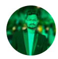
Soil Pollution and Environmental Health

Chapter · August 2023

DOI: 10.5281/zenodo.8331094

3 authors:

Aniket Sunil Gaikwad
Mahatma Phule Krishi Vidyapeeth



Nihal S. Titirmare
Mahatma Phule Krishi Vidyapeeth

Prasad B. Margal

ADVANCES IN SOIL SCIENCE

(Volume - 1)

<u>Editors</u>

Dr. Snehalata A. Chaware

Dr. Sanjib Kumar Sahoo

Munmun Dash

Dr. M. Jagadesh

Satender Kumar

Cite this article: Titirmare, N.S., Gaikwad, A.S. and Margal, P.B. (2023) Soil Pollution and Environmental Health. In: S.A. Chaware et al. (Eds.), Advances in Soil Science 1(13), 267-307. Bright Sky Publications, New Delhi, India. http://dx.doi.org/10.5281/zenodo.8331094

Bright Sky Publications ™
New Delhi

Published By: *Bright Sky Publications*

Bright Sky Publication
Office No. 3, 1st Floor,
Pocket - H34, SEC-3,
Rohini, Delhi, 110085, India

Editors: *Dr. Snehalata A. Chaware, Dr. Sanjib Kumar Sahoo, Munmun Dash, Dr. M. Jagadesh and Satender Kumar*

Edition: *1st*

Publication Year: *2023*

Pages: *455*

ISBN: *978-93-92804-68-7*

Book DOI: *https://doi.org/10.22271/bs.book.87*

Price: *₹ 1802/-*

Cite this article: Titirmare, N.S., Gaikwad, A.S. and Margal, P.B. (2023) Soil Pollution and Environmental Health. In: S.A. Chaware et al. (Eds.), Advances in Soil Science 1(13), 267-307. Bright Sky Publications, New Delhi, India. http://dx.doi.org/10.5281/zenodo.8331094

Chapter - 13

Soil Pollution and Environmental Health

Authors

Nihal Shridhar Titirmare
Ph.D. Research Scholar, Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra, India

Aniket Sunil Gaikwad
Ph.D. Research Scholar, Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra, India

Prasad Balasaheb Margal
Ph.D. Research Scholar, Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra, India

Chapter - 13

Soil Pollution and Environmental Health

Nihal Shridhar Titirmare, Aniket Sunil Gaikwad and Prasad Balasaheb Margal

Abstract

Soil plays a crucial role in sustainable economic and social development, impacting both human health and the construction process. Soil protection is vital to support ecological progress and ensure domestic ecological safety. Soil pollution occurs when toxic chemicals, known as pollutant are present in the soil at concentrations that pose risks to human health and the ecosystem. Soil degradation is a significant issue, affecting all aspects of the country and representing a major weakness in construction. All soils, whether polluted or unpolluted, naturally contain various compounds known as contaminants. These contaminants include metals, inorganic ions, salts, and organic compounds, which are primarily formed through microbial activity and the decomposition of organisms in the soil. Additionally, substances from the atmosphere, such as precipitation water, wind activity, soil disturbances, surface water bodies, and shallow groundwater, can introduce various compounds into the soil. When the levels of these contaminants exceed natural levels, soil pollution occurs. The consequences of soil pollution include vegetation loss, hindered plant growth and development, and the eventual degradation of soil leading to erosion and desertification. Soil pollution can stem from two main causes: anthropogenic (human-made) causes and natural causes. This chapter explores the causes and effects of soil pollution, focusing on both human activities and naturally occurring pollutants. It also discusses measures for preventing and controlling soil pollution.

Keywords: Soil pollution, pollutant, contamination, soil fertility, environment, ecosystem disruption and health.

1. Introduction

In India, soil pollution is a significant environmental concern resulting from various human activities and natural processes. The country's rapid industrialization, agricultural practices, and inadequate waste management contribute to soil pollution. Industries release pollutants such as heavy metals, persistent organic pollutants, and petroleum hydrocarbons, which can contaminate the surrounding soil. The extensive use of chemical fertilizers, pesticides, and herbicides in agricultural practices also contributes to soil pollution. One of the major contributors to soil pollution in India is the improper disposal of industrial and municipal waste. Inadequate treatment and disposal of hazardous waste led to the release of toxic substances into the soil, posing a risk to human health and the environment. The role of soils on human health is widely recognized among the scientific community (Abrahams, 2002; Brevik and Sauer, 2015; Brevik *et al.*, 2017; Brevik and Burgess, 2013; Oliver, 2008; Oliver and Gregory, 2015) and has also been acknowledged in the international political arena inclusion within the Sustainable Development Goal.

Furthermore, the informal recycling sector, which is prevalent in many urban areas, often involves the dismantling and processing of electronic waste and discarded batteries, resulting in the release of hazardous substances into the soil. Soil pollution, which contributes to land degradation, occurs when xenobiotic chemicals or other alterations are present in the natural soil environment. It is primarily caused by industrial activities, the use of agricultural chemicals, and improper waste disposal. Common chemicals associated with soil pollution include petroleum hydrocarbons, polynuclear aromatic hydrocarbons, solvents, pesticides, lead, and other heavy metals. The degree of contamination is closely linked to the level of industrialization and the intensity of chemical substances used. The primary concern regarding soil contamination arises from the associated health risks, which can result from direct contact with contaminated soil, inhalation of vapour from the pollutants, or secondary contamination of water sources within and beneath the soil.

In agricultural areas, the excessive use of chemical fertilizers and pesticides has led to soil degradation and contamination. Prolonged and indiscriminate use of these agrochemicals not only affects soil quality but also impacts water bodies through runoff and leaching, further exacerbating the problem of soil pollution. Mapping contaminated soil sites and carrying out subsequent clean-up efforts are time-consuming and costly endeavours. These tasks require a significant amount of expertise in geology, hydrology, chemistry, computer modelling, and the use of Geographic Information Systems (GIS) in assessing environmental contamination. Additionally, understanding the historical context of industrial chemistry is crucial in effectively addressing soil pollution challenges (Amini *et al.*, 2005; Ji *et al.*, 2012; Rao *et al.,* 2017; Yang *et al.,* 2021). Studies have revealed high levels of soil contamination in various regions of India. For example, agricultural soils in parts of Punjab and Haryana have been found to contain elevated levels of pesticides, particularly organochlorines. Heavy metals such as cadmium, lead, and chromium have been detected in soils near industrial areas, including in states like Gujarat, Maharashtra, and West Bengal. However, developing countries, despite undergoing significant industrialization, tend to have less stringent regulations in place. It is important to recognize that all soils naturally contain compounds that may be harmful or toxic to humans and other living organisms. However, the concentrations of these substances in unpolluted soil are typically low enough that they do not pose a threat to the surrounding ecosystem. When the concentration of one or more toxic substances reaches levels that can cause harm to living organisms, the soil is considered contaminated. The primary causes of soil pollution often stem from agriculture (excessive or improper use of pesticides), excessive industrial activities, and poor waste management practices.

