arsenic, copper, lead, mercury, tin, microplastics, POPs
Nausea, vomiting, diarrhea, cancer of gastrointestinal system, abdominal pain and cramping

Arsenic, lead
Cancer of urinary bladder, urinary changes

Antimony, asbestos, lead, manganese, phthalates, PBDEs, PCBs, PFAS
Testicular atrophy, early menopause, reduced testosterone, reproductive alterations, decreased libido, impotence, sexual dysfunction, endometriosis, hormonal cancers (breast, prostate, testes), infertility, ovary cancer

Cadmium, lead, PCBs, radium and its decay products
Impaired bones development, slow growth, changes in metabolism of calcium and bone formation, osteomalasia, bone cancer

Arsenic, chromium, PAHs, PCBs
Hyperkeratosis, hyperpigmentation, hypopigmentation, skin irritation and inflammation, chloracne, hirsutism, skin, tooth, and nail abnormalities

Figure 4. Main effects of soil contaminants on human health, indicating the organs or systems affected and the contaminants causing them

Source: created from information in ATSDR, 2018; Campanale *et al.*, 2020; Carré *et al.*, 2017 and references cited in Table 2 of Chapter 4 of the full report

Dioxin and dioxin-like compounds

Dioxins and dioxin-like compounds, including polychlorinated/brominated dibenzo-p-dioxins (PCDDs/PBDDs), polychlorinated/brominated dibenzofurans (PCDFs/PBDFs) and dioxin-like polychlorinated biphenyls (dl-PCBs) are groups of organic compounds containing benzene and variable amounts of chlorine. The formation of PCDDs and PCDFs occurs mainly as a by-product of industrial processes associated with incomplete combustion during incineration processes, including improper waste incineration and burning of trash, especially electronic waste. As a minor source they can also be formed during natural processes such as forest fires and volcanoes.

Although concentrations of PCDDs and PCDFs in soils are low, these compounds are extremely persistent and are able to pass through cell membrane and accumulate in living tissues. Currently there is concern about these compounds, since low levels are enough to produce birth defects in small mammals, to interact with DNA, and to cause carcinogenicity (WHO, 2016). Intake of contaminated food is the main route of exposure to dioxins. Dioxins and dl-PCBs have been related to higher incidence of cancer, neurological retardation and ultimately as a cause of death. Non-Hodgkin's lymphoma and suppression of the immune system are also attributed to the exposure to dioxins. Chloracne is probably the most well-known disease related to dioxins exposure but this is caused by exposure to high concentrations (serum levels > 20 000 pg/g fat), several orders of magnitude greater than environmental background levels and food concentrations (Knutsen *et al.*, 2018).

Polychlorinated biphenyls

Non dioxin-like polychlorinated biphenyls (ndl-PCBs) are also widely distributed contaminants, highly persistent in the environment and able to accumulate in the food chain. They are rapidly absorbed from the gastrointestinal tract, from where they are distributed to and accumulate in the liver and adipose tissue. Since they also cross the placenta and are absorbed in milk, PCBs can accumulate in the foetus and infant.

Because of PCBs' high chemical stability and electrical resistance, they were used in a wide range of industrial applications including fluids in capacitors and transformers, hydraulic fluids, fire retardants and plasticizers. Given the concerns regarding environmental persistence and toxicity, PCBs use and production ceased in most countries by the end of the 1970s, and they belong to the group of twelve initial Persistent Organic Pollutants (POPs) under the Stockholm Convention. However, the legacy of PCBs already released into the environment and the control of further releases remain a concern (Klocke and Lein, 2020).

In soils and sediments, PCBs are strongly adsorbed to organic carbon and thus the soil acts as a sink for PCBs. If soil management practices reduce the amount of soil organic carbon, PCBs can be released and enter the food chain. The main route of exposure to ndl-PCBs is through ingestion of contaminated food and water. Ndl-PCBs are endocrine disruptors and have been related to immunotoxicity, neurotoxicity, and carcinogenesis, especially related to breast cancer (Carpenter, 2015).

Polybrominated diphenyl ethers

Since their introduction in 1970s, polybrominated diphenyl ethers (PBDEs) have been used as brominated flame retardants in a broad array of materials such as plastics, foams, resins and adhesives. Their production has been phased out in many countries since their inclusion in the Stockholm Convention list of POPs, and the environmental and human loads have reduced over time since then. However, PBDEs are found in virtually all environmental matrices, including wild organisms and humans, due to their long persistence, and their use in many products (Besis and Samara, 2012).

PBDEs can reach the soils by dump sites, landfill leachates and application of sewage sludge as a nutrient amendment. Relatively high concentrations have been reported especially in e-waste dismantling and recycling areas. In soils, PBDEs can bind to organic matter, persist for a long period of time (estimated half-lives of 28 years), impact soil biota by bioaccumulation and biomagnification across the food chain, and be transferred to aquatic ecosystems (fresh and marine waters) by sedimentation.

PBDEs have been associated with neurotoxicity, and several studies have found sound evidence of the relationship between prenatal PBDEs exposure and impaired motor, cognitive and behavioural abilities in small children, who show lower intelligence quotient (IQ) levels or aggressive behaviour among other effects. These effects may be related to the impact of PBDEs on thyroid hormone production and regulation, with PBDEs being endocrine disruptors. Several cancers have also been associated with the PBDEs body burden, including breast, colorectal, papillary thyroid, and ovarian and cervical cancers or endometrial carcinoma (Wu *et al.*, 2020).

Perfluoroalkyl and polyfluoroalkyl substances

Perfluoroalkyl and polyfluoroalkyl substances (PFASs) are a family of human-made chemicals that have been shown to be persistent in the environment, toxic for both animals and humans, and highly mobile in aquatic environments. The PFAS family may include between 5 000 and 10 000 different chemicals and therefore the range in behaviour is highly diverse. Many PFAS are resistant to oil, water, grease and heat, and hence are used in applications such as water- and stain-resistant fabrics and floor coverings, paints and cleaning products, and fire-fighting foams (ITRC, 2020).

The main sources of PFAS in the environment are spills, air emissions and inadequate disposal of manufacturing waste and wastewater. These sources have left worldwide environmental contamination and pollution in surface and groundwater and soils even in remote areas, as well as in food such as fish, meat and eggs, resulting in public concern for their risk to human health and ecosystems. Recent estimates of global loads of some PFAS in soils range from 1 500 to 9 000 tonnes, showing that soils constitute a global reservoir of these long-lived contaminants (Brusseau, Anderson and Guo, 2020).

PFAS are endocrine disruptors, and interact with thyroid hormones, altering cardiovascular system functioning and lipids metabolism, increasing the risk of obesity. Increased concentration of cholesterol and other lipids in blood, or dyslipidaemia, is one of the major health effects attributable to PFAS, associated to chronic diseases such as obesity, hypertension, diabetes and hepatotoxicity. Some evidence also relate prenatal PFAS exposure to neurodevelopmental impairment, but further research is needed in this field (Sunderland *et al.*, 2019).

Pesticides

Pesticides are active substances, or mixtures of substances, used for preventing, destroying or controlling any pest causing harm to humans or interfering with human activities such as production, processing, storage, transport or marketing of food, wood and wood products, fibres and other agricultural commodities. Insecticides, fungicides, nematicides, rodenticides and herbicides are some examples, which can also include insect repellents and insect or plant growth regulators. Today, there are about 1 000 different pesticides in use composed of more than 800 active ingredients and the number is still increasing.

Historically, the use of pesticides has allowed great advances in agriculture and also in the public health sector as vector control for diseases such as malaria. However, the excessive and inappropriate use of pesticides, and the mismanagement of obsolete and highly harmful pesticide stocks, can cause unintended damage to non-target species (FAO and ITPS, 2017). There is considerable societal concern about the use of pesticides. The greatest problem is that stores of obsolete pesticides still occur in many countries. Spills and leakage from these depots continue to cause significant soil pollution. Accidental spills and leakage of non-restricted pesticides as well as improper disposal of storage containers can lead to unsafe levels of pesticides in soils; this is a widespread point source of soil pollution. Pesticides have been spread throughout the earth-atmosphere system and pesticide contamination occurs worldwide. Many studies have highlighted concerns about the unknown effects of pesticide mixtures in soils on ecosystem and human health; however, given the great number of pesticides in use it is virtually impossible to study and assign toxicity risks to the possible combinations (Bonner and Alavanja, 2017; Kim, Kabir and Jahan, 2017).

Many pesticides are highly persistent in the environment and toxic residues can affect beneficial and non-target organisms, including humans, and contaminate waters and soils on a global scale. A number of pesticides and pesticide residues can bio-accumulate in high concentration in plants and animals and cause biomagnification in the food chain. Some pesticides are also associated with trace element contamination of soils.

Outbreaks of pesticide-contaminated food have been reported in many places, although the source of pesticides are barely studied in depth (Ge *et al.*, 2017; Hwang, Zimmerman and Kim, 2018). Studies on health effects from exposure to pesticides are mainly related to occupational exposure or self-poisoning, at relatively high concentrations that do not occur in the general population. The number of epidemiological studies linking chronic diseases to environmental exposure to pesticides is very low due to their wide distribution and coexistence with other contaminants, and the difficulty of establishing casual relationships, coupled with limited support for this type of research. However, scientific evidence points to a relationship between pesticide exposure and chronic diseases such as cancer, asthma, allergies and development impairment (Kim, Kabir and Jahan, 2017).

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Emerging contaminants

Emerging contaminants are a broad group of synthetic or naturally occurring chemicals and microorganisms that have not been previously monitored in the environment, but that are generating increasing concern among the scientific community and policy makers due to their potential toxicity or risk to human and environmental health.

Pharmaceuticals and personal care products (PPCPs)

Pharmaceuticals can be defined as any active chemical (natural or synthesized) that is designed to prevent or cure diseases and to improve quality of life for humans or animals. There are more than 4 000 pharmaceutical and chemical products that have been used extensively for decades, including pharmaceutical drugs, diagnostic agents, oral contraceptives, cosmetics, fragrances, nutritional supplements and additives used in many household cleaning items. Many PPCPs are biologically active compounds, designed to interact with hormonal processes or living tissues; for this reason, it is important to know their fate, effects and potential risks when they are released into the environment. Some of these chemicals are persistent in the environment while others are considered 'pseudo-persistent' due to the continuous use and release into the environment. Global production is estimated in the range 100 000–200 000 tonnes/year, but only few PPCPs are monitored and regulated, and for most no legal requirements exist to assess the impact of long-term exposure (Boxall *et al.*, 2012).

Pharmaceuticals, after administration, are absorbed and undergo metabolic reactions to produce by-products (metabolites) that can be more harmful than the original compounds or can be transformed back to the original active compounds. A high proportion of drugs are not completely assimilated by humans or animals; the original compound or partially metabolized (sometimes activated) drug residues are excreted in faeces or urine. These compounds cannot always be completely degraded by conventional wastewater treatment plants before entering the environment. PPCPs are thereby continuously being released into urban wastewater and animal manure. When this manure and sewage sludge are applied to agricultural lands as fertilisers, or when treated wastewater is used for agricultural irrigation, crops can uptake PPCPs that may persist in soils from a few to several hundred days (Al-Farsi *et al.*, 2018).

To date, information on the occurrence of PPCPs in the environment is incomplete, as is knowledge on their effects on non-target organisms and potential risk of exposure. The adverse effects of PPCPs exposure include acute and chronic toxicity, bioaccumulation, endocrine disruption, inflammation, irritation, changes in fertility and gender rates in population, and development of asthma, although relevant epidemiological studies are very limited or absent (Pereira *et al.*, 2015; Wilkinson *et al.*, 2016). PPCP release into the environment also leads to microbial and bacterial resistance, causing 700 000 death each year due to drug-resistant diseases (Miranda, Godoy and Lee, 2018).

Plastics and synthetic polymers

Plastics are widely used in nearly all aspects of everyday life because of their versatility, high performance, high resistance and cost effectiveness. Plastics, polymers and other related materials mainly originate from the processing of crude oil and natural gas, and in some cases from other raw materials (such as coal and biomass). The annual worldwide production of polymeric resins escalated since the 1950s, and it is estimated to grow to nearly 500 million tonnes per year by 2100 (Li, Tse and Fok, 2016). Due to the high resistance to degradation and improper disposal, plastic items and residues are commonly found in all environmental compartments. Plastics persist in the environment for decades, and can be partially broken down by mechanical action (agricultural machinery, garbage collection trucks and treatment plants) or weathering, which leads to a great variety of plastics of different sizes in ecosystems.

Micro- and nanoplastics particles can be ingested and absorbed by organisms and transferred across the food chain. Intake of contaminated food and water is the major route of exposure to micro- and nanoplastics for humans. Evidence of bio-accumulation and biomagnification of plastics in the terrestrial food chain suggested that plastics also accumulate in human bodies. New evidence shows the accumulation of micro- and nanoplastics in human tissues, being able even to cross the placenta (Ragusa *et al.*, 2021). However, the risk posed by plastics to human health and the environment is not only their presence *per se*, which may cause oxidative stress, inflammation, severe immune responses, or alter the ability to detect exogenous materials and react against them, but their capacity to adsorb and transport other contaminants and plastic additives that can be released in the organism (Prata *et al.*, 2020). Further research is needed to understand the routes of exposure and the possible adverse effects in our health.

Phthalates and other plasticizers

Plasticizers, such as bisphenol A (BPA) or phthalate esters (PAEs), are additives that increase flexibility or plasticity, and are used in industry as plastic additives to make plastic goods more flexible. They are found in electronic devices, sport equipment, medical devices, food storage containers, reusable bottles, building and construction materials, automotive parts, and in thermal papers, such as credit card slips, bank receipts, and fax papers. Phthalates have been also employed in the cosmetics and perfumery industries (Wang *et al.*, 2018).

The plasticizers are not chemically bound to plastic polymers, and consequently can easily leach into the environment and are released during plastic weathering. PAEs and BPA are found in many agricultural soils close to urban or peri-urban areas and can come from sewage sludge application, agricultural use of plastic films, use of urban wastewater for irrigation, or atmospheric deposition. Both phthalates and BPA have been detected in food and in humans, and are listed as toxic agents in international regulations.

Phthalates are recognized endocrine disruptors and teratogens. Children are the most vulnerable to phthalates exposure, suffering from food allergies and neurobehavioral disorders in prenatal and early life exposure (Benjamin *et al.*, 2017).

Nanomaterials

Nanotechnology emerged in the 1990s and its use and applications have greatly expanded since then. Nanomaterials are defined as materials with at least one dimension between 1 and 100 nm, but the nanoparticles with all three dimensions between 1 to 100 nm are particularly important (ISO, 2008). Manufactured nanomaterials (MNM) have numerous applications in medicine and technology and have enabled many advances in countless scientific fields, including plastics, electronics, textiles, cosmetics, catalysts and medicinal science. MNM are diverse in terms of physical, chemical, electrical and magnetic properties.

The MNMs can be applied deliberately to soil for remediation of pollution but are also released unintentionally through various pathways including wastewater and sludge. Soil is a major sink, and the current growth in nanotechnology for targeted pesticide and fertiliser delivery in food crop production will likely increase MNM input to soil systems (Kuenen *et al.*, 2020).

Their intrinsic characteristics and small size facilitate the diffusion of nanomaterials through cell membranes. The interactions between nanomaterials and cellular components and genetic material have not yet been fully elucidated and vary according to the size, morphology, surface charge and coating of the nanomaterial. Inhalation is the main route of exposure to MNM, especially on occupational exposure, but ingestion may become more relevant as nanotechnologies in food and food packaging evolve. Dermal exposure can also be significant for consumers. Studies of the impacts of MNM on the environment and human health are still at early stages and existing data are not sufficient to understand the mechanisms of toxicity. The evidence that could attribute MNM exposure to different diseases is still very scarce, so no robust conclusions can be drawn. Further research on the fate, behaviour, bio-availability and toxicity in soils, and improved knowledge on environmental concentrations, remains critical for environment and human health protection (Pietroiusti *et al.*, 2018).

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Impacts of soil pollution on ecosystems

Soil pollution affects above and below ground biodiversity, both by reducing the number of organisms due to the toxicity caused by the contaminants, and by producing changes in communities, due to the replacement of more sensitive species by more pollution-tolerant ones. Low concentrations of contaminants in the soil often lead to adaptive strategies through changes in physiology and feeding behaviours. Changes in the activity of soil organisms can also occur, resulting in the alteration of biogeochemical cycles. Additionally, polluted soils in turn become a source of pollution for groundwater, through leaching of contaminants, and for fresh water and the marine environment, since contaminants can be transported off-site through wind and water erosion. All those changes can be gradual or remain inert until an inflexion point is reached and a severe degradation occurs. This triggers a chain of degradation processes in terrestrial and aquatic ecosystems that ultimately leads to the loss of ecosystem services (Figure 5).

Figure 5. Soil pollution causes a cycle of degradation processes that leads to the reduction and ultimately to the loss of ecosystem services

Biodiversity loss reduces the input of litter on the soil surface and litter breakdown and mineralization of organic matter, and hence reduces the input of soil organic carbon and alters the recycling of nutrients. Litter decomposition can be reduced by 10 to 80 percent in severely polluted soil compared to uncontaminated soil (Kozlov and Zvereva, 2015).

Degradation of physical properties caused as a result of the loss of soil organic matter and reduced presence and activity of soil organisms also occur in heavily polluted soils (Korkina and Vorobeichik, 2018). The presence of certain contaminants, such as salts and surfactants, also contributes to the dispersion of clays and the irreversible degradation of the soil structure. This physical degradation of the soil increases the risk of soil erodibility.

Soil acidification is, together with soil pollution, one of the most overlooked threats to soil health, due to the pH buffer capacity of soils; however, pH buffering capacity is limited, especially in sandy soils. In agricultural areas, soil acidification is mainly caused by the application of mineral nitrogen fertilisers and livestock urine, and by the repeated harvesting of plant biomass. It has been estimated that soil pH has reduced globally an average of 0.26 due to acid deposition and N additions (Tian and Niu, 2015). Soil acidification also enhances the mobilization and bioavailability of certain trace elements, increasing the risk to human health and the environment and decreasing crop growth.

N-fertilisers are oxidised to nitrite (NO_2^-) and nitrate (NO_3^-) by nitrifying soil bacteria. Nitrate and nitrite are highly mobile in soils and can be leached to groundwater. Inside the soil matrix, denitrifying bacteria convert nitrate into elemental nitrogen (N_2 gas which is harmlessly returned to the atmosphere), through intermediate species nitric and nitrous oxide (NO and N_2O), which are highly volatile and can escape from soils into the atmosphere. N_2O is a highly potent greenhouse gas, with a global warming potential 256 times greater than CO_2, and therefore contributes significantly to climate change (IPCC, 2014). According to the Intergovernmental Panel on Climate Change (IPCC) report on Land and Climate Change, denitrifying bacteria are responsible for 80 percent of the emissions of N_2O (IPCC, 2019).

Soil pollution impacts on terrestrial ecosystems and the food chain

The ecotoxicological responses to soil pollution in terrestrial ecosystems are highly variable, and depend on the source of pollution, main contaminants, duration of the exposure, the trophic level affected and climate. In general, trophic groups reduce their performance in the sense of body size and survival with the proximity to the pollution source, while primary consumers are more resilient to pollution in terms of diversity and abundance (Kozlov and Zvereva, 2011). However, responses to stress are site-specific and the generalization of local patterns into a global scale has high uncertainties.