The challenges associated with soil remediation are closely linked to the extent of soil pollution. The greater the contamination, the greater the resources required for effective remediation (Liu and Lui, 1997; Wang *et al.,* 2004; Cappuyns, 2013; *Chen et al.,* 2020). The impacts of soil pollution on human health in India are a growing concern. Direct contact with contaminated soil or the consumption of crops grown in polluted soil can lead to the accumulation of toxic substances in the human body. This can result in various health issues, including respiratory problems, neurological disorders, and an increased risk of cancer. In conclusion, soil pollution is a significant environmental challenge, arising from industrial activities, agricultural practices, and improper waste management. The contamination of soil with toxic substances poses risks to human health and the ecosystem. Efforts to tackle soil pollution in India involve legislative measures, adoption of sustainable agricultural practices, and proper waste management strategies.

2. Source of soil pollution: Soil pollutants

Pollutants are substances or agents that are introduced into the environment, either intentionally or unintentionally, and have harmful effects on living organisms, ecosystems, or the environment as a whole. These can be in the form of solid, liquid, or gaseous substances, and they can originate from natural sources or human activities. Pollutants can be classified into various categories, including air pollutants, water pollutants, soil pollutants, and noise pollutants. On the other hand, soil pollutants specifically refer to substances or contaminants that are present in the soil at levels higher than the natural background concentrations and have adverse effects on soil quality, living organisms, and ecosystem functions. Soil pollutants can originate from various sources, including industrial activities, agricultural practices, improper waste disposal, mining operations, and atmospheric deposition. Common soil pollutants include heavy metals (such as lead, cadmium, mercury, and arsenic), organic compounds (including pesticides, herbicides, industrial solvents, and petroleum hydrocarbons), radioactive substances, and nutrients (such as nitrogen and phosphorus) when present in excessive amounts. Chemical substances that serve as environmental contaminants in soil have the potential to pose hazards, and they can be classified as either inorganic or organic compounds. Figure 1 presents a systematic classification of commonly found soil contaminants based on their chemical properties. It is important to note that emerging contaminants, which encompass a broad range of substances, are not included in this categorization.

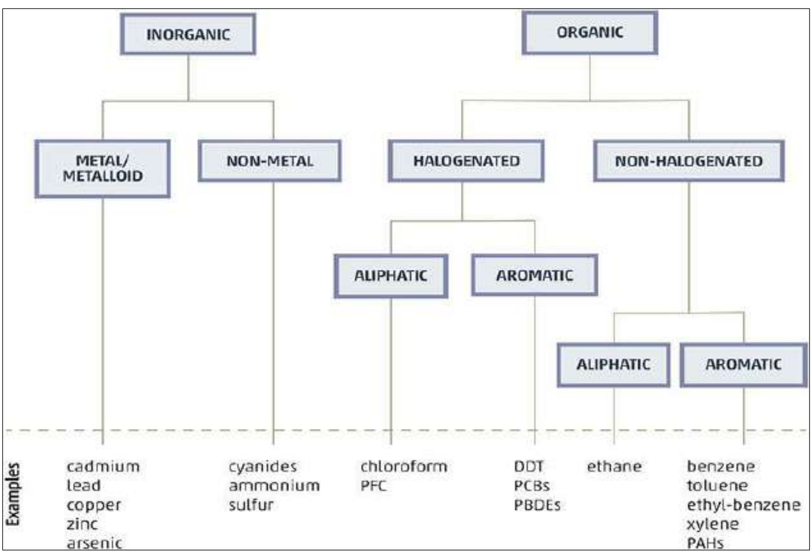


Fig 1: A systematic classification of the major pollutants found in soils according to *International Union of Pure and Applied Chemistry* (IUPAC) guidelines (Nič *et al.*, 2009)

Certain soil pollutants are classified as xenobiotic substances, which are not naturally occurring in the environment and are synthesized by human activities. The term "xenobiotic" originates from Greek roots, with "xenos" meaning "foreigner" and "bios" referring to "life." Many xenobiotics have been identified as carcinogens, posing significant health risks. Some of the different types of soil pollutants include:

2.1 Heavy Metals

Heavy metals are a group of metallic elements with high atomic weights, including lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), nickel (Ni), antimony (Sb), zinc (Zn), nickel (Ni), selenium (Se), beryllium (Be), thallium (Tl), chromium (Cr), and copper (Cu). These metals can enter the soil through industrial activities, mining, improper waste disposal, and the use of certain agricultural products. Heavy metal pollution in the soil can persist for a long time and can be difficult to remediate. These metals are toxic and can accumulate in the soil, adversely affecting plant growth and causing harm to organisms in the soil and the food chain even at low concentrations.

2.2 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds characterized by their composition of carbon and hydrogen atoms and the presence of multiple aromatic rings in their chemical structures. Exposure to PAHs has been associated with various forms of cancer in humans. Additionally, these organic compounds have the potential to induce cardiovascular diseases (Pope *et al.,* 2000; Zhang *et al.,* 2006). Soil pollution resulting from PAHs can be attributed to several sources, including emissions from vehicles, the processing of coke (derived from coal), the extraction of shale oil, and cigarette smoke. (Xiao *et al.,* 2014; Li *et al.,* 2020a).

2.3 Pesticides

Pesticides are substances or mixtures of substances that are employed to eliminate or suppress the growth of pests. However, these chemicals pose significant health risks to human beings. Exposure to pesticides can lead to various adverse health effects, including diseases of the central nervous system, disorders of the immune system, cancer, and birth defects. Pesticides can cause soil pollution through various mechanisms *viz.,* runoff, leaching and accumulation contributing to environmental degradation and potential risks to human health (Figure 2). It is crucial to handle and use pesticides safely to minimize the risks associated with their usage and protect both human health and the environment. In agricultural practices, various types of pesticides are commonly used:

a) **Herbicides:** Herbicides, including triazines, carbamates, amides, hydroxyalkyl acids, and aliphatic acids, are utilized to control and eradicate unwanted plants and weeds (Qisse *et al.*, 2020).

b) **Insecticides:** Insecticides, such as organophosphates, chlorinated hydrocarbons, arsenic-containing compounds, and pyrethrum, are employed to exterminate insects (Pérez-Mayán *et al.*, 2020).

c) **Fungicides:** Fungicides, including mercury-containing compounds, thiocarbamates, and copper sulfate, are used to eliminate parasitic fungi or impede their growth (Sudoma *et al.*, 2021).

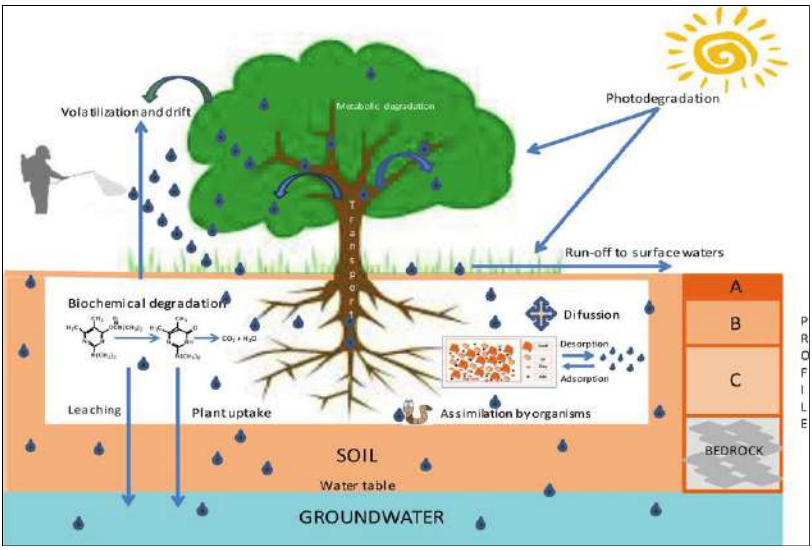


Fig 2: Behaviour and fate of pesticides in the soil

2.4 Radioactive substances and nanoparticles

Radioactive pollutants, such as uranium, radium, and caesium, can enter the soil through nuclear accidents, mining, or improper disposal of radioactive waste. Whereas, nanoparticles, including those derived from engineered nanoparticles and nanoparticles, present in pollution particles (*e.g.*, carbon nanotubes), can enter the soil through various sources such as industrial processes and wastewater treatment. These substances can have long-term effects on soil quality and pose significant risks to human health and the environment due to their potential for radiation exposure.

2.5 Microplastics

Microplastics are tiny particles of plastic less than 5 mm in size (He *et* *al.*, 2018). They can enter the soil through the application of plastic mulch in agriculture, the decomposition of plastic waste, and the weathering of larger plastic items. Microplastics can have negative impacts on soil biota and nutrient cycling. Besides microplastics, larger plastic items like discarded bags, bottles, and packaging materials can also contaminate soil when improperly disposed of or littered. A schematic diagram (**Figure 3**) illustrating the impact of microplastics on various aspects of soil, including soil parameters, soil organisms, plants, microorganisms, and the adsorption of ions.

When these microplastics enter the soil, they can interact with different components and processes, leading to potential consequences. In terms of soil parameters, microplastics can affect the physical properties of the soil, such as its structure, porosity, and water-holding capacity. The presence of microplastics can alter the soil's texture and reduce its ability to retain water, which can impact plant growth and nutrient availability. Soil organisms, including earthworms, insects, and microorganisms, can also be influenced by microplastic pollution. These organisms may mistakenly consume microplastics, leading to physical damage or obstruction in their digestive systems. Additionally, the presence of microplastics can disrupt the soil's microbial communities, affecting important processes such as nutrient cycling and decomposition. Plants, being an integral part of the soil ecosystem, can be affected by microplastics as well. The interaction between microplastics and plant roots can lead to changes in root development, nutrient uptake, and overall plant growth. Furthermore, the accumulation of microplastics in the soil can hinder seed germination and affect the establishment and productivity of plants. Microplastics can also impact the adsorption of ions in the soil. These tiny particles can adsorb or bind to ions present in the soil, altering their mobility and availability to plants. This can disrupt nutrient cycling and potentially lead to imbalances in the soil's nutrient content.

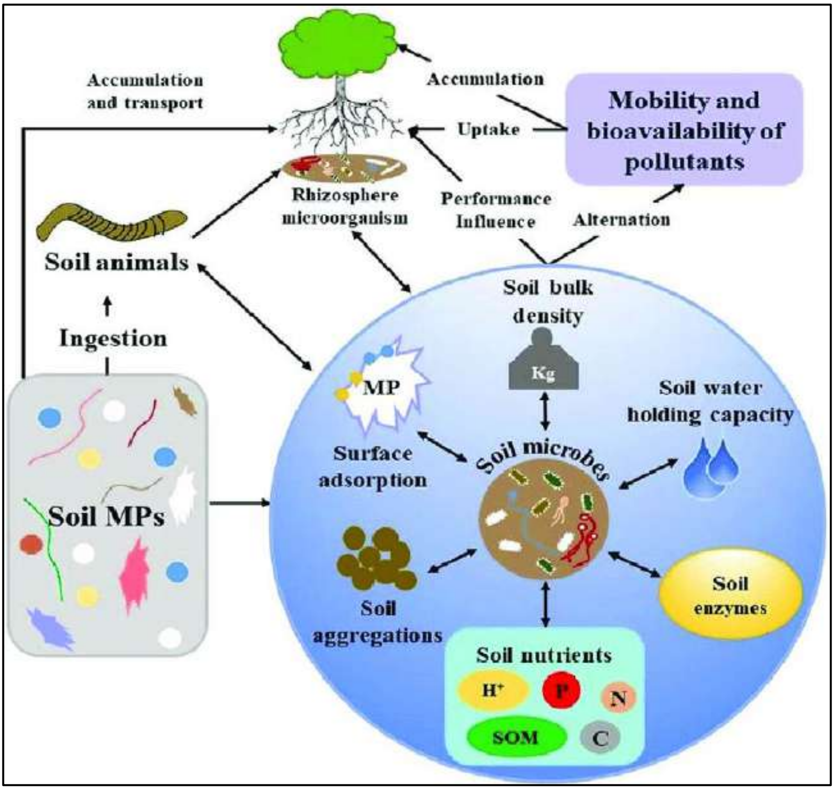


Fig 3: Impact of microplastics on various aspects of soil

2.6 Pharmaceuticals and personal care products (PPCPs)

PPCPs, including medications, hormones, and personal care products, can enter the soil through wastewater treatment plants, sewage sludge application, and agricultural runoff. These substances can accumulate in soil and potentially affect soil organisms and ecosystems.