A wide range of contaminants are absorbed onto plant roots and translocated to edible tissues. Soil-dwelling organisms can also accumulate soil contaminants. Plants and soil organisms are at lower levels in the terrestrial food web, and when they are ingested by grazing animals, birds, amphibians or mammals, contaminants enter in the terrestrial food chain and accumulate in large amounts in animals at the top of the food chain (Figure 6) (Baudrot *et al.*, 2018; Huerta-Lwanga *et al.*, 2017).

Normally, wildlife exposure to contaminants occurs at low-dose levels over their lifetime span, unless heavy release of contaminants has occurred. The health effects of chronic low-dose exposure and the synergistic, summative or antagonistic effects of such mixtures have generally been neglected in terrestrial ecosystems. Soil contaminants have neurotoxic, carcinogenic, teratogenic and endocrine disrupting effects in vertebrates. The effects on animal health and behaviour depend on the type of contaminant and the mix of contaminants to which animals are exposed, the living and dietary habits, which determine the time and intensity of exposure, and the development and immune status of the animal; immature or ill organisms are more susceptible to negative effects and are less able to avoid polluted areas and food (Death, Griffiths and Story, 2019).

Herbivores differ from omnivores in terms of exposure to contaminants, while the former accumulate higher concentrations of trace elements or radionuclides; the latter usually present higher concentrations of lipophilic contaminants, such as PCBs or PFAS (Kowalczyk *et al.*, 2018). Reptiles and amphibians are particularly sensitive to hydrophilic and ionic contaminants, as these can pass their permeable eggs wall, and be in contact with them through the different phases of their life cycle (Sparling *et al.*, 2010).

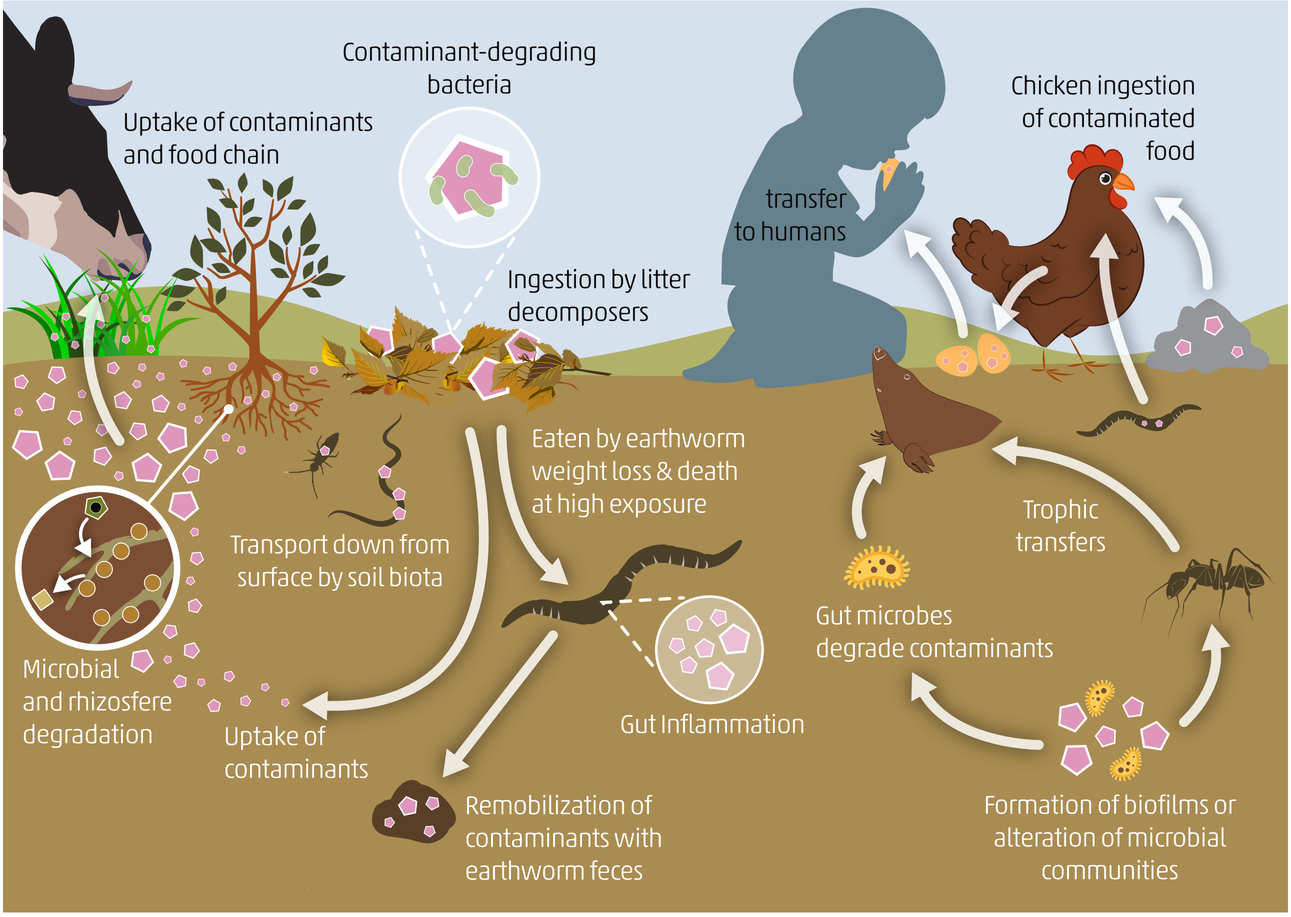

Figure 6. Contaminants' transference into the terrestrial food web from the soil to pastures and crops, which are ingested by wildlife, livestock and humans, or from the soil to invertebrates, ingested by birds and poultry and ultimately transferred to humans

Source: adapted from Ng *et al.*, 2018

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Soil pollution impacts on aquatic ecosystems

Precipitation, floods, snowmelt, and irrigation increase the water content in soil pores and, once soil is saturated, can lead to waterlogging of flat areas and run-off on slopes. Dissolved organic matter, fine particles, and sorbed contaminants are carried by runoff water and can reach nearby wetlands, rivers and lakes, and ultimately be transported to seas and oceans (Shi and Schulin, 2018). Climate change exacerbates these processes, increasing the risk of contamination of the aquatic environment by land-based activities (Figure 7).

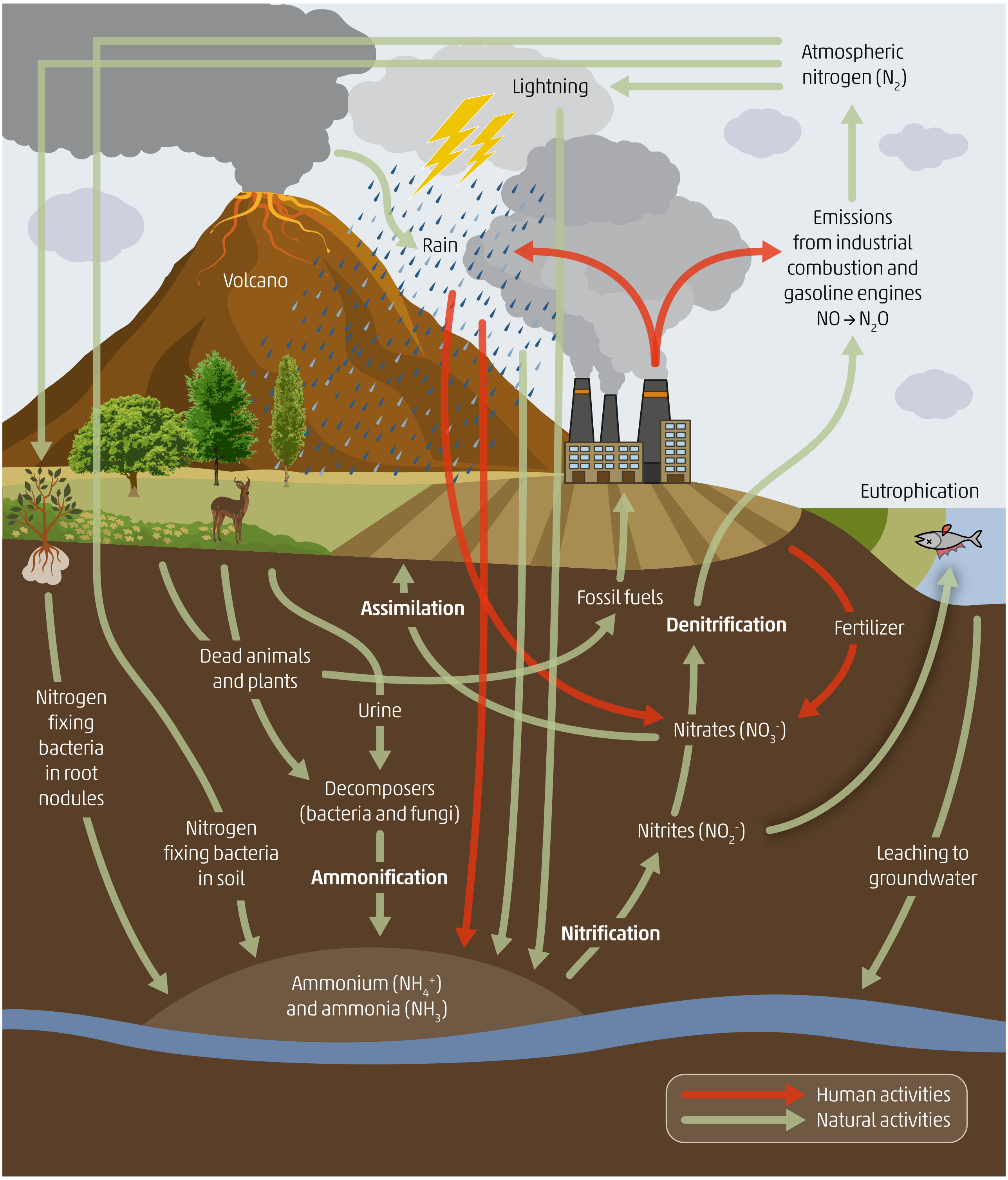

Figure 7. Processes in the terrestrial environment exacerbated by climate change that enhance the impact of soil pollution on the aquatic environment

Source: adapted from Encyclopedia Britannica, 2020; Lehnert *et al.*, 2015

Land-based activities are considered to be responsible for over 80 percent of marine pollution (Cicin-Sain *et al.*, 2011). An estimated 35 billion tonnes of soil are lost and mobilised each year due to erosion; of this total about 12 billion tonnes are agricultural topsoil and topsoil-associated nutrients and contaminants, which are discharged in streams, rivers, lakes and coastal areas every year (Kok, Papendick and Saxton, 2009). Runoff increases nutrient loading causing eutrophication of waters, carries inorganic and organic contaminants that reduce water quality and affect aquatic ecosystems, and also carries soil particles that cloud water and reduce the depth of watercourses.

An estimated average of 50 percent of nutrients added to soils are leached or washed into rivers, lakes and ultimately seas and oceans (Cosme, Mayorga and Hauschild, 2018). Nutrient loss from soil causes excessive levels of nutrients in waterways, which favours eutrophication and the appearance of cyanobacteria and algae blooms that consume large volumes of oxygen, preventing the life of other organisms. Some of these cyanobacteria are also toxic to aquatic organisms and humans (Lehnert *et al.*, 2015). Eutrophication cycles produce "dead zones" in many of the world's major water bodies, such as the Gulf of Mexico, the Bay of Bengal, Hudson River, San Francisco Bay, the Mediterranean Sea, and the Baltic Sea.

Mismanaged waste disposal in coastal countries is responsible for 4.8 to 12.7 million metric tonnes of plastic entering the ocean by wind erosion, or transported via waterways or wastewater, while between 75 000 to 1.1 million tonnes are discharged in rivers from in-land activities (Eunomia, 2016). In agricultural soils alone, the microplastics content is estimated to be between 63 000 - 430 000 and 44 000 - 300 000 tonnes in Europe and North America, respectively (Nizzetto, Futter and Langaas, 2016). Once ingested, micro- and nano-plastics can have various effects on aquatic organisms, ranging from physiological alterations in primary production organisms (alteration of chlorophyll production), to appetite inhibition, reduced growth or even collapse of the digestive system due to accumulation of plastics in higher animals and consequent death. Additionally, plastics adsorb other contaminants into their surfaces, such as trace elements, PAHs, pesticides, and other organic contaminants, contributing to their transfer to the food web and causing additional health effects on aquatic organisms (Alimi *et al.*, 2018).

Socioeconomic impacts of soil pollution

Soil pollution has the greatest impact on the health of the most vulnerable population groups, such as foetuses, children and pregnant women. Pollution also has significant effects on the health and well-being of the poorest and marginalized groups (Landrigan *et al.*, 2018). Low- and middle-income countries accumulate the highest rates of environmentally attributable mortality and burden of diseases, but there are also differences in health status between different social groups within a country.

The most impoverished countries and regions have the least access to clean technologies, to pollution remediation technologies, and their environmental and food safety regulations are often weaker (Mackie and Haščič, 2019). Access to clean green spaces, healthy food, public sanitation or health insurance, environmental and urban development policies, and clean technologies are the major socio-economic determinants influencing the unequal distribution of the burden of disease attributable to the environment (Pasetto, Mattioli and Marsili, 2019).

Many developing countries have proved capable of rapidly adopting standards and measures to reduce the release of contaminants into the soil, but need knowledge and technology transfer from more developed countries (Hilton, 2006).

Soil pollution has a direct cost of remediation and management, which can oscillate from thousands of dollars to hundreds of millions of dollars annually. The cost of remediation varies from site to site depending on the characteristics of the site, such as the size of the affected area, the concentration of contaminants, the environmental compartments to be remediated (topsoil, vadose zone, groundwater, surface water), the protective measures to be taken to protect the population during the remediation work, the acceptable level to be achieved depending on the land use after remediation, as well as the technology chosen (Darmendrail *et al.*, 2004).

There are other indirect costs that are often neglected, leading to underestimation of the impacts of soil pollution. Many ecosystem services are hampered by soil pollution, losing productivity and resilience in the long term (Figure 8). Soil pollution causes reduced crop yields and food wastage due to high levels of contaminants, loss of biodiversity and increased incidence of pests, decreased water quality and eutrophication of the marine environment. The economic cost of soil pollution-related illnesses, many chronic and with long-term effects, and the loss of human productivity are often overlooked (Attina and Trasande, 2013).

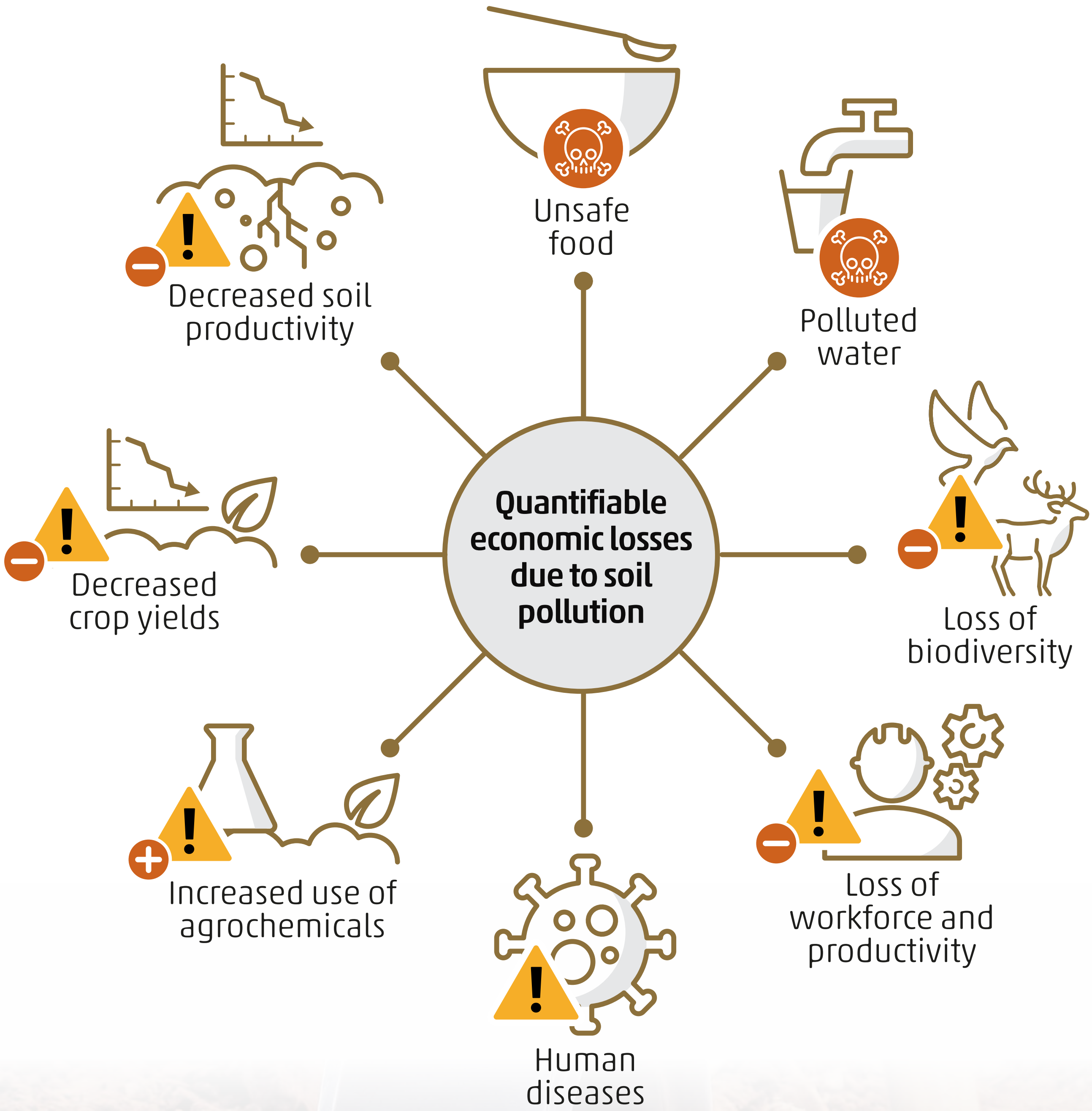

Figure 8. Quantifiable economic losses due to soil pollution

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Regional status and trends of soil pollution

An assessment of the extent and severity of existing polluted soils is essential to understanding the magnitude of the problem and to determining the priority that addressing the problem should have, given the many stressors on the environment that exist.

Although most soil contaminants are ubiquitous, their distribution and major sources vary among regions. There are also significant differences in the regulatory frameworks that attempt to address soil pollution. The following sections summarize the major sources of soil pollution and present the state of knowledge of soil pollution in the different regions (Figure 9).