2.7 Volatile organic compounds (VOCs) and explosives

VOCs are organic chemicals that have a high vapor pressure and can easily evaporate into the air. Examples include benzene, toluene, xylene, and formaldehyde. These compounds can enter the soil through industrial emissions, gasoline spills, and improper disposal of chemicals. On the other hand, explosives like TNT (trinitrotoluene) and RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) can contaminate soil in areas where explosives manufacturing, testing, or military activities have taken place.

2.8 Industrial waste

Soil pollution can occur when industrial waste is discharged into the soil. The industrial waste can contain various pollutants, including:

a) **Chlorinated industrial solvents:** These solvents, commonly used in industrial processes, can contaminate the soil and pose a risk to human health and the environment.

b) **Dioxins:** Dioxins are produced during the manufacture of pesticides and through waste incineration. They can contribute to soil pollution and have harmful effects on living organisms.

c) **Plasticizers/dispersants:** These substances, commonly used in industries such as plastics and textiles, can leach into the soil and have negative impacts on soil quality and ecosystem health.

d) **Polychlorinated biphenyls (PCBs):** PCBs are widely used in electrical equipment and other industrial applications. They are persistent pollutants that can accumulate in the soil and have adverse effects on organisms.

e) **Asbestos:** Asbestos is a naturally occurring mineral fibre that are commonly used in building materials for its heat resistance and durability. Soil can become contaminated with asbestos fibres from the demolition or deterioration of asbestos containing structures.

f) **The petroleum industry** is also a significant contributor to soil pollution. Petroleum hydrocarbon waste products, such as benzene and methylbenzene, are known to be carcinogenic and can contaminate the soil (Zhang *et al.,* 2020).

2.9 Nutrients

Nutrients, while essential for plant growth, excessive amounts of certain nutrients in the soil can lead to nutrient pollution. For instance, nitrogen and phosphorus from agricultural fertilizers, livestock waste, and sewage can leach into the soil and contaminate groundwater and surface water bodies. This leads to eutrophication, where excessive nutrient levels cause algal blooms and oxygen depletion in water bodies, disrupting aquatic ecosystems. This occurs primarily due to the overuse of fertilizers in agriculture, runoff from livestock operations, and sewage disposal.

2.10 Chlorinated Solvents and Acidic Substances

Chlorinated solvents such as trichloroethylene (TCE) and perchloroethylene (PCE) are commonly used in industrial processes, dry cleaning, and degreasing. Improper handling and disposal of these solvents can lead to soil contamination. Acidic substances such as sulfuric acid and hydrochloric acid can contaminate soil through industrial processes, acid rain, and improper disposal of acidic waste. Acidic soil can affect plant growth and soil microbial activity.

3. Mechanisms of soil pollution: Causes and factors

Soil pollution is a complex issue influenced by various mechanisms, causes, and factors. Understanding these mechanisms is crucial for identifying the root causes of soil pollution and implementing effective prevention and mitigation strategies. This section explores the different mechanisms involved in soil pollution, highlighting the causes and factors contributing to this environmental problem. Soil pollution can be categorized into five distinct groups, which include:

i) Naturally induced soil pollution and

ii) Anthropogenic soil pollution resulting from human interventions. Furthermore,

iii) Environmental factors,

iv) Contaminant transport, and

v) Soil characteristics also contribute to the occurrence of soil pollution.

These classifications help in understanding the different sources and factors that contribute to soil pollution, enabling effective strategies to address and mitigate its adverse effects.

3.1 Intrinsic soil pollution or naturally induced soil pollution

While anthropogenic activities are major contributors to soil pollution, natural processes can also play a role. Volcanic eruptions, weathering of rocks and minerals, and the decomposition of organic matter can release naturally occurring pollutants into the soil. However, it is important to note that the concentration of these natural pollutants is generally low and does not pose significant harm unless exacerbated by human activities. In rare instances, certain pollutants may naturally accumulate in soils through exceptional processes (Shaltami, 2014). Additionally, natural soil pollution can occur when soil pollutants are transported through precipitation water. A notable example of natural soil pollution involves the accumulation of compounds containing the perchlorate anion (ClO_4^-) in dry, arid ecosystems. It is important to acknowledge that some contaminants can be naturally synthesized within the soil under specific environmental conditions. For instance, the interaction between chlorine, certain metals, and lightning strikes during thunderstorms can result in the production of perchlorates, which can accumulate in the soil. (Tao *et al.,* 2020). Furthermore, natural soil pollution can result from the deposition of atmospheric pollutants. Airborne particles, such as dust and pollen, can settle on the soil surface, introducing organic and inorganic materials. Volcanic ash, wind-blown sediments, and atmospheric emissions from natural sources like wildfires can contribute to the deposition of pollutants onto the soil.

3.2 Human induced soil pollution or anthropogenically driven soil contamination

Human activities play a significant role in soil pollution. Various anthropogenic activities contribute to the release of pollutants into the soil. These activities include industrial processes, agricultural practices, improper waste disposal, mining operations, and the use of chemical substances such as fertilizers, pesticides, and herbicides. The accumulation of pollutants from these activities can have detrimental effects on soil quality and ecosystem health. The majority of instances of soil pollution are of anthropogenic origin, meaning they are caused by human activities. A wide range of human actions and practices can contribute to the contamination of soil. Presented below are several factors that can lead to soil pollution.

3.2.1 Oil spills

Oil spills, whether they occur in marine or terrestrial environments, have significant implications for soil pollution. When an oil spill occurs on land, the spilled oil can infiltrate and contaminate the soil, leading to adverse effects on soil health and ecosystem functioning (Apiratikul *et al.,* 2020). The presence of oil in the soil can have various detrimental effects. Firstly, it can alter the physical properties of the soil, such as its texture, structure, and porosity. The oil can create a layer or film on the soil surface, reducing water infiltration and air exchange, which are vital for supporting plant growth and the activity of soil organisms. Furthermore, oil contains a complex mixture of hydrocarbons and toxic substances, including polycyclic aromatic hydrocarbons (PAHs), heavy metals, and volatile organic compounds. These compounds can persist in the soil for extended periods and pose risks to both human health and the environment. PAHs, for example, are known to be carcinogenic and can accumulate in plants and organisms, entering the food chain and potentially causing long-term harm to ecosystems. The presence of oil in the soil can also disrupt the balance of soil microorganisms.