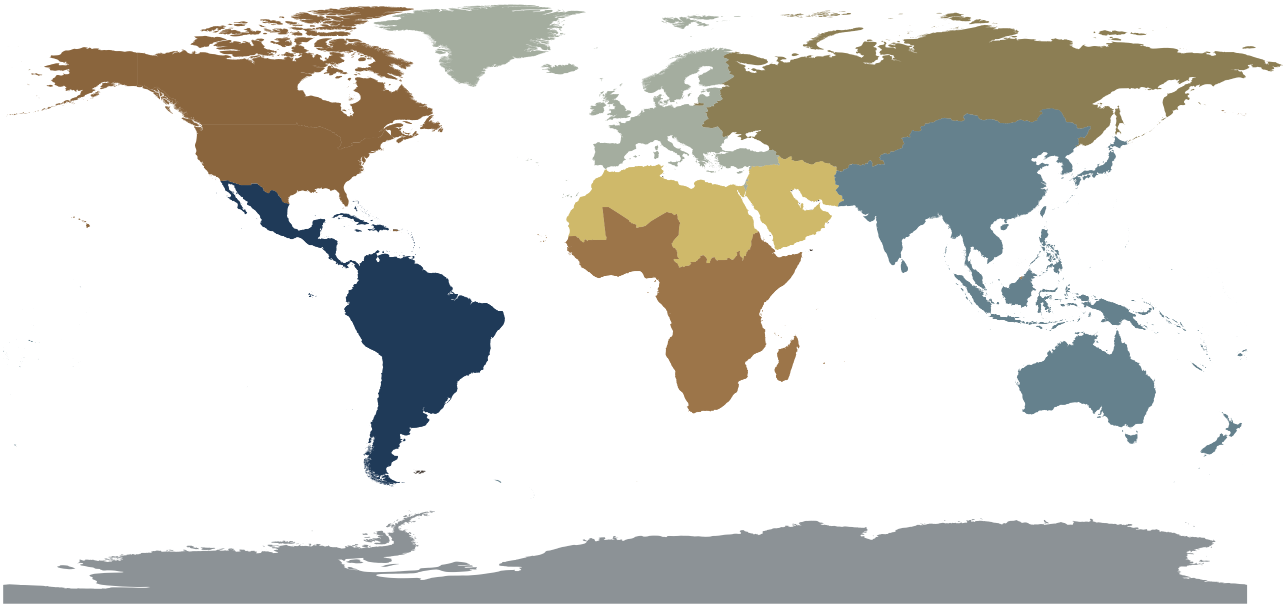


Figure 9. Global Soil Partnership regions as considered in this report
Source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

To assess the regional extent of current soil pollution, two methodologies were adopted. First, a questionnaire developed by the leading United Nations agencies was sent to countries through the Global Soil Partnership (GSP) Focal Points and partners' networks as well as the UNEP network. The questionnaire (included in Annex 1 of the main report) was used to gather information about national and regional legislation, the main polluting activities as perceived by the government agencies, and existing data on soil pollution in inventories and soil monitoring systems, as well as monitoring systems related to human health. Second, the authors gathered publicly available information from a broad range of sources, including reports from international organizations, regional and national agencies, environmental organizations, and scientific literature. This report also complements existing relevant data collected during the last decade through the *Status of the World's Soil Resources* report (FAO and ITPS, 2015), the *Proceedings of the Global Symposium on Soil Pollution 2018* (FAO, 2018b), and the publication *Soil pollution: a hidden reality* (Rodríguez Eugenio, McLaughlin and Pennock, 2018) that accompanied the 2018 Symposium.

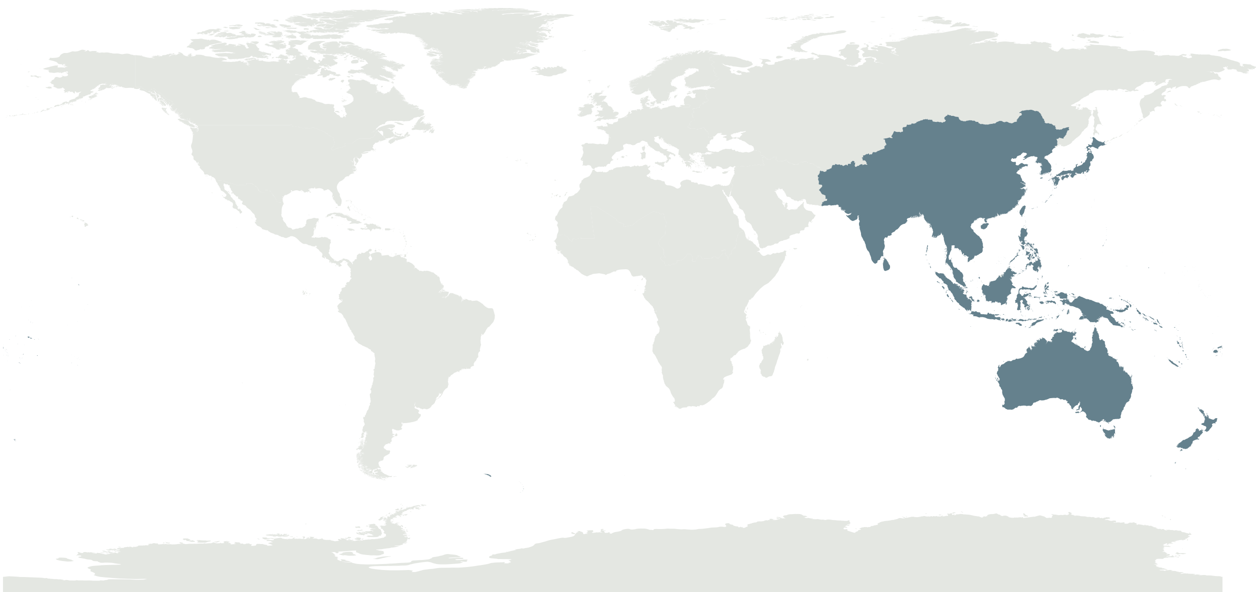
For several regions, a major source of information is the database of the Toxic Sites Identification Program (TSIP, Pure Earth, 2020). The TSIP was initiated by the Blacksmith Institute (now Pure Earth/Blacksmith Institute) in 2005 with the goal of identifying and screening toxic sites in low- and middle-income countries. The TSIP has assessed nearly 5 000 sites in 50 countries. The TSIP is not intended to be a comprehensive inventory of contaminated sites but is rather an effort to begin to understand the scope of the problem.

Asia and the Pacific

The Asia and Pacific region covers 41 countries in four sub-regions: East Asia, South Asia, Southeast Asia, and the Pacific. Some details of the main sources of soil pollution in Asia and the Pacific and their distribution in the region are shown below (Figure 10).

Figure 10. Hierarchical chart showing the main sources of soil pollution in Asia and the Pacific

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Agriculture

Agriculture is an important source of pollution in Asian countries. Several countries such as China, Bangladesh, South Korea or New Zealand have carried out national or regional studies of soil pollution in agricultural areas and have observed that the values of the safety guidelines for trace elements are often exceeded. Major sources of trace elements are irrigation of paddy fields using arsenic-contaminated groundwater, wastewater discharged from industrial parks and transport areas, and as a result of historical pollution by long-term use of cadmium and fluorine contaminated phosphate fertilisers.

The large-scale application of POP pesticides, has in the past contaminated large areas with PCDDs and PCDFs in East Asia. In Japan, rice fields throughout the country have been contaminated with more than 450 kg PCDD/PCDF, and PCDD/PCDF have been transported for decades in association with soil particles in rivers, lakes and ocean sediments. In Australia, more than 2 000 km^2 of agricultural soils and sediments on the east coast are affected by PCDD/PCDF from past use of PCPs in agriculture. Similarly, the use of PCP in China for snail control has contaminated agricultural soils. The more recent use of pesticides containing PCDD/PCDF, such as quintozene and 2,4-D in agriculture or on golf courses, has resulted in the release and additional formation of PCDD/PCDF. Polluted soils have also been identified in Vietnam at a former pesticide storage site.

The Indian subcontinent has long used persistent pesticides, including DDT and HCH. Soils are contaminated at pesticide production sites such as former HCH producers in India or former DDT production in Pakistan. In Bangladesh, organochlorine pesticides (OCPs) are present in soil and water due to the widespread use of these chemicals before OCPs were banned by the Stockholm Convention. Agricultural soils in China also show a high concentration of organic contaminants, but to a lesser extent than trace elements pollution. In New Zealand, agrochemical use and livestock treatment has resulted in soil pollution by the legacy compound DDT, as well as dieldrin, trace elements and their compounds such as arsenic and lead arsenate.

The use of Agent Orange, containing dioxin compounds, during the Vietnam War between 1962 and 1971 reportedly resulted in both non-carcinogenic and carcinogenic health risks to local civilians and military personnel involved in the war. However, the health risk associated with dioxin pollution from Agent Orange and its bioavailability in soil has been investigated in only a very small number of studies due to technical difficulties.

The identification of "emerging contaminants" in soil is also gaining relevance in the region and some countries, including Australia, have started identification and monitoring programmes for these contaminants of growing concern.

Industrial activities

The risks of soil pollution in industrial regions in China are more severe than in agricultural regions. In general, trace element pollution is more serious in southeast China than in northwest China. A comprehensive assessment focusing on soil pollution by trace elements in mining areas recommended that the southern provinces and Liaoning province should be prioritized for pollution control. Compared to soils influenced by metal mining, trace element concentrations in coalmine soils were lower. Roadside soil pollution in China's urban and suburban areas is caused by the deposition of toxic chemicals emitted by vehicles.

Due to India's very rapid economic growth through industrial, agricultural, and mining activities, soil pollution with trace elements in India is significant, including copper, cadmium, nickel, lead, arsenic, and chromium. Anthropogenic activities were considered as the main possible driver.

In Bangladesh, tanneries and brick kiln industries are sources of soil pollution by trace elements and pose a threat to the environment as well as to human health. Hazaribagh, in the city of Dhaka, is considered a highly polluted site due to tannery effluent loaded with chromium. Extremely high levels of chromium were detected at the site and there is excessive concentration in subsoils.

Monometallic minerals sources are most exploited by China, followed by India, Vietnam, Indonesia, South Korea and Japan. There is potential for deteriorating air and water quality in the vicinity of quarrying activities. However, there is no aggregated information on the effect of quarrying on soil pollution status in the Asia-Pacific region.

Trace element pollution is high in Southeast Asian countries and the problem has worsened due to the growing number of chemical industries and generally weak environmental regulation in the region (Ding, 2019). Mining is the main cause of trace element pollution in soil, sediments and surface waters in Thailand.

Australian mine sites, both former and active mines, present a soil pollution risk through acidic drainage/sludge, leakage from oil storage and on-site landfilling of process wastes. Australia has approximately 60 000 abandoned mining sites.

In New Zealand, a number of industrial sites are polluted with various toxic substances. Former timber treatment and gasworks sites may contain trace elements such as arsenic, chromium, copper, boron and organic compounds, such as coal tar and pentachlorophenol. Accidental leaks of chemical facilities from urban and industrial sites cause soil pollution by petroleum hydrocarbons; while mining operations, such as mineral processing and legacy sites with tailing dams are another source of soil pollution by trace elements (such as arsenic and cadmium).

Waste disposal and management

Thailand is one of the fastest-growing economies in the region, and concern about polluted sites is also growing, not only because of native wastes but also because of imported contaminants. The main sources of pollution are mining, petrochemical industries and illegal dumping, as well as waste processing facilities (including landfills and recycling facilities).

In Australia, solid waste generated by the rapid growth of solar panel installations now appears to be a new concern for landfills. Normally, the lifetime of a solar panel is about 20 years, so the earliest installation panels are being retired in Australia. The main components of solar panels - the photovoltaic panel - are glass, polymer and aluminium, but they may also contain potentially hazardous materials such as lead, copper and zinc, gallium, tellurium, indium, rare earth and plastics.

The unregulated or superficially regulated disposal of end-of-life (EOL) vehicles and ships is a source of soil pollution. In this region, in addition to domestically disposed vehicles, the disposal of imported EOL vehicles and ships is also a growing market – this is mainly referred to as the "wreckage industry." For example, Bangladesh has one of the largest ship-breaking industries in the world, where EOL ships come from many developed countries. The threat posed by EOL vehicles to soil and sediment health depends largely on management and regulation. For example, EOL vehicles constitute a large market for recycling aluminium. On the other hand, they are a significant source of chemicals that are harmful to humans and ecosystems. Contaminants include trace elements (cadmium, mercury, copper, chromium, lead), PCBs, PAHs and other POPs. Local atmospheric pollution from these priority substances can also lead to soil pollution through aerial deposition and fallout.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Geogenic sources

This region is particularly affected by contaminants of geogenic origin. Arsenic is considered the most serious mobile contaminant from geogenic sources in South Asia. Although arsenic has been detected in groundwater worldwide, as a consequence of natural processes, South Asian countries are among the most vulnerable to arsenic pollution of groundwater. The source of arsenic in groundwater/aquifer is derived from arsenic-bearing sediments, mainly from the reductive dissolution of iron oxyhydroxides where organic matter and microbes play a crucial role in the mobilization of arsenic. Heavy groundwater withdrawals for irrigation are thought to be the main reason for such pollution. South Asia, particularly the Bengal delta region, is a major hotspot for arsenic pollution from geogenic sources. Geothermal and volcanic activity on the Pacific "ring of fire" also contributes arsenic and other metals to soils and waters of the region.

Industrial accidents and military activity

In Japan, soil pollution by radioactive substances remains a significant problem. The case of Fukushima is a notable incident. On 11 March 2011, the Fukushima Daiichi nuclear disaster occurred. In May 2013, the UN scientific committee on the effects of atomic radiation concluded that there was no immediate health impact from exposure, but that future impacts were still undetermined. However, soils contaminated primarily with caesium-137 (^{137}Cs) remain a significant concern. The authorities initially planned to use the massive amount of soil collected from the 13 000 km^2 of exposed area for construction purposes, such as road foundation and embankments. However, there has been considerable public concern about the possibility of reusing these contaminated soils.

Defence operations, military weapons testing and the legacy of nuclear bomb testing remained a key issue in the Asia-Pacific region. However, information on the effect and extent of these operations on soil pollution in particular is often limited. The legacy of nuclear testing in the Pacific Islands by the United States of America includes soil pollution. For example, approximately 85 000 m^3 of radioactive waste was buried on Runit Island – with an estimated decay time of 24 000 years.

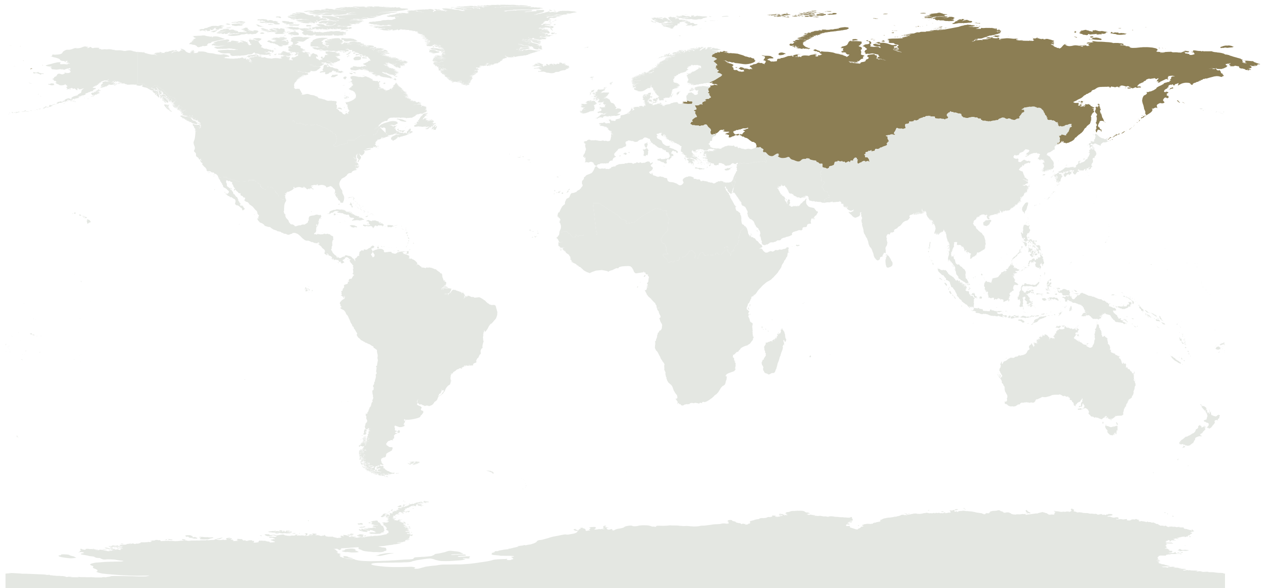
Eastern Europe, Caucasus and Central Asia (Eurasia)

The Eurasian region covers an area of about 2 million hectares with an estimated population of 239.8 million people. According to political and cultural differences, geographical location and socio-economic background, the 12 countries can be divided into three sub-regions: Eastern European countries (Belarus, the Republic of Moldova, the Russian Federation and Ukraine), Caucasus republics (Armenia, Azerbaijan and Georgia), and Central Asian countries (Kyrgyzstan, Kazakhstan, Uzbekistan, Tajikistan and Turkmenistan).

Eurasia has an array of soil pollution problems primarily dating from activities carried out in the former Soviet Union, of which all of the Eurasian countries were a part prior to its collapse in 1991. The soils of Eurasia could be regarded as strongly polluted due to the intensive and rapid industrial development of the Soviet Union, excessive militarization of some areas, and the imbalanced use of agrochemicals (FAO, 2018b). Some details of the main sources of soil pollution in Eastern Europe, Caucasus and Central Asia and their distribution in the region are shown below (Figure 11).

Figure 11. Hierarchical chart showing the main sources of soil pollution in Eastern Europe, Caucasus and Central Asia

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

There are no regional or comprehensive national inventories of polluted sites available for the region. According to the TSIP database there are 424 polluted sites in eight countries of the Eurasian region (Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, the Russian Federation, Tajikistan, Ukraine and Uzbekistan). Trace element pollution occurs at 54 percent of the sites, with lead (16 percent), and arsenic (10 percent), together with radionuclides including uranium (15 percent), accounting for the majority of sites. Persistent organic pollutants accounted for 27 percent of sites, while the remaining 19 percent of sites included volatile organic compounds, sulphur dioxide, particulate matter, asbestos and cyanide. Of the sites examined, 177 were legacy sites, 102 were active, and 118 were both. The report states that only a small fraction of the total hotspots was captured in data, but it does provide useful overview information.

Agriculture

A 2016 report by the International HCH & Pesticides Association assessed obsolete pesticides (OPs) and other persistent organic pollutant (POP) waste in countries of Eastern Europe, Caucasus, and Middle Asia. Pesticide waste was greatest in the Middle Asian countries (76.1 thousand tonnes), followed by Eastern Europe (34 thousand tonnes) and Caucasus (17.75 thousand tonnes). Other POP waste was highest in the Middle Asian countries (242.6 thousand tonnes) followed by Eastern Europe (44.95 thousand tonnes) and Caucasus (2.8 thousand tonnes). Kazakhstan accounts for a high percentage of the total other POP waste with 240.400 thousand tonnes of other POP waste.

No comparable estimates were found for the Russian Federation, but large organochlorine production sites have been operated in the Russian Federation (such as Ufa and Chapaevsk) that have created large POPs contaminated areas including dioxin contamination.

There were 183 former pesticide disposal sites and agro-airstrips at the end of 1990 in southern Kyrgyzstan. In total, at least 1 876 tonnes of pesticides were buried, including 1 033 tonnes of POPs in two major dumpsites. Soil pollution still exists in the areas of pesticide disposal, former pesticides storehouses, agro-air strips and cotton fields, whose production required the application of large quantities of pesticides.

The different inventories accomplished in the Eurasian region have stated that statistical data on OPs and POPs have not been collected in a systematic way, and that existing data are insufficiently defined and unreliable, leading to an inherent uncertainty in the data and land use plans. For example, in Ukraine in 2005, the number of OPs was 22 000 tonnes in 5 000 deposits, while, according to the inventories carried out in 2007, larger quantities were reported, with 25 000 tonnes in 4 000 depots. Data received during the 2015 inventory again reported about 24 500 tonnes, despite the fact that in the period 2007-2015, some 35 000 tonnes were destroyed abroad.

At the beginning of 2000, the reduction of soil pollution by OPs started throughout the Eurasian region. Thus, under the Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP), approximately 2 000 tonnes of OPs were repackaged in north-western Russia. With the support of the World Bank, 1 150 tonnes of POPs and 1 060 tonnes of PCB and PCB-polluted soils were treated in Moldova in 2006-2007. The Dutch Ministry of Foreign Affairs, in cooperation with the Dutch Foundation DOEN and PSO, financed the reduction of OPs in Moldova, Kyrgyzstan and Georgia (2005-2008); about 400 tonnes of OPs were repacked and stored. In Armenia under the framework of an FAO programme, 1 050 tonnes of POP pesticides were destroyed and 12 700 tonnes of soil less polluted by POP pesticides were buried.

Industrial activities and mining

Mining and ore processing are major point sources of trace element pollution throughout the region. In Armenia, the major sources of soil pollution are wastes from chemical and mining industries, which were intensively exploited during the Soviet era. In particular, areas affected by waste from the Nairid synthetic rubber plant (Nairid), copper mining (Alaverdi), and molybdenum mining (Kajaran and Megri) are of concern in Armenia. In Tajikistan, local industry is causing transboundary pollution, such as the Tursunzade aluminium plant, which is one of the largest smelters in the region and is continuously polluting the soil with fluorine at the border with Uzbekistan. In Kyrgyzstan, the main cause of soil pollution is past and present mining activities, in particular uranium mining.

Soil pollution in Uzbekistan and Kazakhstan was caused by the Aral Sea disaster. The enormous water withdrawals carried out over decades have led to the reduction of the Aral Sea. In the 1980s, the lake was reduced by 75 to 80 percent in volume and 50 to 60 percent in area; in 1990s, it was separated into the small Aral Sea in the north and the large Aral Sea in the south. In 2019, only 10 percent of the former Aral Sea is water-filled and the rest has been transformed into desert. The former seabed has become a constant source of pollution through the mobilization of sediments polluted by pesticides and trace elements; about 75 million tonnes per year of toxins and salts are mobilized by the erosion of the polluted sediments and deposited over thousands of square kilometres.

The Russian Federation and Kazakhstan rank on the first and second position among Eurasian countries in terms of the extent of polychlorinated (PCB) polluted soils. The inventory of PCBs in industrial waste was carried out in the Russian Federation in 2000 for 600 enterprises, and the chemical and petrochemical sectors, ferrous and non-ferrous metallurgical industries, mechanical engineering and timber (beside military sector) were reviewed. Industrial wastes released about 3 160 tonnes of PCBs into the soil, in addition to the Sovtol spill, which polluted soil with about 140 tonnes of PCBs.

In Kazakhstan, a programme for the control, management and monitoring of POPs was developed in accordance with the "Concept of environmental protection of the Republic of Kazakhstan for 2004-2015." Since then, 80 tonnes of electrical transformers and 169 tonnes of electrical capacitors have been incinerated in France, and 10 052 electrical capacitors have been disposed of in Germany. Approximately 56 000 capacitors are still located in different areas, 15 000 of which were buried in the Semipalatinsk nuclear facility.

In Azerbaijan, Turkmenistan, Kazakhstan, and the Russian Federation, the petroleum industry is one of the main sources of soil pollution. In Azerbaijan, a massive petroleum pollution occurred in the past when oil from the Caspian Sea was supplied intensively throughout the Soviet Union. An area of more than 33 000 ha is considered to be contaminated by oil pumping and processing activities in the Absheron Peninsula, and almost half of this area – 15 000 ha – is heavily polluted and is a major environmental concern. In Turkmenistan, the main causes of soil pollution are the oil and chemical industries located in the western part of the country on the banks of the Caspian Sea.

In the Russian Federation, around 100 000 ha of agricultural land and pastures are contaminated due to oil spills. In the oil regions of Western Kazakhstan and the Torgay plain, an area of more than 500 thousand hectares, there are large sections of soil contaminated with oil and radioactive materials, high levels of salinity with industrial wastewater, and technological transformation of the soil landscape, leading to the accumulation of toxic trace elements such as lead, cobalt, nickel and vanadium.

Urban expansion and municipal waste treatment

Urban expansion is one of the main drivers of soil pollution in the Russian Federation and Ukraine. Urban sprawl leads to an increase in municipal waste and overloading of landfills, soil pollution from transport, and the expansion of transport infrastructure including gasoline and oil stations, airports, railway and bus stations. This is particularly true for metropolitan cities.

Military activities

In Ukraine and other points in the region, past and present military activities are an important driver of soil pollution. During the Soviet era, Ukraine was actively exploited by the Soviet army for test sites, rocket storage, and tank and aircraft parking area. After independence in 1991, some 4 500 military sites were reported to have occupied 600 000 ha of agricultural land, and only a very limited number of these sites were monitored. The sites were found to be severely polluted with trace elements, petroleum products, and other chemicals and military by-products.

The mining sites abandoned and destroyed during the military conflict in eastern Ukraine in the Donbass region represent an environmental challenge. When a mine is abandoned, groundwater is no longer pumped out; it fills mine cavities, leading to water and soil pollution and subsidence. There are about 35 mines already flooded, and 70 are predicted to be flooded in the upcoming years. Annual runoff of contaminated water from flooded mines is estimated at 760 million m^3, of which nearly 2.5 million tonnes/year of salts and trace elements (mercury, lead and arsenic) are deposited to water bodies and soil.

Soil pollution by radionuclides and trace elements from former military activities has been identified as the cause of pollution of military sites in Abkhazia, South Ossetia and Kazakhstan; however, at some sites there is little or no information available on where radioactive materials were buried in the past.

Industrial accidents

Soil pollution by radionuclides is a serious problem through the region, from both the Chernobyl catastrophe (Ukraine) of April 1986 and the legacy of extensive uranium mining and former military activity in other parts of the region. Global radionuclide contamination resulting from the Chernobyl catastrophe is estimated at 34 million hectares. Of the total contaminated area, 20 million hectares of highly polluted radioactive soils are in Europe, 70 percent of which are in Eastern European countries: Belarus, Ukraine and the Russian Federation. In 1986, right after the explosion at the Chernobyl nuclear power station, an area of 400 000 ha surrounding the reactor was isolated in Ukraine (known as the 30-km "death zone") and there is no activity there even today. In addition, an area polluted by radionuclides equal to 204 000 ha was excluded from cultivation in Ukraine, 210 000 ha was excluded in Belarus and 17 000 ha was excluded in the Russian Federation.

Over the years, the level of air and water pollution has decreased; however, secondary pollution has appeared due to the transfer from soil to plant, as radionuclides have moved to the flora and fauna from polluted soil and water. Humans are affected by the consumption of contaminated agricultural products that exceed the permitted levels of radionuclides, especially long-rooted crops such as potatoes, beets or carrots, berries and mushrooms, because the radioactive contamination moves from the surface to deeper layers of the soil. In addition, fish, meat, and dairy products have become sources of secondary radioactive pollution, due to the consumption of contaminated grass by animals. Since 2010, a third source of radionuclide pollution has appeared as a result of frequent fires in the area around the Chernobyl reactor and dust storms that carry contaminated particles over long distances by wind and precipitation.

Uranium mining and processing activities have been carried out in Central Asia since the 1940s, particularly in the mountainous areas above the Syr Darya River and the Fergana Valley, where the borders of Kyrgyzstan, Kazakhstan, Tajikistan and Uzbekistan meet. Closed 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. The risks have been recognized by United Nations Resolution 68/218 of 2013, which calls for assistance to Central Asia in the remediation of these sites.

In Turkmenistan, radioactive wastes that were generated as a by-product during the manufacture of iodine and bromine from groundwater by absorption methods had also affected soil quality in Khazar and Balkanabat locations. Radioactive waste was generated during the years 1940-1990, when the method of adsorption with activated carbon was used for the production of iodine and bromine from the mineral groundwater of these two cities. In 2009-2012, Turkmenistan implemented a programme in which 47 500 m^2 of the plants' territories were remediated. The radioactive wastes from the most polluted sites were collected, packaged in bags or containers and transported to the storage site, built in the desert, some seven kilometres from the Caspian Sea. In 2010, the storage site was additionally reinforced with concrete walls and equipped by monitoring drill holes and a drainage system.

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Europe

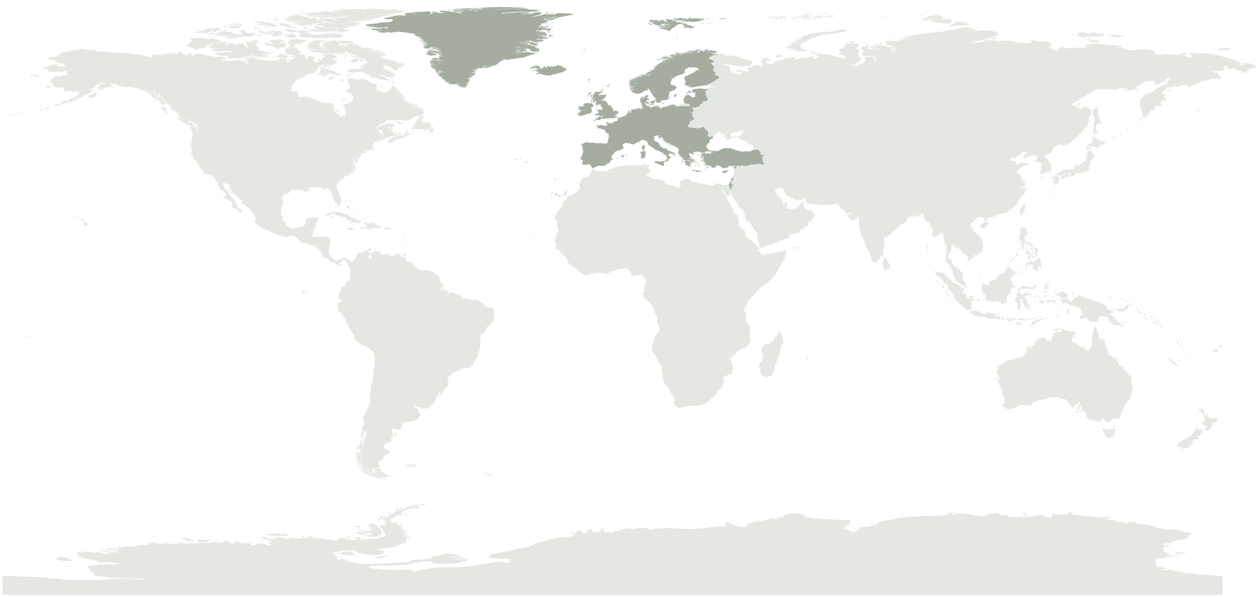
The European chapter presents the situation and trends of soil pollution in the 27 Member States of the European Union (EU) and Albania, Bosnia and Herzegovina, Iceland, Israel, Montenegro, North Macedonia, Norway, Serbia, Switzerland, Turkey and the United Kingdom. The region has a total population of about 550 million and is relatively homogeneous in terms of development and income.

The main source of information on the state of soils and the environment in 37 of the 38 countries are the regular reports and indicators of the European Environment Agency and the European Environment Information and Observation Network (EIONET). For Israel, scientific literature has been reviewed.

In Europe, there are about 650 000 sites identified as potentially polluted and that are inserted in national and/or regional inventories. Some details of the main sources of soil pollution in Europe and their distribution in the region are shown below (Figure 12).

Figure 12. Hierarchical chart showing the main sources of soil pollution in Europe

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Industrial and commercial activities

European countries have a long industrial history that, together with commercial activities and waste disposal and treatment, have caused almost two thirds of the point source soil pollution. The main contaminants associated with these industrial activities are mineral oils, trace elements (such as arsenic, cadmium, lead, nickel, or zinc) and organic contaminants such as halogenated and non-halogenated solvents, PCBs and PAHs. PFASs are also a major concern in Europe having been detected in soils, groundwater, biota, and in the European population. PFASs are used in a wide range of consumer products and industrial applications, although the exact amount and type of PFASs used in Europe are unknown. There are an estimated 100 000 PFAS-emitting sites.

In EU Member States, about 2.8 million sites are suspected to be potentially polluted, although only one quarter are included in national registries. In Switzerland, 60 percent of polluted sites correspond to industrial areas while the rest are landfills and areas where industrial accidents occurred. High levels of cadmium in Slovenian soils originate primarily from the past industrial activity, such as zinc smelters. According to the 2014 report of the Israeli Ministry of Environmental Protection, industrial activities are responsible for three quarters of the polluted sites in the country, mostly due to inadequate treatment or disposal of industrial wastewater, waste and hazardous materials.

Agriculture

Agriculture has traditionally been the major land use activity in Europe and represents around 25 percent of Europe's land cover (194 304 ha of land). Agriculture represents a significant source of diffuse pollution in the region, mainly due to the use of agrochemicals. The analysis of agricultural soils sampled under the EU LUCAS survey showed that 80 percent of agricultural soils contain pesticide residues, with 58 percent of soils presenting a mixture of pesticides residues and only 17 percent of soils being free of pesticides. The main pesticides detected in agricultural soils were glyphosate and its by-products, DDT and its residues and fungicides. In France, the most common pesticide found in soils were by-products of lindane, especially in the northern region, that may have come from volatilization of lindane applied to intensively cultivated areas, which was then transported by prevailing winds coming from the southwest and deposited in a densely inhabited basin. In Finland, about 15 percent of groundwater samples situated in intensive agricultural areas contained pesticides and exceed quality standards for pesticide content.

Although the gross nitrogen balance has decreased in recent decades in EU Member States, 45 percent of nitrogen inputs still come from synthetic fertilisers, while manure accounts for 38 percent of nitrogen inputs. Approximately 65-75 percent of agricultural soils in the EU-27 exceed the critical value for N in runoff to surface water (2.5 mg N/l) above which eutrophication is expected. About 40 percent of agricultural soils would need a reduction of N inputs to avoid eutrophication of surrounding water bodies. In North Macedonia, animal husbandry and manure management, overuse of inorganic nitrogen fertiliser and manure additions to soils were responsible of 89 percent emissions of ammonia (NH_3). This percentage increases to 98 percent of ammonia emissions in Bosnia and Herzegovina.

Trace elements such as arsenic, cadmium, copper, chromium, mercury, nickel, lead, and zinc have also been detected in agricultural soils originated from multiple sources, including pesticides, synthetic fertilisers, animal manure, liming materials, sewage sludge, compost, and atmospheric deposition. About 21 percent of agricultural soils in Europe present levels of cadmium above the regulatory thresholds.

Urban settings

Around 73 percent of Europe's population lives in cities, and this proportion is expected to reach 82 percent by 2050. Urban soils are affected by car exhaust emission, improper waste disposal and a variety of household contaminants, especially organic contaminants.

Around 640 million tonnes of construction and demolition, municipal, and electronic waste are produced in Europe annually, of which only half is recycled on average, although recycling rate is reduced to 30 percent for electronic waste. Israel has a high rate of landfilling with only 21 percent of the country's municipal solid waste (MSW) recycled while the rest is disposed in landfills that are reaching maximum capacity and have the potential to contaminate soil and groundwater.

Although there has been significant progress in Europe in terms of landfill control and containment measures, there are still numerous illegal landfills scattered throughout Europe. For example, about 340 illegal dumpsites were identified in Bosnia Herzegovina in 2018.

Mining

Mining activities are common and widely distributed in Europe, but differences in regulations have led to an unequal impact on the environment. Mining and mineral processing has played a vital part in the history and economy of the Western Balkans and Turkey, especially of antimony, cobalt, copper, gallium, lead, rare-earth elements, zinc and asbestos. Abandoned and orphan sites are scattered throughout the region without the proper containment measures in place. Montenegro has seen an increase in hazardous waste from mining in the last few years, reaching values of 326 000 tonnes in 2019. Mineral and coal mining activities in Serbia have also left some long-lasting industrial landfills that pose a risk to neighbouring populations.

In Spain, at the Guadiamar site, several hundred cubic metres of mine tailings were discharged into nearby water systems affecting 4 600 ha of agriculture and pastures due to the dam break in 1998. In Hungary, in 2010, about 1 million m^3 of red sludge suspension was released into the environment due to a failure of a tank wall in an alumina industry. The emergency response and remediation measures cost the Hungarian government about EUR 127 million. In Montenegro, 3.9 million tonnes of toxic flotation tailings from the lead and zinc mines were deposited on the banks of the Ćehotina River.

Military activities

Many countries in Europe still suffer from the legacy of pollution caused by arms manufacturing industries, as well as chemical weapons stockpiles, and munitions left over from the First and Second World Wars. In Germany alone, some 3 200 polluted sites await remediation.

The Kosovo conflict has also left stockpiles of weapons in the Balkan countries. In Montenegro, despite demilitarisation and management of the remaining weapons, the soil polluted by depleted uranium bombs still poses a risk to the population. Routine measurements are now being carried out at four sites in Serbia to monitor depleted uranium contamination. After the war, Serbia had the highest rate of malignant tumours in Europe, with more than 30 000 people diagnosed with cancer in the first 10 years since the bombing, and a mortality rate of one in three cases. Bosnia and Herzegovina is one of the most landmine-polluted countries in the world. To date, it has some 1 366 settlements affected by landmines, which limit agricultural and livestock activities, due to the release of trace elements and organic contaminants such as PAHs or PCBs.

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Latin America and the Caribbean

The Latin American and the Caribbean region includes 43 countries and territories. The countries in the region can be grouped into three sub-regions: the Caribbean, Central America, and South America.

The Economic Commission for Latin America and the Caribbean (ECLAC, 2019) indicated that the region has the highest inequality in the world, especially with regard to access to healthcare and the exercise of political, economic, social, and cultural rights.

Some details of the main sources of soil pollution in Latin America and the Caribbean and their distribution in the region are shown below (Figure 13).

Figure 13. Hierarchical chart showing the main sources of soil pollution in Latin America and the Caribbean

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance

Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Agriculture

Latin America and the Caribbean has the world's largest reserves of arable land. During the last 50 years the region's agricultural surface area increased from 561 million ha to 741 million ha.

The main agricultural practices contributing to soil pollution in the region are the mismanagement of mineral fertilisers and pesticides, which are widely applied in the region, and the use of uncomposted manure and slurry as fertilisers. Latin America and the Caribbean has the highest average pesticide use per cropped area in the world. According to ECLAC (2012), poor pesticide use and management practices can lead to transboundary impacts of pesticide-laden runoff into rivers and the ocean.

Fertiliser use has also increased in recent decades. Mexico, Argentina and Chile are the countries with the highest rates of nitrogen pollution in water due to excessive application of nitrogen fertilisers in the Latin American and the Caribbean region. The use of phosphate fertilisers has also increased in the region during the 21st Century, and is especially relevant in South American countries. Besides the high eutrophication risk posed by phosphates leached or transported by runoff to neighbouring water bodies, phosphate fertilisers constitute a source of trace elements, in particular cadmium.

There is a pressing need to deal with hazardous stockpiles of obsolete pesticides in the region. Abandoned pesticide containers and buried stockpiles are a widespread issue. For example, in Colombia, about 500 tonnes of obsolete pesticides are located in warehouses and illegal burials in different parts of the country, but these sites have still not been accurately identified. In El Salvador, the Ministry of Environment and Natural Resources found more than 62 tonnes of pesticide wastes, in addition to contaminating solvents and equipment.