Some microorganisms may be capable of degrading certain components of the oil, while others may be sensitive to its toxic effects. This imbalance in the microbial community can affect important soil processes such as nutrient cycling, organic matter decomposition, and plant-microbe interactions. The long-term impacts of oil spills on soil can be far-reaching, depending on factors such as the type and volume of the spilled oil, soil properties, climate, and the effectiveness of remediation efforts. Overall, oil spills on land have the potential to cause significant soil pollution, disrupting soil chemistry, compromising plant and animal life, and posing risks to human health. Proper prevention measures, prompt response to spills, and comprehensive soil remediation efforts are essential in mitigating the adverse impacts of oil spills on soil ecosystems.

3.2.2 Acid rain

Acid rain, a form of environmental pollution, occurs when pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are released into the atmosphere from industrial processes, vehicle emissions, and the burning of fossil fuels (Figure 4). These pollutants react with water, oxygen, and other substances in the air, forming sulfuric acid and nitric acid. When acid rain falls on the ground, it can have significant implications for soil quality and ecosystem health. Acid rain, characterized by elevated levels of hydrogen ions that contribute to its acidic nature, can have detrimental effects on soil chemistry when it infiltrates the ground. Consequently, this acidic rain can have a negative impact on plants and essential soil microorganisms, ultimately disrupting the food chain (Chen *et al.,* 2012). The acidic nature of rainwater alters the pH of the soil, leading to soil acidification. This change in pH can affect various soil properties, including nutrient availability, microbial activity, and the solubility of metals and minerals. Acidic soils may become depleted of essential nutrients like calcium, magnesium, and potassium, hindering plant growth and development.

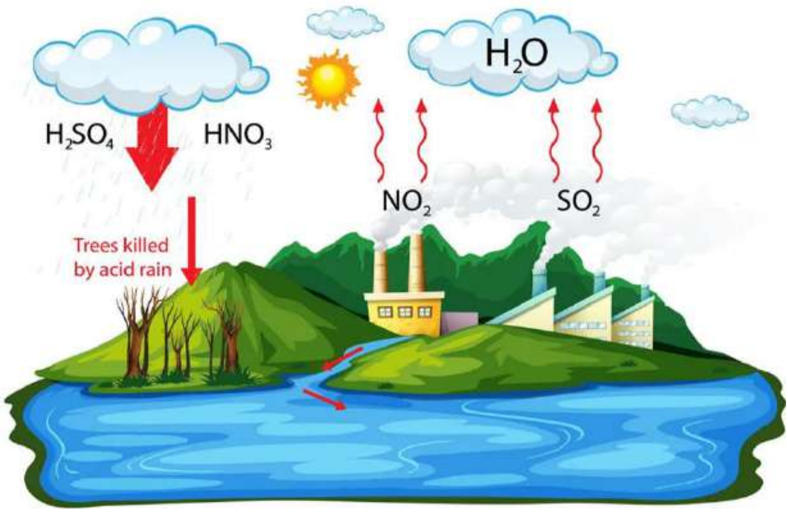


Fig 4: Acid rain pathway

The adverse effects of acid rain on soil extend beyond nutrient imbalances. Acidic conditions can disrupt the symbiotic relationship between plants and beneficial soil microorganisms, such as mycorrhizal fungi. These fungi play a crucial role in nutrient uptake by plants, particularly phosphorus, and their decline can limit plant productivity. Furthermore, acid rain can mobilize toxic metals such as aluminium, lead, and mercury present in the soil. These metals are released from their bound forms and become more soluble, posing a risk of contamination to plants, groundwater, and aquatic ecosystems. Additionally, acid rain can increase the leaching of nutrients from the soil, leading to nutrient loss and reduced fertility. The impact of acid rain on soil pollution can have cascading effects throughout the ecosystem. As soil health declines, it affects the growth and productivity of plants, which can disrupt food chains and biodiversity. Soil organisms that are sensitive to acidic conditions may also suffer, further compromising the overall ecological balance. Efforts to mitigate the effects of acid rain on soil pollution involve reducing the emissions of sulfur dioxide and nitrogen oxides through stricter regulations and cleaner technologies. Additionally, liming, a process that involves adding substances like limestone to the soil, can help neutralize the acidity and restore soil pH.

3.2.3 Discharge of sewage

When wastewater is discharged into the environment without proper treatment, it can contribute to soil pollution by allowing contaminants to leach into the soil. This can have detrimental effects on soil quality, ecosystem health, and human well-being. If these pollutants penetrate water sources, they can lead to the emergence of waterborne illnesses (Chung *et al.,* 2011). The discharge of untreated wastewater introduces a range of pollutants into the soil. These pollutants include organic matter, nutrients (such as nitrogen and phosphorus), heavy metals, pathogens, and various chemical compounds. These substances can have adverse effects on soil fertility, plant growth, and the overall balance of the soil ecosystem. Organic matter present in untreated wastewater can lead to increased microbial activity in the soil, which may result in oxygen depletion and nutrient imbalances. Nutrients such as nitrogen and phosphorus, when present in excessive amounts from wastewater, can promote the growth of algae and other aquatic plants in nearby water bodies. This can lead to eutrophication, where excessive plant growth depletes oxygen levels in the water, negatively impacting aquatic organisms.

Furthermore, the presence of heavy metals in wastewater can pose significant risks to soil and environmental health. Heavy metals are toxic to plants, animals, and humans, and their accumulation in soil can persist over long periods. The uptake of heavy metals by plants can lead to their transfer to the food chain, potentially causing harmful effects on human health. Pathogens present in untreated wastewater, such as bacteria, viruses, and parasites, can also contaminate the soil. This poses a risk of water-borne diseases, especially if the contaminated soil comes into contact with water sources used for drinking, irrigation, or recreational purposes. To mitigate the impacts of wastewater discharge on soil pollution, proper wastewater treatment systems should be in place. These systems help remove or reduce the levels of contaminants before the wastewater is released into the environment. Additionally, implementing measures to properly manage and treat sewage can prevent the contamination of soil and water resources, safeguarding both environmental and human health.

3.2.4 Waste disposal

Improper waste disposal practices can have significant implications for soil pollution. When waste is not appropriately managed or disposed of, it can introduce a variety of harmful substances into the soil. Chemicals, toxins, and pollutants present in waste materials can leach into the soil, resulting in soil contamination (Zhou *et al.,* 2021). One of the primary sources of soil pollution from waste disposal is the leaching of chemicals. When waste is dumped or buried in landfills without proper containment measures, rainwater or other forms of moisture can percolate through the waste, picking up harmful substances along the way. These contaminated liquids, known as leachate, can then infiltrate the underlying soil, carrying pollutants with them.