As well as issues with storage of obsolete pesticides, many areas in the region are polluted by past pesticide use. For example, in Nicaragua, toxafeno, DDT, dieldrin, endrin, lindane and endosulfan were used intensively in the 1980s and 1990s, and residues remain in the soil.

Mining

Mining is a source of soil pollution by trace elements in the region and it is associated with the extraction of precious metals such as gold, lead, nickel, silver, zinc, lithium, iron, tin, bauxite and aluminium, and copper. The ECLAC 2018 report indicates that Latin America and the Caribbean has a significant share in the world's reserves of the main metallic minerals, with 61 percent for lithium, 39 percent for copper, 32 percent for silver and nickel, 25 percent for molybdenum and tin, 23 percent for zinc, 18 percent for bauxite and aluminium, 15 percent for iron and lead, and 11 percent for gold (ECLAC, 2018).

Significant pollution by trace elements associated with mining has been reported in Jamaica, Mexico, Colombia, Ecuador, Chile, Brazil, Suriname and Argentina. In Central America, gold, silver, lead, and zinc are the most common mined elements, associated to iron, lead, mercury, cadmium, arsenic, and cyanide contaminants. Artisanal and small-scale gold mining operations are generally high in the region. The use of mercury and arsenic compounds in mining activities and the use of huge amounts of water for shale oil exploitation cause downstream pollution in soils and waters. There is no comprehensive summary for the region and this list is likely to be incomplete.

Urban waste management

The mismanagement of solid waste and wastewater has led to serious soil pollution in the region. Direct dumping into the nearest watercourse without prior treatment is a frequent practice that has a direct impact on soils.

In 2016, the region generated 231 million tonnes of municipal solid waste, of which, on average, only 55 percent was properly managed and 4.5 percent was recycled. However, there were great differences between countries.

Three quarters of wastewater flows back into rivers and other water sources, some of which are then used to irrigate crop soils. Wastewater can contain a diverse range of contaminants, from pathogenic microorganisms to organic pollutants and trace elements such as chromium, copper, mercury and zinc, which can create public health and environmental problems. Many countries in the region have collection and distribution pipes for wastewater flows, which in many cases have been poorly maintained and have started to leak, causing pollution of soil and groundwater.

Additionally, the mixing of household and hazardous industrial waste was a common practice in the Latin American and Caribbean region. Hazardous and industrial wastes were discharged in open dumps with no containment or leachate management, and without previous treatment posing risk to the environment and human health (Figure 14). Industrial activities release mixtures of organic and inorganic contaminants into the soil.

Figure 14. Possible source of solid waste and their impact on human and environment

Source: adapted from Ferronato and Torretta, 2019

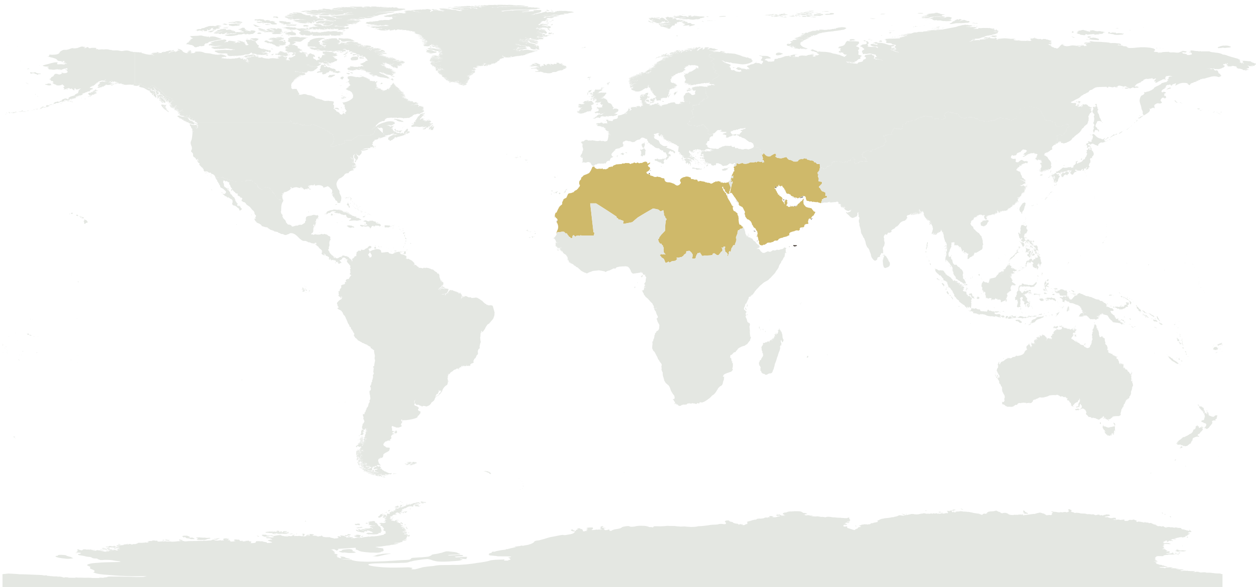
Near East and North Africa

The Near East and North Africa (NENA) region consists of 20 countries. These include Algeria, Bahrain, Egypt, Iran (Islamic Republic of), Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, and Yemen.

The total population in the NENA region is over 485 million people, of which rural populations represent approximately 38 percent, although for some countries this percentage is significantly less. The gross domestic products in the NENA region also differ widely between countries. With a significant part of its territory either desert or degraded lands (more than 80 percent by area), the NENA region has a low proportion of productive soils, and the dispersion of contaminants by dust transport is a particular concern in this region. Some details of the main sources of soil pollution in Near East and North Africa and their distribution in the region are shown below (Figure 15).

Figure 15. Hierarchical chart showing the main sources of soil pollution in Near East and North Africa

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Urban waste management and transport networks

In the NENA region, solid waste management mainly consists of landfilling or uncontrolled open dumps. The landfills and dumps often receive domestic, hospital and industrial wastes, which are often burned. More than 81 million tonnes of municipal solid waste are generated each year in Egypt, of which less than 20 percent is adequately treated and less than 5 percent is recycled. In the Islamic Republic of Iran, more than 2 000 tonnes of hazardous medical wastes including infectious, toxic, spontaneously combustible materials, and potentially carcinogenic, corrosive and reactive substances were disposed in the same landfill as domestic wastes without any control. Eighty-five percent of urban waste is collected in Morocco, but less than 40 percent is disposed in controlled landfills.

Transport is the major source of pollution in Algeria, Bahrain, Iran, Iraq, Kuwait, Lebanon, Libya, Oman, Qatar, Saudi Arabia and the United Arab Emirates. Transport is not only the source of gas emission but also the main source of trace elements (such as cadmium, chromium, lead and nickel) input to the soil. Dust collected from street pavements in Abadan, the Islamic Republic of Iran, in areas with dense vehicle traffic showed high levels of trace elements.

Industrial activities

The principal industries in the region are manufacture of paper, plastic and pipes; cement industry; food processing; construction; oil extraction, transportation and refining; and energy production. Industry is one of the main sources of soil pollution by trace elements (arsenic, barium, cobalt, chromium, nickel, and zinc) in the NENA region.

Dust input has been reported as the main source of diffuse pollution that carries trace elements emitted by industry and energy production, and can be found in air, water and soil in significant parts of the NENA region. There is a growing concern in the region about the increasing frequency of dust storms from bare and desert lands, which carry particulate matter due to wind erosion. Dust blown from the soil surface can also carry fixed trace elements. As it travels, the particulate matter can be enriched with emission from industrial and transport and can cause health problems in urban areas. For example, monitoring of lead, zinc, cadmium, chromium, and nickel content of indoor house dust and outdoor street dust was carried out at 76 sites in Bahrain. Lead was predominant among the trace elements in areas with heavy traffic, but elevated levels of zinc, cadmium, chromium and nickel were also noted. Automobile exhaust and dust were the main sources of lead and nickel in both the street and indoor dust.

In Sudan, severe environmental damage such as dust and gas emission, deforestation, mercury pollution and the deterioration of landscape from gold mining are observed.

Agriculture

Agricultural intensification has long been a priority to address food security for a growing population in the region, and has been closely linked to the use of agrochemical inputs. Agriculture in this region is often concentrated in deltas and river floodplains. Trace elements and many other contaminants migrate attached to eroded soil particles and settle as sediments in water bodies. Floods can then mix the sediments with lowland soils. For example, the Ibrahim River (Lebanon) river bed sediments and adjacent floodplain soils show increased levels of cadmium, chromium, copper, iron, manganese, nickel, lead and zinc from the upstream source to the sea outlet.

Agricultural soils along the Orontos River in Syria have increased levels of trace elements in the topsoil due to intensive agricultural practices, agrochemical application and irrigation with untreated sewage water in a densely populated semi-arid area in south-western Syria with urban and industrial expansion. Agricultural soils revealed acceptable levels of lead concentration, but areas located along and in the vicinity of the riverbanks showed high values of lead that exceed Syrian standards.

Phosphorus fertilisers may contain trace elements as impurities, mainly cadmium, zinc, lead, copper, antimony, silver, palladium, niobium and molybdenum. Based on agricultural practices and the excessive application of fertilisers prevailing in the eastern Mediterranean countries, the average annual load of zinc, copper, lead and cadmium is expected to reach levels that can be tolerable in the short term, but which might in the long term lead to trace element accumulation in the soil.

The NENA countries are characterised by high pesticide use on agricultural soils, although there are significant variations, with Palestine (9 kg/ha/y) and Lebanon (7 kg/ha/y) applying the highest rates, while Iraq, Sudan, Yemen or Mauritania apply much lower doses (<0.2 kg/ha/y).

An emergent problem for the NENA region is the management of obsolete pesticides, amounting to several thousand tonnes, stored in inappropriate locations and in a risky manner. Toxic chemicals, often stored outdoors where leakage is common, seep into the soil and water and increase the risk of poisoning.

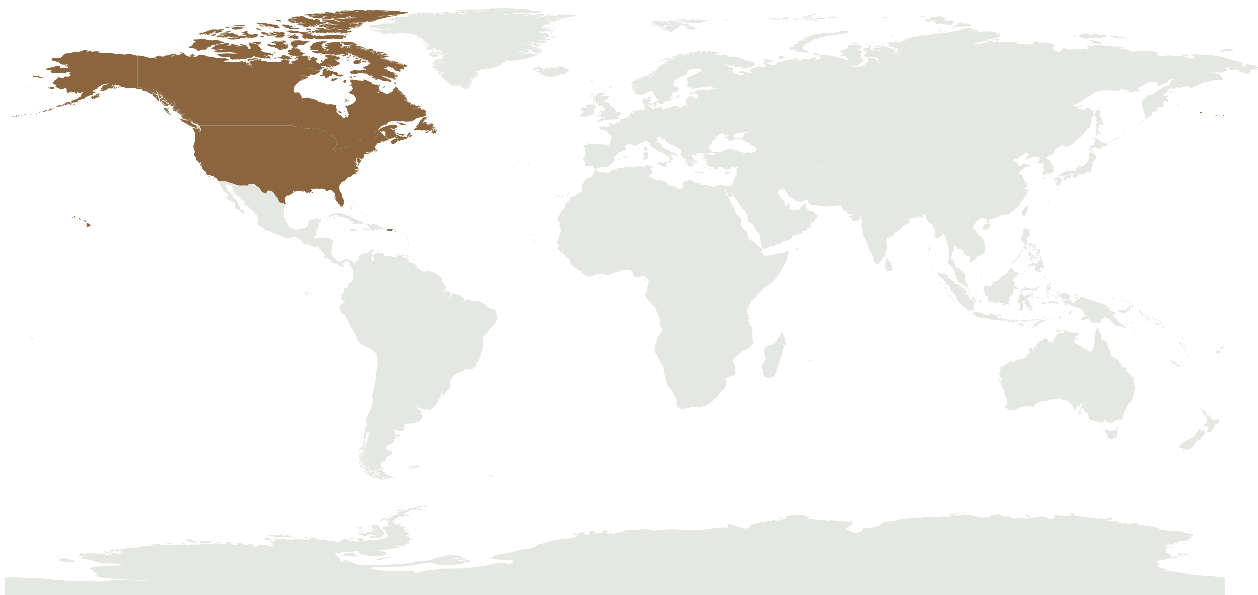
North America

The North America region includes the United States of America (US) and Canada. The United States of America and Canada are large countries (9.83 million km² and 9.98 million km², respectively) with highly developed, diversified, economies with large resource extraction, agriculture and manufacturing sectors. Similar economies and levels of development have led to similar soil pollution sources and extent. There are thousands of polluted sites in both countries, of varying size and significance, in settings ranging from abandoned buildings in inner cities to large areas polluted with toxic materials from past industrial or mining activities.

In 2017, United States of America EPA and its state partners reported monitoring approximately 640 000 to 1 319 100 facilities to prevent releases to communities. The monitoring programme only cover sites currently producing potential contaminants and not legacy sites or areas polluted by nonpoint sources. In July 2019, there were 23 663 federal sites included in Canada's Federal Inventory of Contaminated Sites, with 16 845 sites listed as closed because remediation is not feasible. Some details of the main sources of soil pollution in North America and their distribution in the region are shown below (Figure 16).

Figure 16. Hierarchical chart showing the main sources of soil pollution in North America

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Industrial activities

The environment protection agencies of both countries receive an annual report from the industries on the amount of toxic substances released in the three environmental compartments: water, air and land. The dataset is publicly available in the form of inventories called the National Pollutant Release Inventory (NPRI) for Canada and the Toxics Release Inventory (TRI) for the US.

NPRI's 2018 registry, contains information on emissions from some 7 699 facilities, which released approximately 2.8 million tonnes of contaminants directly into the environment (air, water and land), while 1.37 million tonnes were disposed of in landfills, applied to soil or injected into the subsoil, either on-site or off-site.

In Canada during 2017 the facilities responsible for the release of the largest amounts of contaminants to land were those supporting air transport activities, followed by hardware manufacturing, scheduled air transport, wastewater and sewage distribution systems. In the case of land and soil, ethylene glycol, used as antifreeze and de-icing agents for cars and airplanes, was the contaminant with the highest levels recorded.

In 2017, the United States of America EPA TRI reported that approximately 1.72 billion kg of contaminants were released into all environmental compartments (e.g. soil, air and water) by industrial activities. The main contaminants were lead (35 percent), followed by zinc (23 percent), arsenic, manganese, barium, copper and others. Soil represents the largest recipient of these contaminants (70 percent of the total amount of contaminants released to the environment), coming mostly from metal mining (72 percent), followed by the chemical industries, energy companies, primary metal mining and processing, hazardous waste and others.

An issue of increasing concern in the US, as in other developed countries in the globe, is the vast contamination of drinking water and soils from per- or polyfluoroalkyl substances, or PFAS, which includes a family of thousands of chemicals, including PFOA and PFOS, among others. These chemicals are used for their waterproof, greaseproof, and non-stick properties in many consumer goods and in PFAS manufacturing and processing facilities, airports, and military installations that use firefighting foams. They are persistent in the environment and tend to accumulate in living tissues, causing serious health issues.

To date, PFAS pollution has been detected in the tap water of 1 400 communities across the US, including 300 military sites. The two most used and most studied of these, PFOA and PFOS, are no longer manufactured in the US. However, the largest share of PFOS and PFOA was used on carpets, textiles, furniture and food contact paper such as fast food wrapping and pizza boxes from 1970 to 2000, and has been largely disposed to landfills for the last four decades. The release of PFAS from municipal waste landfills in the United States of America is estimated to be 500 kg per year. Considering that tens of thousands of tonnes of PFAS were disposed in landfills, this release will likely continue for centuries, since PFAS are more persistent than the containment systems of landfills.

Mining and extractive activities

Canada has many sources of soil pollution related to its large resource extraction industries (metals, radionuclides, oil, natural gas, bitumen, coal), as well as a developed industrial and manufacturing sector. Canada is the global leader in the production of potash and ranks among the top five global producers for cadmium, cobalt, diamonds, gemstones, gold, graphite, indium, nickel, niobium, platinum group metals, salt, titanium and uranium. Canada also accounts for a significant proportion of the global production of primary aluminium from imported bauxite and alumina. Although most mines are regulated to avoid pollution from effluents and mine waste by the Metal Mining Effluent Regulations, the metal mining sector has reported sporadic exceedances of prescribed limits for arsenic, copper, cyanide, nickel, zinc, radium 226 and pH.

An important component of Canada's oil extraction comes from the oil sands in Alberta, the world's third largest oil reserve, which contributes considerably to Canada's economy. The oil and gas sector, besides being a source of many hazardous contaminants, including greenhouse gas (GHG) emissions and chemicals, has also been causing habitat destruction and fragmentation and water resources consumption. The vast tailing ponds associated with the oil sands are a considerable concern for water resources in the region, but no studies were found about their impact in soils. Emissions and deposition of polycyclic aromatic hydrocarbons (PAHs) from the oil and gas sector in Alberta has been a major focus for research on their effects on human health and the environment, but soil pollution with PAHs and trace elements has been reported only from sites located near oil sands extraction operations. There is concern about the occurrence, reporting and remediation of fuel spills at exploration sites in remote areas that have little or no regulatory oversight, and the impact this may be having on soils and the environment.

In 2019, production in the United States of America of crushed stone, cement, construction sand and gravel, gold, copper, industrial sand and gravel, iron ore, lime, salt, zinc, soda ash, phosphate rock, and molybdenum were each valued at more than USD 1 billion. The mining industry disposes of the largest amount of waste primarily in the form of on-site land disposal. Lead and zinc are the main contaminants being released from mining activities in the US. In addition to active mines, abandoned mines are also a major soil pollution problem in the US. In the state of Colorado alone, there are an estimated 23 000 abandoned mines in need of rehabilitation.

Most of the waste from metal mining accumulates in unregulated landfills and surface deposits, increasing by 35 percent between 2007 and 2017 (from 900 million tonnes to 1.2 thousand million tonnes). The mining sector alone is responsible for 96 percent of the lead and 87 percent of the zinc dumped into the soil, while 42 percent of total grams of dioxins released come from mineral ore extraction. Dioxins are the by-products of many forms of combustion and several industrial chemical processes. Since 2010, dioxin releases increased by 102 percent and in 2017, about 52 percent of dioxins were released into the soil.

Agriculture

Agriculture has also been identified as a significant source of contamination causing pollution of water sources. In many cases, the main point sources of pollution, such as current or historical industrial waste dumps, are similar across the country, while other diffuse and point sources are specific to the region, such as different types of mining or fossil fuel extraction and processing.

Agriculture and Agri-Food Canada (AAFC) calculates a series of agri-environmental indicators as key measures of environmental conditions, risks and changes resulting from agriculture and of the management practices that producers use to mitigate these risks. AAFC data suggested that after 100 years of sustained inputs from the application of fertilisers, manure and municipal biosolids to agricultural soils, concentrations of some trace elements (arsenic, cadmium, copper, lead, selenium, and zinc) are estimated to be three times higher than natural background levels.

The United States of America has 44 percent of its land devoted to agricultural use, so management practices have a major impact on the national rate of soil pollution. Fertiliser use has peaked in recent decades, with a 215 percent increase since 1960. In contrast, pesticide use has declined due to increased use of genetically modified seeds and conservation farming practices. In addition to pesticides currently registered for use, banned pesticides now known to have long-lasting environmental impacts can be found in soil decades after application and may still be hazardous.

Biosolid application as fertiliser in is regulated both in Canada and the United States of America but certain amounts of potentially toxic contaminants are allowed within regulatory guidelines. Over 400 contaminant compounds, including trace elements, have been identified as potentially present in biosolids. As trace elements tend to remain where they are applied over time their content in soils increases. PFAS are also recognized as potentially present in biosolids, but allowable limits have yet to be set.