Moreover, certain waste materials, such as industrial effluents or hazardous chemicals, may be directly discharged onto the soil surface or nearby water bodies. This can lead to immediate contamination of the soil, as these substances seep into the soil matrix, affecting its composition and quality. Improper waste disposal also includes the indiscriminate dumping of solid waste, such as plastics, metals, and organic matter, on open land or in unauthorized areas. Over time, the decomposition of organic waste can release harmful gases and pollutants into the soil, altering its chemical balance and fertility. Furthermore, the disposal of electronic waste (e-waste) poses a significant risk of soil pollution. E-waste often contains toxic substances like heavy metals, flame retardants, and chemicals. When e-waste is improperly disposed of, through methods like burning or burying, these hazardous components can find their way into the soil, causing long-term contamination.

3.2.5 Accidental spills and industrial accidents

Accidental spills or leaks of agrochemicals stored in large quantities also pose a substantial threat. These spills can result in the contamination of surrounding soil, leading to adverse effects on soil quality and the organisms residing in it. Moreover, the accumulation of these chemicals in the soil can disrupt the delicate balance of the ecosystem and pose a risk to human health through the food chain. Industrial incidents, such as the Chernobyl Nuclear Disaster, have the potential to introduce hazardous substances and toxins into the soil, thereby causing contamination. These incidents can lead to severe consequences for both the ecosystem and human health. One of the significant concerns arising from such incidents is the release of radiation, which can persist in the environment and pose long-term risks.

In some extreme cases, industrial accidents can even result in catastrophic explosions, as exemplified by the 2020 Beirut Industrial Disaster (BYJU'S, 2020). Such incidents can cause widespread damage, including the release of various toxic substances into the environment. When these substances come into contact with the soil, they can cause significant contamination and further exacerbate the adverse effects on the ecosystem and human well-being. It is crucial to prioritize industrial safety measures, proper handling of hazardous materials, and effective emergency response protocols to minimize the occurrence and impact of industrial accidents on soil pollution. Implementing stringent regulations, conducting regular inspections, and promoting awareness about the potential risks associated with industrial activities are essential steps in safeguarding the environment and preventing soil pollution resulting from such incidents.

3.2.6 Electronic waste

Electronic waste, commonly known as e-waste, contains various components that can potentially pose a threat to human health due to their toxic nature. Improper disposal of e-waste can result in the leaching of these harmful substances into the soil, consequently impacting the surrounding life forms and ecosystems (Salam and Varma, 2019). E-waste consists of electronic devices such as computers, mobile phones, televisions, and other electrical appliances. These devices often contain hazardous materials like lead, mercury, cadmium, brominated flame retardants, and other toxic substances. When e-waste is improperly managed or disposed of in landfills or open dumping sites, these toxic components can gradually release into the soil through processes such as leaching and runoff. Once these toxins enter the soil, they can have detrimental effects on the environment and living organisms. The contaminated soil can negatively impact plant growth, impair soil fertility, and disrupt the balance of the ecosystem.

Additionally, if the contaminated soil is used for agriculture or if the toxins leach into groundwater, there is a risk of these harmful substances entering the food chain, posing a threat to human health. To mitigate the adverse impacts of e-waste on soil pollution, proper management and disposal practices are essential. Implementing effective e-waste recycling programs, promoting awareness about the hazards of improper e-waste disposal, and enforcing regulations for the safe handling and recycling of electronic devices are crucial steps towards minimizing the leaching of toxins into the soil and safeguarding both the environment and human well-being.

3.2.7 Chemical agents of war

Chemical substances that are intentionally created to cause harm or induce fatality can pose a significant risk if they seep into the soil and retain their potency (Li *et al.,* 2020b). Certain chemicals are specifically designed and synthesized with the purpose of inflicting harm or lethal effects on living organisms. These toxic substances can range from chemical weapons to highly potent pesticides or other harmful compounds. In scenarios where these chemicals come into contact with the soil, either through intentional or accidental means, they have the potential to infiltrate and persist within the soil matrix. The persistence of these harmful chemicals in the soil can pose serious consequences for both the environment and human health. The contaminated soil may adversely impact the growth and development of plants, disrupt the delicate balance of soil microorganisms, and potentially contaminate nearby water sources through leaching or runoff.

Furthermore, the presence of potent chemicals in the soil can lead to long-term environmental contamination, as they may persist for extended periods without undergoing significant degradation or breakdown. This can result in a sustained risk to ecosystems and human populations in the surrounding areas. To address this issue, it is crucial to implement rigorous safety measures and regulations regarding the handling, transportation, and disposal of such hazardous chemicals. Strict monitoring and control of their production, storage, and use can help minimize the potential for leakage into the soil and mitigate the associated risks to the environment and human well-being.

3.2.8 Landfills and illegal dumping

Soil contamination can occur when leachate, which is produced when water filters through waste and accumulates dissolved substances, infiltrates the soil (Krcmar *et al.*, 2018). When water percolates through waste materials, such as garbage or landfills, it collects various dissolved components, forming a liquid known as leachate. This leachate can contain a wide range of contaminants, including organic and inorganic substances, heavy metals, and other pollutants. If the leachate is not properly managed and allowed to filter through the soil, it can lead to soil contamination. As the leachate permeates the soil layers, it can introduce dissolved contaminants into the soil matrix. These contaminants can have detrimental effects on the soil's chemical composition, physical properties, and biological processes.

The consequences of soil contamination from leachate can be significant. It can adversely impact soil fertility, disrupt microbial activity, and impair the growth and development of plants. Moreover, if the contaminated soil is used for agricultural purposes or comes into contact with groundwater, it can pose risks to human health and the environment. To prevent and mitigate soil contamination from leachate, proper waste management practices are essential. Implementing effective landfill designs, such as liners and collection systems, can help contain and treat leachate before it reaches the soil. Additionally, employing strategies like leachate treatment and proper disposal of waste materials can minimize the potential for soil contamination and protect both soil quality and ecosystem health.

3.2.9 Coal ash

Coal ash also known as fly ash, refers to the fine particles that are produced during the combustion of coal in boilers. When coal is burned, the combustion process releases flue gases that carry along with them these tiny particles. These fly ash particles can vary in size, ranging from a few micrometres to submicron levels. It is important to note that fly ash contains trace amounts of toxic elements such as arsenic, cadmium, and mercury (Komonweeraket *et al.,* 2015). These elements are naturally present in coal and can become concentrated in fly ash during combustion. Arsenic, cadmium, and mercury are known to be hazardous to human health and the environment due to their toxicity. The release of fly ash from coal-fired boilers can have significant implications for air quality, as well as soil and water contamination. When fly ash particles settle onto the ground, they can contaminate the soil and introduce these toxic elements into the environment. This can pose risks to ecosystems, including plants, animals, and microorganisms, as well as human populations in proximity to coal-fired power plants.