Plastics also pose a worrying risk to North America's agricultural soils. Used as mulch for crops, plastic tubing for irrigation, feed bags, fruit bags, and plastic for greenhouses, plastics play an essential role in fruit and vegetable production, but if not managed properly they are a source of soil pollution. Canada has included the use of plastics in agriculture in its Action Plan for Zero Plastic waste. Canadian farming organizations have also identified that agroplastics need to be more effective managed and have undertaken recycling and waste characterization initiatives.

Farmers in the United States of America currently use 57 million kg of plastic mulch and 191 million kg of plastic containers annually. However, there are no policies to require or encourage recycling agricultural plastics in the United States of America and knowledge about the long-term effects of plastic residues in agroecosystems is sparse.

Natural disasters

In the United States of America and Canada, there have been cases of mobilization of contaminants caused by natural disasters. The vulnerability of people depends on their proximity to the sources of contamination. To date, many cases can be listed following hurricanes and floods. The hurricane Katrina that hit the city of New Orleans in 2005 caused the sewage system to break down and contaminants spread all over the city. High concentrations of lead were measured in soils in downtown New Orleans, compared to the surrounding area. During the 2011 floods in the state of Colorado, mine tailings from the Jamestown mine were mixed with sediments and water. Furthermore, the flood swept petroleum storage devices distributing oil and other products into the floodwaters. In 2015, an error in the restoration of the mine tailing caused the discharge of cadmium, arsenic, lead and aluminium into the Colorado River, turning it orange for 100 miles.

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Sub-Saharan Africa

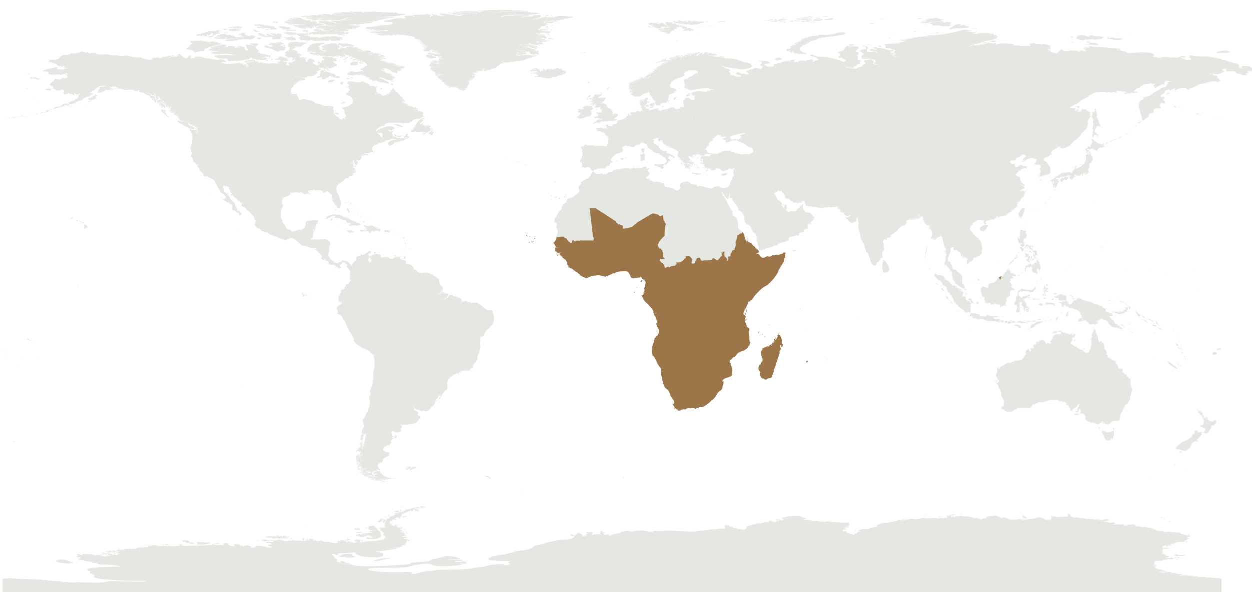
Sub-Saharan Africa includes 48 African countries that either are located south of the Sahara desert or include a portion of the desert in the more northern parts of these countries.

The region has experienced dramatic population growth, from an estimated 227 million in 1960 to 1.08 billion people in 2018. Africa's urban population increased by 2 000 percent between 1950 and 2015. In contrast to developed countries and several developing countries, the rapid urbanization in sub-Saharan Africa has resulted in the absence of the conventional land-use zoning approach, and people have settled in areas directly next to industrial areas, mines or agricultural processing facilities to be in close proximity to areas with employment opportunities. This poses significant threats to human health in areas with polluted soils. A particular risk factor in sub-Saharan Africa is the practice of geophagy (deliberate ingestion of soil).

No large-scale regional assessment of soil pollution has yet been conducted for the region. Reports on trace elements' contamination and pollution dominates the information available about known and emerging contaminants and other major contaminants include pesticides, hydrocarbons and PCBs. Some details of the main sources of soil pollution in sub-Saharan Africa and their distribution in the region are shown below (Figure 17).

Figure 17. Hierarchical chart showing the main sources of soil pollution in sub-Saharan African

The boxes represent an estimate of the relative importance of each source as perceived by regional experts, and their size is related to their relative importance. The larger the size, the greater the relative importance



Map source: UN, 2020, modified according to the GSP Regional Soil Partnership organization

Mining

Sub-Saharan Africa has significant mineral resources and oil deposits, the extraction and processing of which can stimulate economic activity and provide livelihoods for the population. However, the extraction and processing of mineral deposits, both in large-scale and artisanal and small-scale operations, have caused extensive environmental damage and soil pollution in the region. Mining and quarrying are major sources of trace elements' contamination and pollution in sub-Saharan Africa.

The dust fallout from mine and ore smelters can cause soil pollution of nearby areas, including residential and agricultural areas, with documented cases where levels of trace elements have been detected to pose a risk to the environment and human health throughout the region. Trace elements at mining sites are often accompanied by other organic contaminants which results in more complex combinations that requires advanced remediation techniques. Dust suppression is a practice implemented in the large-scale mining sector in order to reduce the negative impact of dust emissions from the bare surface haul roads that are used for the transportation of the ore from the mine. However, this practice can also introduce contaminants to the soil where it is applied. Acid mine drainage from tailings storage facilities is a major cause of soil acidification in mining areas. The reduced pH levels of both soil and tailings increases the mobility of trace elements and radionuclides.

Artisanal and small-scale mining largely depends on human labour and primitive extraction technologies to extract the mineral from the ore. While the exact number of people dependent on this type of mining in sub-Saharan Africa could not be calculated, it is considered a key contributor to at least 23 of the regional economies. Countries in the region where artisanal and small-scale mining provide rural livelihoods include Burkina Faso, Mali, the United Republic of Tanzania, Sierra Leone, and the Democratic Republic of the Congo.

The two major contaminants of concern associated with the artisanal and small-scale mining of gold are mercury and cyanide. Elemental mercury is used to remove gold from silt by formation of a mercury-gold amalgam that is again melted to remove the gold. The washing process leaves mercury behind in the tailings and adds it to soil or nearby water resources. The use of cyanide to recover gold is now used by small-scale and artisanal miners in Mozambique, the United Republic of Tanzania, Burkina Faso and Zimbabwe. It has been stated that artisanal and small-scale mining is globally the largest emitter of mercury, with Burkina Faso contributing 35 tonnes to the estimated 1 400 tonnes per year. In reference to the polluted sites registered by Pure Earth, the International Institute for Environment and Development reported that 75 sites in sub-Saharan Africa have been registered as being polluted by mercury. It is estimated that these sites affect 2.4 million people. Sites polluted with elemental mercury have been identified in seven countries in the region (Ghana, Guinea, Kenya, Mozambique, Senegal, the United Republic of Tanzania and Uganda).

Apart from the mining of minerals, the extraction and processing of fossil fuels are also contributing to soil pollution in the region. The highest occurrence of soil pollution by trace elements and hydrocarbons as a result of the petroleum industries has been reported for Nigeria and Angola. Nigeria has suffered more than 4,000 oil spills between 1960 and 2010, with volumes estimated at more than 2 million barrels (320 000 m^3), the main cause being sabotage. In Angola, the oil and gas industry is responsible for the oil leaks and spills that have been reported since 2009 in the provinces of Cabinda and Zaire, which have caused the pollution of coastal and riverine sediment with at least 15 PAHs.

Waste management and transport

In 2012, approximately 81 million tonnes of Municipal Solid Waste (MSW) was generated in sub-Saharan Africa. It is projected that by 2025, the volume of MSW will grow to 244 million tonnes. A rising demand for electrical and electronic equipment (often with a short lifespan) such as used cell phones and computers results in an increase of electronic waste. Nigeria is one of the main receivers of e-waste from Asia and Europe. In addition to the waste that is generated, the region receives end-of-life vehicles, used tyres and electronic waste from countries in other regions. The average recycling rate of MSW waste in Africa is around 4 percent.

In addition to waste generation within the region, the shipment of waste from other regions adds to the heavy pollution burden associated with waste in sub-Saharan Africa.

The negative human health implications of e-waste sites have been illustrated in a study that linked the concentration of contaminants present in the blood levels of 245 people to the import and processing of e-waste in the 16 African countries. A majority of the participants from sub-Saharan Africa hailed from Western Africa and Central Africa. It was found that people, especially children, from areas where e-waste processing is a major activity are exposed to levels of trace elements such as aluminium, arsenic, vanadium, chromium, mercury and lead that present a high risk to their health. Areas where e-waste is processed through open burning, such as at the Agbogbloshie waste site in Ghana, have been identified as sources of soil pollution.

Historically, one of the major sources of soil pollution associated with transport was the contamination of roadside soil with lead through the use of leaded fuel. Although the phasing out of leaded fuels started almost forty years ago, progress in sub-Saharan Africa was slow in comparison to that made in Europe, the United States of America and even other developing countries.

While none of the countries in sub-Saharan Africa use leaded fuels anymore, vehicular emissions from areas with high traffic density has been linked to elevated trace metal concentrations in urban soils, especially antimony and cadmium.

Industrial activities

Through the Toxic Sites Investigation Program, Pure Earth/Blacksmith Institute has identified sites in sub-Saharan Africa that are polluted with trace elements. These include arsenic, cadmium, chromium (both hexavalent and total), lead, mercury and uranium. Sites with toxic lead concentrations are the most prevalent of the trace element polluted sites. Countries where lead pollution has been detected by the TSIP include Senegal, Kenya, the United Republic of Tanzania, Ghana, Rwanda, Madagascar, Uganda and Nigeria. The high lead concentrations in soil originate from a wide range of activities. These activities include lead battery recycling, transport, weapon manufacturing, tanneries, wastewater treatment plants, power plants that use coal or oil, mining and ore processing, smelters, auto repair workshops and medical waste.

Within residential areas a plethora of small industrial operations can be found ranging from dry cleaning, lead battery recycling and auto mechanic shops. High levels of trace elements have been documented in the soil and biota around metal smelters. Although each individual operation may be small, together they represent a major source of soil pollution.

The informal recycling of used lead-acid batteries is a significant source of lead in soil. At a typical informal recycler, the plastic box that holds the battery components is broken open with a hand axe or machete and the sulphuric acid solution inside is dumped on the ground or into a storm drain. The lead plates are removed and placed in a hole in the ground, which is then is filled with charcoal and ignited. The molten lead is then ladled into ingot moulds, cooled, and sold back to battery manufacturers. The process is typically conducted with no pollution control equipment or regulatory oversight.

Agriculture

Agricultural activities in the region have also been a source of soil pollution. Chemicals such as hazardous pesticides, persistent organic pollutants and products containing trace elements such as lead and mercury are still used in the region, to the detriment of both environmental and human health. While the use of these toxic chemicals is banned or controlled in developed countries, their illegal dumping in Africa provides a significant challenge for the management of environmental pollution.

Pesticide use by the agricultural sector is considered the most significant contributor of soil contaminants. Significant levels of endosulfan and DDT, both organochlorine insecticides, were detected in soils of the Awash valley state farms in Ethiopia and are attributed to historical agricultural practices in the area. In Burkina Faso, endosulfan and profenofos, an organophosphate insecticide, are present in the soil of both old and new agricultural fields used for cotton production.

Although DDT for agricultural purposes has been banned in the region, some countries in the region have been granted exemptions under the Stockholm convention to continue to use DDT for malaria's vector control. Unfortunately, supplies of DDT can sometimes leak from malaria control to be sold through local markets into the agricultural sector.

The past burial of obsolete pesticides is another source of soil pollution that may also be a diffuse source of groundwater pollution through seepage. The World Bank has reported that in 2013, approximately 50 000 tonnes of obsolete pesticides have been identified across the African continent. The extent of pesticide pollution Africa, including those classified as POPs, was determined by the Africa Stockpiles Programme (ASP) of FAO. Countries that have more than 1 000 tonnes of obsolete pesticides include Tunisia, the United Republic of Tanzania and Mali. Four of the regional countries have stockpiles of these pesticides in excess of 400 tonnes. These countries are Rwanda, Côte d'Ivoire, the Democratic Republic of the Congo and Benin. Soils polluted with pesticides have also been identified by the TSIP. The countries where these sites have been identified are Benin, Cameroon, Ethiopia, Ghana, Kenya, Senegal, Somalia and the United Republic of Tanzania.

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Actions to tackle soil pollution

Governance and legal frameworks to tackle soil pollution

International conventions regulating persistent organic pollutants and other hazardous substances

Although there is currently no binding international agreement focusing specifically on soil pollution prevention, control and remediation, a series of binding conventions partially support this objective.

The *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* was adopted in 1989 and became effective in May 1992 (Basel Convention, 2011). The principal aims of the Convention are the reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal; the restriction of transboundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management; and a regulatory system applying to cases where transboundary movements are permissible. Currently there are 188 parties to the Basel Convention.

The *Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade* is a multilateral treaty to promote shared responsibilities in relation to the importation of hazardous chemicals (Rotterdam Convention, 2010). The goals of the Convention are to promote shared responsibility and cooperative efforts among the Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm; and to contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, providing for a national decision-making process on their import and export and disseminating these decisions to Parties. The Convention was adopted in 1998 and entered into force in February 2004. Currently there are 164 parties to the Convention.

The *Stockholm Convention on Persistent Organic Pollutants* (signed in 2001 and effective from May 2004) aims to restrict or eliminate the production and use of persistent organic pollutants (POPs), characterized by their persistence in the environment, their resistance to degradation, and high toxicity (Stockholm Convention, 2008). As well as prohibiting the production and use of the listed POPs, the Convention also ensures that stockpiles and wastes consisting of or contaminated by POPs are managed in an environmentally sound manner. Improper storage and disposal of POPs is a major source of global soil pollution. Currently there are 184 Parties to the Convention.

The *Minamata Convention on Mercury* is a global treaty to protect human health and the environment from the adverse effects of mercury (Minamata Convention on Mercury, 2019). The Convention was adopted in 2013 and entered into force in August 2017. The major highlights of the Minamata Convention include a ban on new mercury mines, the phase-out of existing ones, the phase-out and phase-down of mercury use in a number of products and processes, control measures on emissions to air and on releases to land and water, and the regulation of the informal sector of artisanal and small-scale gold mining. The Convention also addresses interim storage of mercury and its disposal once it becomes waste, sites contaminated by mercury as well as health issues. To date there are 129 parties to the Convention.

The status of adoption of these conventions is summarized in the regional chapters, along with any regional agreements that exist.

International voluntary agreements to tackle soil pollution

The *Global Soil Partnership* (GSP) was established in 2012 as a mechanism to develop a strong interactive partnership and enhanced collaboration and synergy of efforts between all stakeholders (GSP, 2019). The GSP has the mandate of improving governance of the limited soil resources of the planet in order to guarantee healthy and productive soils for a food secure world, as well as support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources. The GSP addresses all soil threats and seeks on the one hand to improve knowledge and available data and information for informed decision making, and on the other hand to increase awareness of all stakeholders, with a final goal of to implementing field actions aimed at sustainable soil management and soil restoration and protection.

The *Voluntary Guidelines for Sustainable Soil Management* (VGSSM) endorsed by FAO Council in 2016 provide technical and policy recommendations for achieving sustainable soil management (FAO, 2017). The VGSSM identify ten threats to soil functioning and health, including soil pollution, and propose a set of principles to minimize and control these threats. Countries are encouraged to implement or strengthen inclusive regulations conducive to sustainable soil management in order to prevent and minimize the accumulation of contaminants in soil, as well as to promote soil information by testing, monitoring and assessing potentially contaminated soils in order to reduce risks to human health and the environment.

The *International Code of Conduct for the Sustainable Use and Management of Fertilizers* (Fertilizer Code) was endorsed by FAO Conference in 2019 and provides a set of voluntary practices that promote the judicious use of synthetic and organic fertilisers (FAO, 2019a). The Fertilizer Code defines roles, responsibilities, and actions to prevent fertiliser misuse and its potential impacts on human health and the environment. It encourages Member Nations to set standards, limits and guidelines on the harmful contents of contaminants in fertiliser products. It also includes provisions on monitoring, training, research and development, and public access to information.

The *International Code of Conduct on Pesticide Management* (Pesticide Code), adopted by FAO Member Nations in 2013, establishes voluntary standards of conduct for the various stakeholders involved with pesticide use to ensure the judicious use of pesticides (FAO and WHO, 2014). The Pesticide Code is intended to serve as a basis for countries who currently have no or weak national legislation to regulate and control the quality and suitability of pesticide products. The standards set out in the Pesticide Code aim to ensure that pesticides are used effectively and efficiently in a sustainable manner to minimize adverse effects on human health and the environment while contributing to the sustainable improvement of agriculture.

The *Global Action Plan on Antimicrobial Resistance* aims to prevent and combat antimicrobial resistance, which undermines human and animal health and hampers medicine advances to effectively treat infectious diseases (WHO, 2015). Endorsed in 2015 by the WHO Assembly, the Action Plan sets out five goals to combat antimicrobial resistance: raising awareness, increasing understanding and knowledge of antimicrobial resistance, reducing the incidence of infections, optimizing the use of antimicrobial medicines, and increasing investment in new medicines. By promoting the judicious use of antibiotics and other veterinary drugs and thereby controlling the emergence of antimicrobial resistant bacteria in livestock, the burden of antibiotic residues, and antimicrobial resistant bacteria and genes, released into the soil through faeces and urine is significantly reduced, which contributes to prevent soil pollution from these sources.

Founded in 1963, the *Codex Alimentarius* sets international food standards, guidelines and codes of practice to contribute to the safety and quality of international food trade (WHO and FAO, 2018). Although Codex standards and related texts are voluntary and must be translated into national legislation to be applicable, Codex standards often serve as the basis for national legislation. Currently, the Codex Alimentarius Commission has 189 Members, 188 Member Nations and a Member Organization, the European Union. San Marino and Timor-Leste are the latest country to join the Codex Alimentarius Commission, in 2016 and 2018 respectively. The relevance of the Codex to soil pollution lies primarily in its provisions on food additives, residues of pesticide and veterinary drug residues, contamination of food goods, methods of contaminants analysis and sampling, and import and export inspection and certification.

Established in 2003, *the International Nitrogen Initiative* (INI) is a science-policy platform for responding to the growing concern about nitrogen pollution (INI, 2017). INI seeks to '*optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects on human health and the environment resulting from food and energy production*'. To achieve this, the initiative coordinates regional efforts to improve and raise awareness on nitrogen management. The INI is not an official initiative of the United Nations but formed by international scientist and experts on nitrogen fertilisers' management.