To mitigate the environmental impact of fly ash, various strategies can be employed. These include implementing advanced filtration systems in coal-fired power plants to reduce the emission of fly ash particles, as well as proper containment and disposal of the generated fly ash to prevent its dispersion and potential contamination of soil and water resources. Furthermore, ongoing research and technological advancements aim to develop methods for the safe utilization and management of fly ash, such as its incorporation into construction materials or its treatment to minimize the release of toxic elements. These efforts contribute to reducing the environmental impact of fly ash and protecting ecosystems and human health from the associated risks.

3.2.10 Mining

Mining operations have the potential to significantly impact soil through various mechanisms such as soil erosion, the creation of sinkholes, and the leaching of chemicals used during the mining process into the soil (Gyamfi *et al.,* 2019). The process of mining involves the extraction of valuable minerals or resources from the earth's crust. While it is crucial for meeting the demands of various industries, mining activities can have detrimental effects on soil quality and composition. One of the primary ways in which mining affects soil is through soil erosion. The removal of vegetation and topsoil during mining operations can leave the land vulnerable to erosion by wind and water. This erosion can result in the loss of fertile soil and essential nutrients, degrading the overall soil quality and impairing its ability to support plant growth. Another consequence of mining is the formation of sinkholes. Underground mining, particularly in areas with soluble rock formations, can lead to the collapse of the ground surface, forming sinkholes. These sinkholes can disrupt the integrity and stability of the soil, posing risks to infrastructure and the surrounding ecosystem. In addition, the chemicals and substances used in the mining process can leach into the soil, further contributing to soil pollution. These chemicals, including heavy metals and toxic compounds, can contaminate the soil, posing risks to both environmental and human health. The leaching of these substances into the soil can persist long after mining activities have ceased, causing long-term ecological damage.

To mitigate the adverse impacts of mining on soil, various measures can be implemented. These include implementing erosion control measures, such as revegetation and the use of erosion control barriers, to prevent soil erosion. Adequate waste management and treatment of mining-related chemicals can also minimize the leaching of pollutants into the soil. Additionally, reclamation and rehabilitation efforts aim to restore mined areas, including the rehabilitation of soil quality and ecosystem functions. Through careful planning, responsible mining practices, and adherence to environmental regulations, the negative impacts of mining on soil can be minimized, ensuring the preservation and sustainable use of soil resources for future generations.

3.2.11 Corrosion of underground storage tanks

Storage tanks play a crucial role in safely containing various chemicals and substances. However, over time, these tanks can deteriorate, leading to corrosion and potential leaks. When the tanks corrode, the stored chemicals have the potential to escape into the surrounding soil, causing contamination and altering the soil's chemical composition. If storage tanks that hold toxic chemicals or substances capable of altering soil chemistry begin to corrode, there is a potential risk of soil pollution (Hudak *et al.,* 1999). Toxic chemicals stored in such tanks can pose significant risks to both the environment and human health if they come into contact with the soil. These chemicals may seep into the soil and persist, negatively impacting soil quality and potentially entering groundwater systems. The presence of these contaminants in the soil can have detrimental effects on plant and microbial life, disrupt ecosystem balance, and pose risks to organism’s dependent on the soil for their survival.

To prevent or minimize soil pollution from storage tank corrosion, it is essential to implement proper maintenance and monitoring practices. Regular inspection of storage tanks for signs of corrosion and damage is crucial to identify potential leaks or vulnerabilities. Additionally, implementing appropriate protective measures, such as corrosion-resistant coatings or secondary containment systems, can help prevent leaks and mitigate the risk of soil pollution. Proper management of storage tanks, including regular maintenance, timely repairs, and adherence to safety regulations, is essential to ensure the containment and integrity of hazardous substances. By taking proactive measures, the potential for soil pollution caused by corroded storage tanks can be significantly reduced, safeguarding both the environment and human well-being.

3.2.12 Nuclear wastes

Improper disposal of nuclear waste poses significant dangers to human beings. If nuclear waste is not handled and disposed of in a safe and appropriate manner, it has the potential to render an area uninhabitable (An *et al.,* 2020). Nuclear waste is a byproduct of various nuclear activities, including power generation, research, and medical applications. It contains highly radioactive materials that emit harmful radiation and can persist in the environment for long periods. If nuclear waste is not effectively managed and stored, it can have severe consequences for human health and the surrounding ecosystem. When nuclear waste is not properly disposed of, there is a risk of contamination and radiation exposure. Radioactive elements present in the waste can leach into the soil, water bodies, and air, spreading radiation and posing significant health risks to living organisms. Exposure to radiation can lead to various health problems, including radiation sickness, cancer, genetic mutations, and other long-term health effects. Moreover, the potential for rendering an area uninhabitable arises from the long-lasting nature of nuclear waste. Some radioactive isotopes found in nuclear waste have extremely long half-lives, meaning they remain hazardous for thousands or even millions of years. If these materials contaminate the soil and surrounding environment, they can persistently emit radiation, making it unsafe for human habitation or agricultural activities.

To mitigate the risks associated with nuclear waste, proper disposal and containment methods are crucial. This includes the construction of secure storage facilities designed to isolate and prevent the release of radioactive materials into the environment. Additionally, adherence to strict regulations, ongoing monitoring, and periodic assessment of storage sites are essential to ensure the safety and security of nuclear waste. The management of nuclear waste requires a comprehensive and rigorous approach, involving scientific expertise, advanced technologies, and stringent safety protocols. By implementing robust waste management practices, including safe storage, transportation, and disposal, the potential for rendering areas uninhabitable due to nuclear waste can be minimized, protecting both human well-being and the environment.