Regional legal frameworks addressing soil pollution

Besides international agreements, there are other agreements at regional level that deserve to be taken into account. Although they do not specifically refer to soil pollution, they are intended to have an impact on the prevention and control of some of the most important sources of contaminants.

Within the framework of the Association of Southeast Asian Nations (ASEAN), environmental cooperation and coordination among its ten Member States (Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam) has been promoted. Coordination focuses on seven priorities: chemicals and waste, sustainable cities, nature conservation, water management, coastal environment, climate change and environmental education. While none of these priorities specifically address soil pollution, most of them can support the prevention of soil pollution and help harmonise countries' response through the exchange of knowledge and experience.

There is also Asia-Pacific regional collaboration on mitigating soil pollution, promoted by the Taiwan Environmental Protection Administration (Taiwan EPA). The Asia-Pacific Working Group on Remediation for Soil and Groundwater Pollution, established in 2011 and consisting of representatives from the Ministries of Environmental Protection of 12 countries (Taiwan Province of China, Republic of Korea, Japan, Philippines, Malaysia, Thailand, Viet Nam, Indonesia, Sri Lanka, India, Australia and New Zealand) aims to raise awareness and encourage bilateral cooperation between countries to prevent soil pollution and groundwater pollution.

The Member States of the Eurasian Economic Union, namely the Republic of Armenia, the Republic of Belarus, the Republic of Kazakhstan, the Kyrgyz Republic and the Russian Federation, have several agreements in place to control the movement of hazardous waste between countries and to ensure safety of chemical products to be imported.

The European Commission has recently launched the EU Green Deal, an ambitious plan to boost resource efficiency by moving towards a clean and circular economy, restore biodiversity and reduce pollution. Within the framework of the Green Deal, the action plan "Towards a Zero Pollution Ambition for air, water and soil – building a Healthier Planet for Healthier People" is to be adopted in 2021. This Action Plan aims to improve the governance of pollution policies, including at the international level, with a particular focus on improving data availability and existing models and new technologies that will enable more data to be obtained. The Action Plan will also address the international aspects of the EU's Zero Pollution Ambition, such as diplomacy, trade policy and development support. The newly adopted Green Deal will complement the existing set of directives regulating the main sources of pollution.

An agenda is also being developed to extend the Green Deal to the Western Balkans. The Western Balkans Economic and Investment Plan aims to stimulate the economies of the Western Balkan states and, at the same time, bring the region up to EU environmental standards and climate targets.

The Cartagena Convention, adopted by 21 countries in Latin America and the Caribbean, imposes obligations to prevent, reduce and control pollution. While the Convention focuses largely on the marine environment, it covers many sources of marine pollution including land-based pollution by prohibiting the dumping or discharge of wastes and coastal disposal or discharges causing pollution. Other land-based pollution includes wastewater, pesticides, heavy metals, radioactive substances, solid waste and more, all of which could affect soil preservation as well. The Protocol on Pollution from Land-based Sources and Activities includes regional limitations on domestic wastewater effluents and requires the development of plans to prevent, reduce and control non-point agricultural sources of contaminants.

Regional agreements have been adopted between Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, and Mexico, El Salvador, Guatemala and Honduras to prevent the import and transit of hazardous waste to Central America from third states.

The United States of America and Canada have one of the oldest and most effective environmental partnerships in the world. The Canada-US Joint Inland Pollution Contingency Plan focuses on implementing measures to address soil pollution and reduce the risks to the environment and human health when it occurs along the border between the two countries. Other major agreements with a greater focus on water quality implicitly address soil pollution through requirements to consider water pollution derived from inputs from upland watersheds.

The Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movements and Management of Hazardous Wastes in Africa was adopted within the framework of the Basel Convention. Its main objectives are to stop the import of hazardous wastes and potentially hazardous wastes, including radioactive waste, from other parts of the world and the management of wastes already present in Africa. However, there was little acceptance and implementation, leading to the Libreville Declaration on Health and Environment in Africa in 2008, promoted by WHO. This declaration included the establishment of different levels of legislative framework, capacity building to address the issues, initiation and coordination of applied research. It also commits to effective implementation and the establishment of monitoring and evaluation at the national level.

National legal frameworks addressing soil pollution

The existence of legal frameworks and the distribution of responsibilities differs from country to country. Few countries have specific legislation to prevent, manage and remediate soil pollution. Many countries, on the contrary, include soil management aspects in environmental legislation, which is often very general and does not provide an adequate framework to address the different sources of soil pollution.

For most countries, soil pollution prevention is a priority in legislation and policymaking. However, as polluting sources are varied, soil pollution itself is not legally defined or recognized, and instead, most countries have legislation related to urban and industrial waste management and agricultural inputs and practices. These measures seem to be insufficient to prevent and control soil pollution as they remain the main sources of contaminants.

In the absence of clearly defined soil polluting activities, opportunities for developing management strategies, monitoring plans, compliance, and enforcement activities are limited.

Improved knowledge, monitoring and reporting

Despite the large amount of existing information, there are still numerous knowledge gaps to be clarified. More research and harmonized data collection is needed on the amount of contaminant emissions into the environment, their fate in the soil and beyond, and the spatial distribution of polluted sites, with special attention to hot spots that pose the greatest danger to human and environmental health.

It is necessary to improve the mechanisms for communicating the causes, risks and prevention actions of soil pollution among all stakeholders, but especially among the general public. The actions of the Global Soil Partnership following the Global Symposium on Soil Pollution and on the occasion of World Soil Day celebration in 2018 demonstrated that there is a great interest in this topic.

Management of soil contamination and pollution

The management approach for polluted soil sites (posing risk to human health and the environment) is very different from the approach for contaminated sites. Polluted sites must be isolated from human and animal contact, and then the levels of the contaminants reduced below the point where they cause harm to non-target organisms. This reduction in levels is called soil remediation. Contaminated sites would undergo remediation only rarely; instead, the management of the site may need to be altered in order to minimize the risk of harm to organisms (Cachada, Rocha-Santos and Duarte, 2018).

The costs of safeguarding and eliminating a concentrated contaminant before it has leaked are orders of magnitude less than the cost of remediating the soil afterwards. The cost of inaction in eliminating global stocks of soil contaminants is unacceptable. Given the possibility of permanent degradation of land, the risks to public health and environment, and the expense and complexity of remediation, the avoidance of soil pollution is an obvious priority.

Identification and risk assessment

The initial stage for site assessment is to identify sites where pollution may exist. Sites may be selected on the basis of historical analysis (for past activities) or based on knowledge of accident sites. After preliminary research on the site's historical use, an initial assessment is carried out to define whether contaminants are present and whether they are posing any risk to the environment and to human health – that is, to distinguish between site contamination and site pollution. In many cases soil screening values (SSVs) are used. These are generic soil quality standards based on generic exposure pathways and scenarios, and they have been adopted in many countries to allow identification of polluted soils (Carlon *et al.*, 2007).

The determination of the degree of pollution and its potential for harm is carried out in a risk assessment framework. Risk management decisions for soils or sediments focus on identifying relevant pathways of exposure that pose a risk to human health or the environment and developing appropriate remedial measures. These could include treating or removing sources or cutting off pathways of exposure, or both. Risk assessment approaches are tools to take science-based political and technical decisions and are similar worldwide. These allow polluted sites to be distinguished from contaminated sites, and thus to facilitate the selection of appropriate management techniques.

Management of contaminated sites

Soil contamination often results from the spread of contaminants from polluted sites by wind or water erosion, irrigation of soils with polluted ground or surface water, or land spreading of contaminated manures or sewage sludge; all of these would be considered diffuse sources of contamination. It can also occur from wind dispersal of contaminants from a point source – such as a smelter or waste incinerator. Close to the source, the soil may be polluted, but further downwind the soil has contaminant levels below those known to cause harm to non-target organisms.

Management of these sites usually consist of adaptation to the presence of contaminants and follows the general principles of Sustainable Soil Management (SSM); specific approaches are summarized in section 3.5 of the *Voluntary Guidelines for Sustainable Soil Management* (FAO, 2017). These approaches often involve a change in land use at the contaminated site, including change of crop selection – for example, a change to crops that do not bio-accumulate and biomagnify the particular contaminant that has been detected. Another key management approach is to reduce or eliminate dispersal of contaminants by wind or water erosion by implementing soil conservation measures on the contaminated site. Similar approaches can be used to reduce or eliminate leaching of contaminants to groundwater by, for example, growing deep-rooted plants with high water use.

Management of polluted soils

In general, where soil is found to be polluted (that is, where the level of contaminants can cause harm to non-target organisms), the polluted soil must be isolated from causing harm to people, organisms or aquatic systems. Soil remediation (reducing the concentration of the contaminant in the soil) is a permanent approach to managing pollution. Remediation of polluted sites is a site-specific approach that includes identification, characterization, risk assessment and selection of remediation technologies, and is mainly focused on point-source pollution (Figure 18).

If pollution is confirmed and remediation measures are necessary, the first management step should be to exclude people and animals from the site using fencing or other physical barriers and warning signs. This step should be supported by communication programmes to sensitize the population of the dangers to them and their animals of entering the site.

Next, a detailed investigation must be accomplished to determine the extent and possible remediation measures. Risk management and/or remediation strategies are subsequently defined and implemented (Aven, 2016).

Remediation techniques can be divided in two main groups: *in situ* (on the site) and *ex situ* (removal of contaminated soil for treatment off the site) remediation. Available remediation options include physical, chemical and biological treatments (e.g. phytoremediation, Figure 19), and these options offer potential technical solutions to most soil pollution. For both *in situ* and *ex situ* measures, the net effect on the contaminants can be categorized as a) reducing the concentration, b) reducing the bio-availability without reducing the concentration, c) encapsulating the polluted soil in an inert matrix, d) containment and e) removal. After clean-up, measures are essential to confirm that the risk has been reduced and that the source of pollution has been controlled.

In cases where remediation is not chosen (for logistical, economic, or political reasons), risk management can be practised using a number of strategies. Capping the polluted soil with clean soil, a hard surface or other containment material is an option where the risk of groundwater contamination is very low. Where the groundwater contamination risk is higher, an impermeable barrier may have to be installed below the polluted soil.

Stages in the remediation of site contamination

NRF guideline

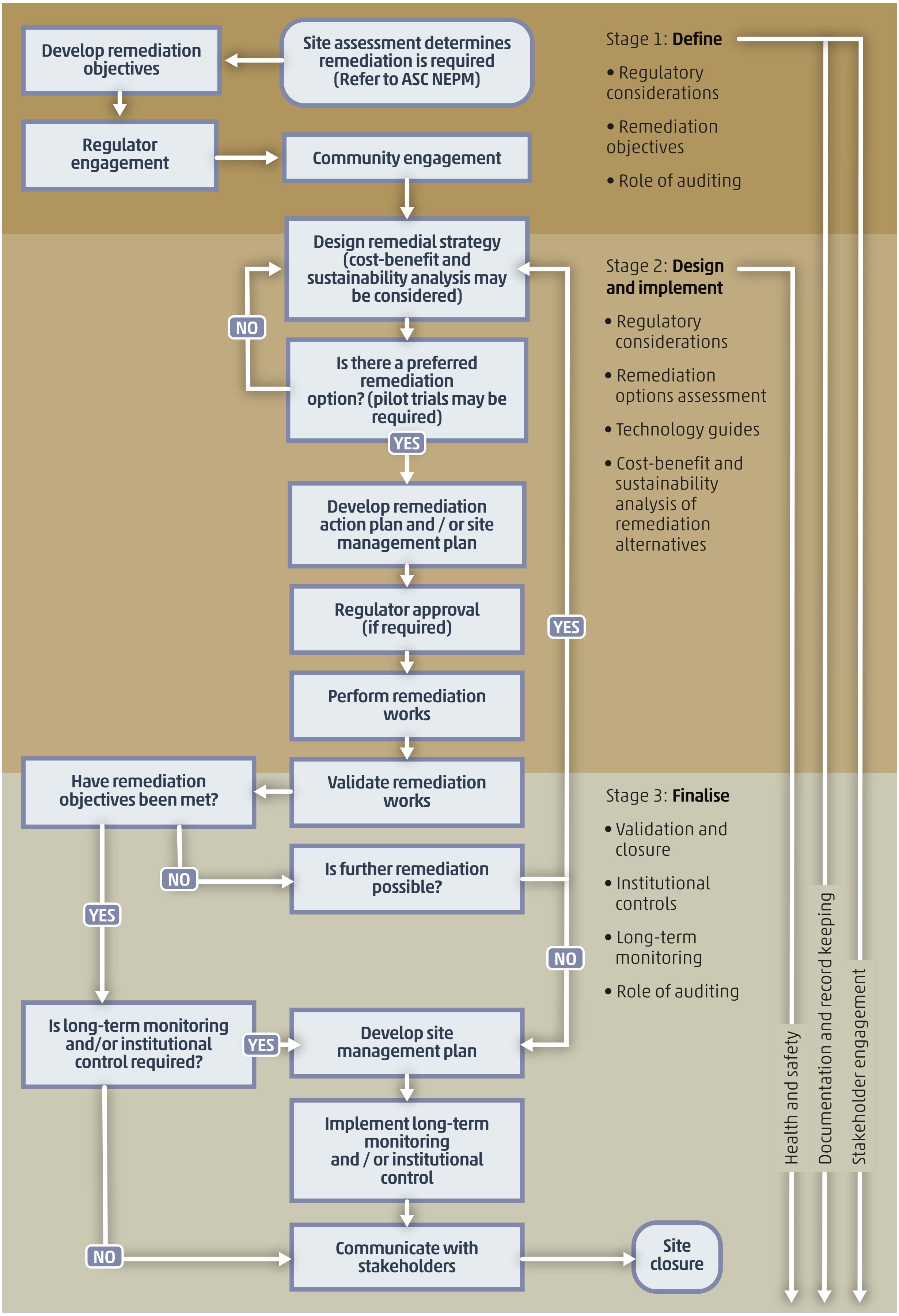

Figure 18. Stages in the remediation of site pollution according to National Remediation Framework guideline

Source: CRC CARE, 2018

Management of soils as a source of pollution

A final aspect to management of pollution is to reduce or eliminate water pollution that occurs as a result of chemicals, primarily agrochemicals, moving from the soil to both surface water and groundwater. This transport of agrochemicals is one of the leading causes of water pollution globally and affects both freshwater and marine environments. Both the *Voluntary Guidelines for Sustainable Soil Management* (FAO, 2017) and the *International Code of Conduct for the Sustainable Use and Management of Fertilizers* (FAO, 2019) outline specific techniques that can be used to ensure that agrochemicals are safely and sustainably added to the soil system so as to prevent off-site pollution.

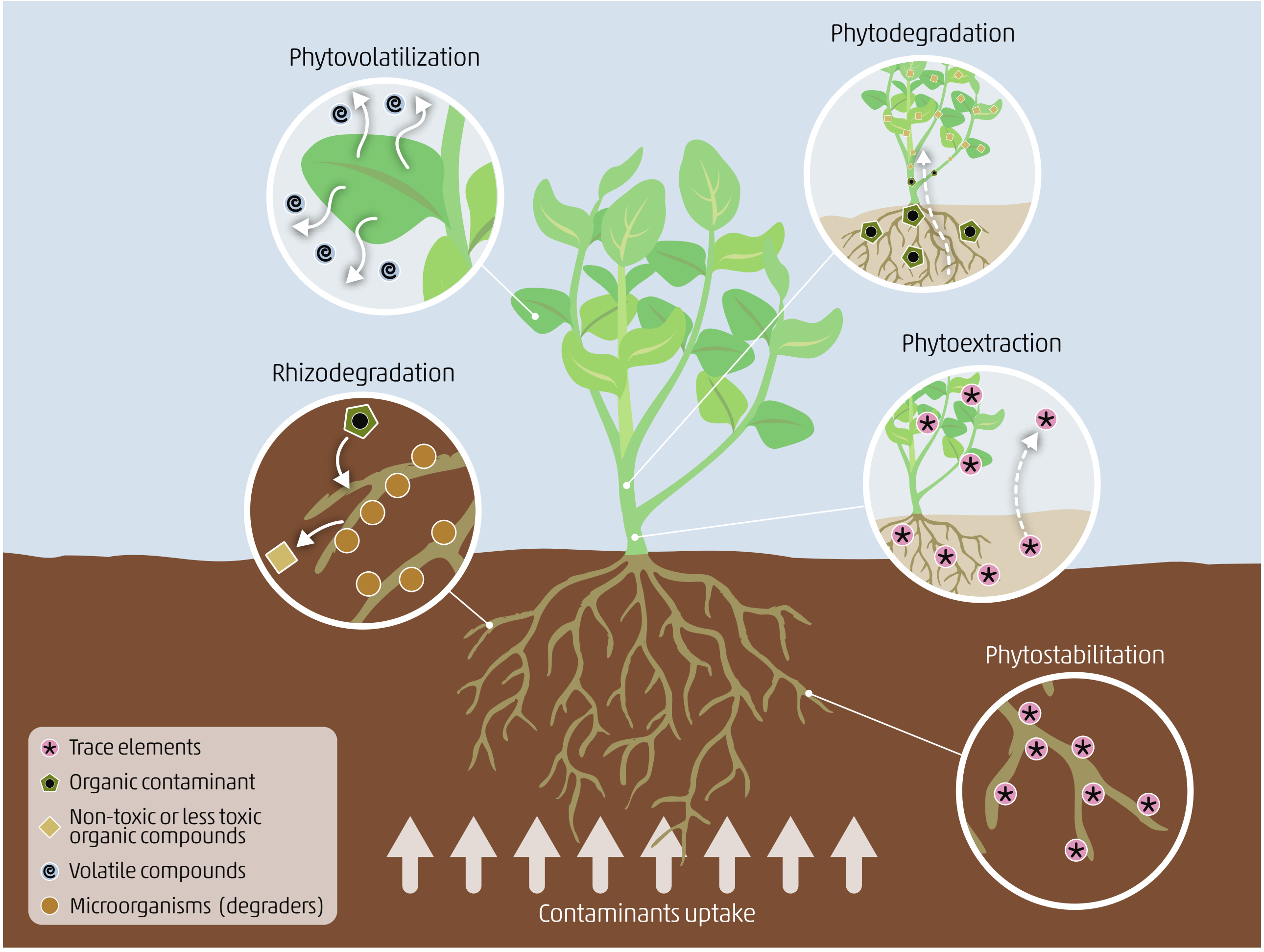

Figure 19. Plant mechanisms for the uptake and stabilization of organic and inorganic contaminants

Source: adapted from Gómez-Sagasti *et al.*, 2012; ITRC, 2009; Tangahu *et al.*, 2011

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Priority Actions to prevent and halt soil pollution and to remediate polluted soils

Based on the scientific evidence gathered for this report, as well as comments and discussions from multiple stakeholders who have participated in different Global Soil Partnership and UNEP fora, a number of key recommendations to tackle soil pollution imminently and effectively are defined below.

The first and foremost action against soil pollution is prevention. All stakeholders must take decisive steps in the prevention of soil pollution, starting with small actions in people's consumption decisions and extending to the development of stringent policies and incentives that encourage industrial innovation and the adoption of environmentally sound technologies.

Knowledge gaps

From assessment to monitoring

- Harmonise standard operating procedures for laboratory methods of soil contaminants analysis and develop standardized threshold levels of soil pollution.
- Promote the inclusion of soil pollution into the conventional soil surveys, data and information on soil pollution into national and global soil information systems.
- Increase the investment in targeted research on emerging contaminants: detection, fate in the environment, risks assessment and remediation.
- Develop and strengthen the inventory and monitoring of point-source and diffuse soil pollution at national, regional and global levels.
- Establish and strengthen national biomonitoring and epidemiological surveillance systems to identify, assess, and monitor damage and diseases attributable to soil pollution and support preventive actions.
- Promote the establishment of the Global Soil Pollution Information and Monitoring System.

From policy to technical actions

- Enforce compliance with international agreements on chemicals, persistent organic pollutants, waste, and sustainable soil management (including the Voluntary Guidelines for Sustainable Soil Management, and the International Codes of Conducts for the Sustainable Use and Management of Fertilizers and Pesticides).
- Establish a system of incentives and recognition to efforts to stop soil pollution, including eco-labelling or compliance to schemes like the Voluntary Guidelines for Sustainable Soil Management by providing labelling to agriculture products implementing those tools/schemes.
- Advocate for a global commitment towards preventing, halting and remediating soil pollution in the framework of Zero Pollution/Towards a Pollution Free Planet ambitions, using regional efforts and targets such as the European Green Deal as a basis.
- Improve national and international regulations on emissions from industry and mining and promote environmentally friendly industrial processes.
- Develop and promote "right to repair" policies and de-incentivize planned obsolescence of manufactured materials to reduce waste, including e-waste.
- De-incentivize and reduce single-use items, particularly in packaging for materials and foodstuffs.
- Implement appropriate waste collection and green management policies that promote recycling and ensure the adequate treatment of different types of waste within and among countries.
- Promote and incentivize the use of sustainable transport.
- Implement policies aimed at sustainable management of agricultural soils with a special focus on reducing dependence on agrochemicals and controlling the quality of irrigation water and organic residues.
- Develop and include in national reporting mechanisms soil pollution targets and indicators related to the achievement of the Sustainable Development Goals.
- Scale up nature-based and environmentally sound sustainable management and remediation technologies (e.g. bioremediation).

Awareness-raising and communication

- Launch a global awareness raising campaign on soil pollution aimed at the general public for them to understand why soil pollution matters to all and how they could be part of the solution.
- Foster citizen science activities and citizen observatories to improve early warning systems and community-based soil pollution monitoring.
- Promote public awareness of responsible and environmentally friendly consumption and encourage separation at source and the waste hierarchy, in particular the 4R approach (reduce, reuse, recycle and recover) (Figure 20).
- Advocate for the inclusion of soil health and soil pollution topics at schools.

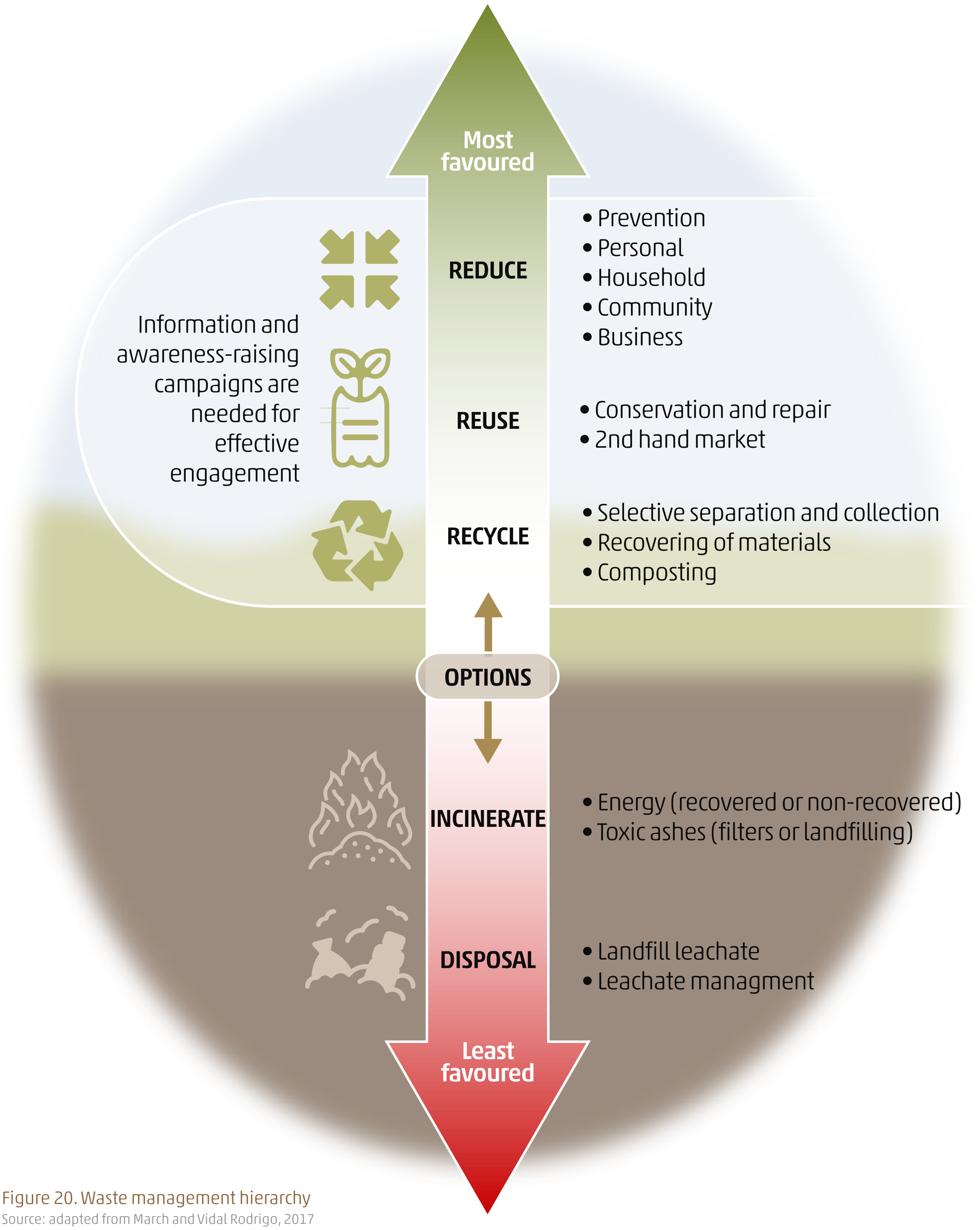

Figure 20. Waste management hierarchy
Source: adapted from March and Vidal Rodrigo, 2017

Regional cooperation

- Facilitate the transfer of scientific knowledge through international events and promote the publication of information in open access sources.
- Advocate for technology transfer and cross-capacity building for the whole cycle of soil pollution, from prevention to detection, monitoring, management, and remediation, from regions and countries with high expertise and experience on soil pollution to countries with less or no expertise in the topic (Figure 21).
- Build and strengthen transboundary monitoring networks to prevent, manage, and remediate diffuse pollution.
- Establish a global training programme for developing capacities on the full cycle of soil pollution.

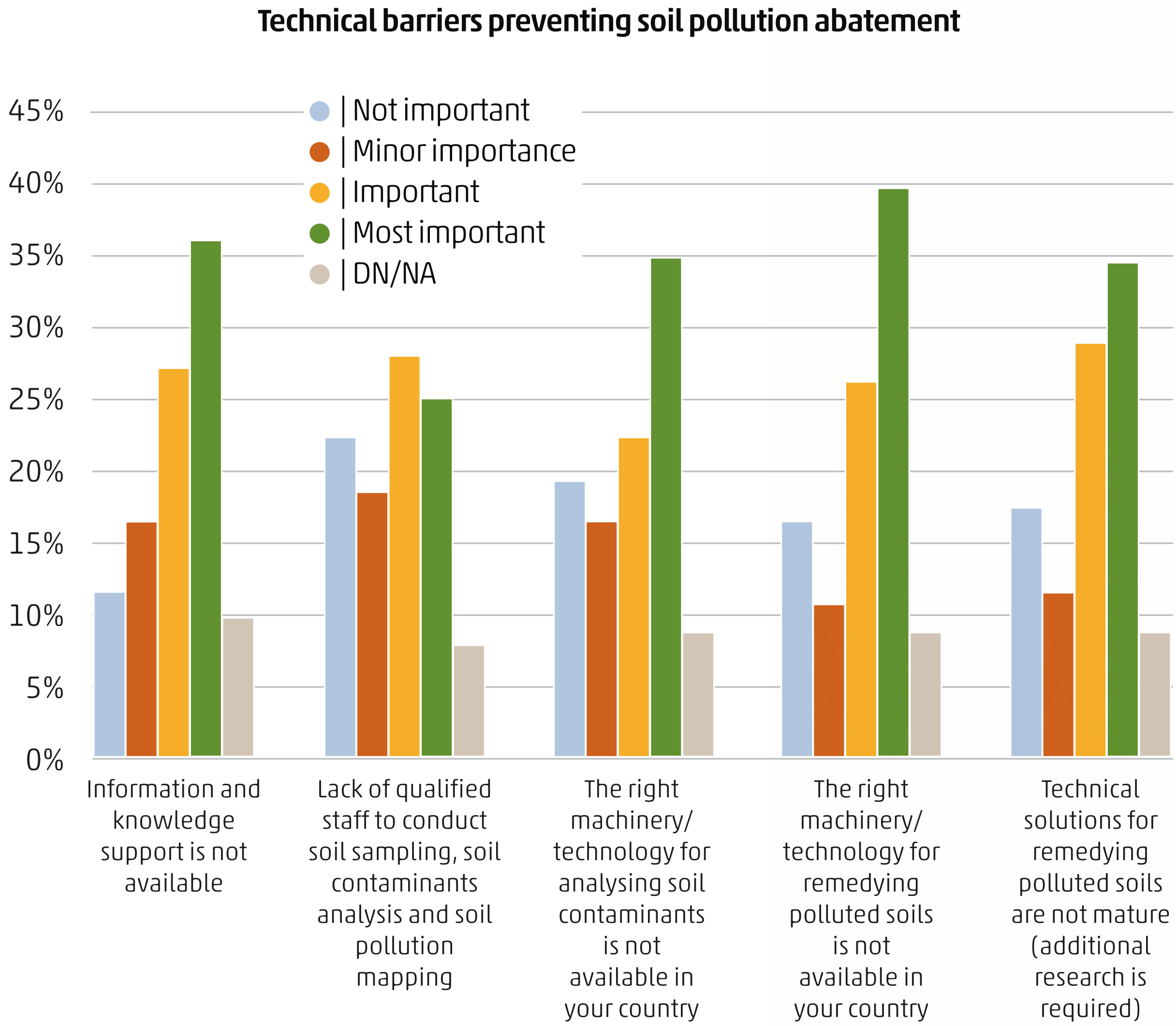

Figure 21. Technical barriers to the abatement of soil pollution according to the perception of the experts who contributed to the preparation of this report


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Glossary

Bioavailability. The portion of the total quantity of a chemical/substance that is 'freely available' to cross an organism's cellular membrane from the medium the organism inhabits at a given time (Semple *et al.*, 2004), and which can be metabolically active in a living organism (Klaassen, Casarett and Doull, 2013). 'Freely available' is defined operationally by different methods. Bioassays on plants or animals (Ng *et al.*, 2015) are often time and resource-consuming and may comprise ethical issues. Indirect single-step or sequential chemical extractions using reagent(s) simulating the interaction of plant or human fluids/exudates with the contaminant(s) of interest are also employed (Cipullo *et al.*, 2018). Some of these extractions have been standardized and taken into consideration in the legislation of some countries. Other extractions are undergoing standardization, a process necessary to make bioavailability a concept that can be included in legislation and policies for soil protection, and as a tool for risk assessment (Harmsen, 2007; Kim *et al.*, 2015). In soil, contaminant bioavailability can be affected by soil properties (e.g., pH, redox potential, clay content, organic matter content, etc.) (Gupta *et al.*, 2019; Sinche *et al.*, 2018), contaminant chemical properties (e.g., polarity, oxidation states, acidity, etc.), and/or environmental factors (e.g., moisture content, temperature, etc.). These properties are not static in time or place, thus it is important to understand the limitations of operationally-defined determinations of bioavailability when evaluating actual bioavailability at a given site temporally and spatially.

Bioaccumulation. The net result of all processes of absorption and loss, such as respiratory absorption and through food ingestion, and loss by egestion, passive diffusion, metabolism, transfer to offspring and growth (Borgå, 2013). It comprises the specific processes of *bioconcentration* and *biomagnification*.

Biomagnification. The enrichment of a chemical/substance in an organism relative to the chemical/substance in the organism's food, when the major exposure route occurs from the organism's diet (Drouillard, 2008). Biomagnification leads to increased chemical/substance concentration with higher trophic position in the food web (Borgå, 2013).

Biomonitoring. The use of living organisms to assess environmental contamination or pollution by measuring accumulation of chemicals in organism tissues or by assessing biomarkers of exposure on indicator species.

Carcinogenicity. The ability of a physical phenomenon (e.g. radiation), or of a chemical or biological agent to cause cancer or increase its incidence (United Nations, 2011).

Contaminant. A substance, compound or chemical element at a concentration that exceeds natural concentrations (Chapman, 2007) (natural background value) (ISO, 2016). The presence of a contaminant does not necessarily indicate harmful or deleterious effects. The term is often used as a synonym for pollutant.

Diffuse soil pollution. Pollution that is spread over wide areas and that accumulates in the soil. Diffuse pollution is often more difficult to attribute to a single source. Two main types of diffuse pollution occur. 1. unintended spreading of a chemical or of contaminated particles from a point-source site or polluting activity (e.g. industrial emissions) to the broader landscape. This spreading can occur by wind or water transport of chemicals and particles on the soil surface, by atmospheric transport and deposition of volatile chemicals, or by leaching of chemicals from the soil to groundwater. 2. diffuse pollution occurs through intended application of a contaminant or a source of contaminants – for example, irrigation with contaminated groundwater or untreated wastewater, land application of sewage sludge, or agricultural use of non-rapidly-degradable pesticides or contaminants introduced with fertilisers.

Endocrine disruptor. An exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations (IPCS, 2002).

Eutrophication. The excessive enrichment of surface waters with plant nutrients, primarily N and P (FAO, 2019b).

Mutagenicity. The ability of any contaminant to damage the genetic information in a cell, producing transmissible genetic alterations to other cells and progeny (Gupta, 2016).

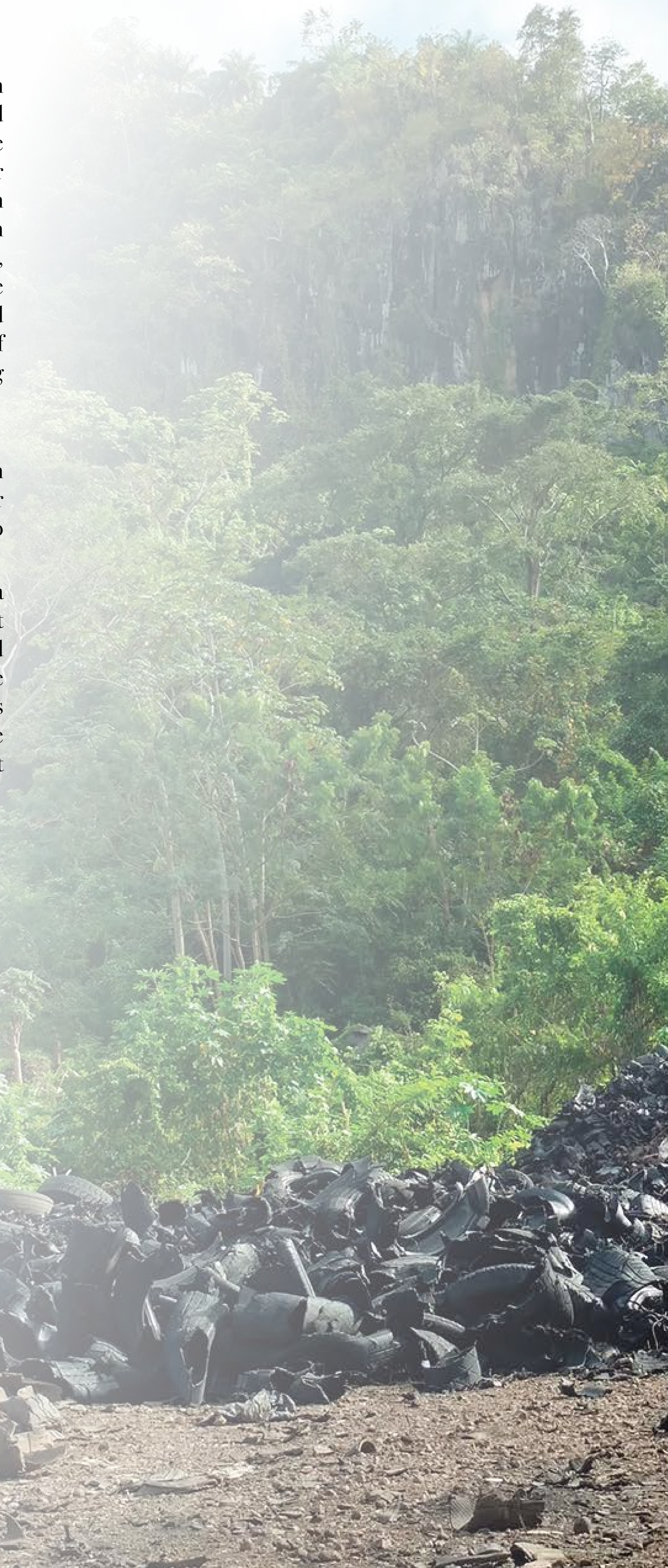
Natural (geochemical) background concentration. The natural concentration (given in a range or in absolute value) (Reimann and Garrett, 2005) of an element or compound in the soil due to geological and pedological processes, in a given place and time, the origin and presence of which has no anthropic influence (adapted from ISO, 2015a; Tian *et al.*, 2017). Natural soil background concentrations are variable depending on the mineralogical composition of the soil parent material and on the pedogenetic (soil-forming) processes (Kabata-Pendias and Pendias, 2001; Wilson *et al.*, 2008).

Neurotoxicity. Any adverse effect on the structure and/or the normal activity of the nervous system after exposure to contaminants (neurotoxins) (Spencer and Lein, 2014).

Point-source soil pollution. Point-source soil pollution occurs in a limited area, and in most cases the source and identity of the pollution is readily identified. The cause of the point-source pollution can be accidental (for example, through spills of contaminants or leakage from storage containers) or it may occur as a by-product of an intentional activity (e.g. former factory sites, landfills, lead battery or electronic waste recycling sites, and mine tailings). Ideally, appropriate governance regulates and prevents soil pollution. However, many examples of lack of regulation, or weak implementation of existing regulations, for soil pollution are included in this report.

Soil contamination. Soil contamination occurs when the concentration of a chemical or substance is higher than would occur naturally, but is not at a level known to cause harm to non-target organisms.

Soil pollution. Soil pollution refers to the presence of a chemical or substance that is out of place and/or is present at a higher than natural background concentration, and that has an adverse effect on any non-target organism. The specification of non-target organisms in these definitions recognizes that some chemicals and substances are added to plants and soils specifically to suppress target organisms such as pesticides.

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GLOBAL SOIL PARTNERSHIP

The Global Soil Partnership (GSP) is a globally recognized mechanism established in 2012. Our mission is to position soils in the Global Agenda through collective action. Our key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.

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