3.3 Environmental factors

Various environmental factors play a significant role in determining the magnitude and impact of soil pollution. Climate conditions, precipitation patterns, temperature variations, and the extent of vegetation coverage all exert influence on the transportation and fate of pollutants within the soil matrix. The presence and activity of microorganisms and soil organisms also have a crucial role in either facilitating the degradation and breakdown of pollutants or contributing to their persistence. Climate conditions, such as temperature and humidity, can affect the physical and chemical processes occurring in the soil. For instance, high temperatures can accelerate the volatilization of certain volatile organic compounds (VOCs), while moisture levels can influence the leaching and transport of pollutants through the soil profile. Additionally, precipitation patterns and water availability can determine the extent of pollutant dilution or concentration in the soil. The presence of vegetation cover can significantly impact soil pollution dynamics. Vegetation acts as a physical barrier, reducing the direct contact between pollutants and the soil surface. Plant roots also play a crucial role in the uptake and accumulation of certain contaminants, potentially mitigating their presence in the soil. Moreover, plant-microbe interactions can enhance the microbial degradation of pollutants through processes such as rhizo-degradation. Microorganisms and soil organisms, including bacteria, fungi, earthworms, and other soil invertebrates, can influence the fate and persistence of pollutants in the soil ecosystem. Some microorganisms possess the metabolic capabilities to degrade or transform certain pollutants, contributing to their remediation. In contrast, the absence or low abundance of specific soil organisms may hinder the breakdown of pollutants, allowing their accumulation and persistence in the soil.

Furthermore, the physical properties of soil, such as texture, structure, and composition, can influence the mobility and retention of pollutants. Soil with high clay content, for example, can adsorb and retain contaminants more effectively than sandy soils. The presence of organic matter can also affect pollutant interactions and bioavailability in the soil environment. Understanding the environmental factors that influence soil pollution is crucial for developing effective strategies to mitigate its impact. By considering climate conditions, vegetation cover, soil characteristics, and the role of soil organisms, scientists and policymakers can design appropriate measures to minimize the transport, accumulation, and persistence of pollutants in the soil. This knowledge aids in promoting sustainable land management practices and safeguarding soil quality and ecosystem health.

3.4 Contaminant transport

Soil can be exposed to contaminants through multiple pathways, leading to soil pollution. One common route is atmospheric deposition, where pollutants emitted from industrial sources or vehicle exhaust settle onto the soil surface. This deposition can occur through the process of dry deposition, where airborne particles and gases directly deposit onto the soil, or through wet deposition, where pollutants are carried by precipitation and deposited onto the soil. Another pathway for contaminant transport is through runoff water. When rainwater or irrigation water flows over agricultural fields, industrial sites, or landfills, it can pick up pollutants and carry them into the soil. This contaminated runoff can introduce a wide range of pollutants, including pesticides, fertilizers, heavy metals, and organic compounds, into the soil environment. Soil erosion is yet another mechanism that contributes to the transport of pollutants in soil. When soil is eroded by wind or water, it can carry with it the contaminants present in the soil. Wind erosion occurs when strong winds lift and transport soil particles, potentially spreading pollutants to new areas. Water erosion, on the other hand, happens when rainfall or water flow dislodges and transports soil particles along with attached contaminants, leading to the redistribution of pollutants in the soil landscape.

These various pathways of contaminant transport pose significant challenges in controlling and mitigating soil pollution. Efforts to reduce atmospheric emissions, implement effective water management strategies, and employ erosion control measures are crucial in minimizing the entry of pollutants into the soil. Additionally, sustainable agricultural practices, proper waste management, and land use planning can help prevent or reduce the contamination of soil through these pathways. By addressing these sources of contamination, we can work towards preserving soil quality and protecting ecosystems and human health.

3.5 Soil characteristics

The inherent properties and characteristics of soil significantly impact its vulnerability to pollution. Factors such as soil texture, structure, permeability, and organic matter content influence how pollutants interact with and persist in the soil environment.

Soil texture refers to the relative proportions of sand, silt, and clay particles in the soil. Soils with higher clay content generally exhibit a greater capacity to retain pollutants due to their smaller particle size and larger surface area, which promotes adsorption and retention of contaminants. In contrast, sandy soils with larger particle size and lower surface area may be more prone to the leaching of contaminants, allowing pollutants to move more easily through the soil profile.

The soil structure, which refers to the arrangement and aggregation of soil particles, also affects pollutant behaviour. Well-structured soils with stable aggregates tend to have better pore spaces and drainage, allowing for the movement of water and air. This can facilitate the transport of contaminants deeper into the soil, potentially increasing their persistence and the risk of groundwater contamination.

Permeability, or the ability of soil to allow the flow of water, is another important factor. Soils with higher permeability, such as sandy soils, may have faster water movement, which can lead to greater leaching of pollutants through the soil profile. In contrast, soils with lower permeability, such as clay soils, may exhibit slower water movement, potentially increasing the chances of contaminants accumulating in the upper soil layers.

The organic matter content of soil also plays a significant role. Soils rich in organic matter tend to have greater cation exchange capacity, which can bind and retain pollutants. Additionally, organic matter enhances soil structure, water-holding capacity, and microbial activity, all of which can influence the fate and transport of contaminants in the soil.

4. Health implications of soil pollution

Health implications of soil pollution refer to the various adverse effects on human well-being that can arise from exposure to contaminated soil. These implications encompass a wide range of health concerns, including both acute and chronic effects. Exposure to pollutants present in the soil can have detrimental effects on human health. Some of the potential health implications of soil pollution include:

a) **Toxicological effects:** Contaminants present in the soil, such as heavy metals, pesticides, and industrial chemicals, can enter the human body through direct contact with the soil or ingestion of contaminated food and water. These pollutants can accumulate in the body over time, leading to toxicological effects. They can interfere with vital physiological processes, damage organs and tissues, and contribute to the development of various diseases.

b) **Respiratory disorders:** Soil pollution can release airborne particles and pollutants, especially in dry and windy conditions. Inhalation of these particles can cause respiratory problems such as asthma, bronchitis, and other pulmonary disorders. Dust and particulate matter containing harmful substances can irritate the respiratory system and compromise lung function.

c) **Water contamination and waterborne diseases:** Soil pollution can contaminate nearby water sources, including groundwater and surface water. When pollutants leach into water bodies, they can contribute to the spread of waterborne diseases. Pathogens, chemicals, and other contaminants present in the soil can contaminate drinking water supplies, leading to gastrointestinal illnesses, microbial infections, and other waterborne health issues.

d) **Skin disorders:** Direct contact with contaminated soil can result in skin disorders and irritations. Toxic substances in the soil, such as heavy metals and certain chemicals, can cause dermatological problems, including rashes, allergic reactions, and skin infections. Prolonged exposure to contaminated soil without proper protective measures can exacerbate these skin conditions.

e) **Carcinogenic effects:** Some pollutants present in soil, such as certain heavy metals, organic compounds, and persistent organic pollutants, are known or suspected carcinogens. Prolonged exposure to these carcinogens through contaminated soil can increase the risk of developing various types of cancer, including lung, liver, kidney, and skin cancer.

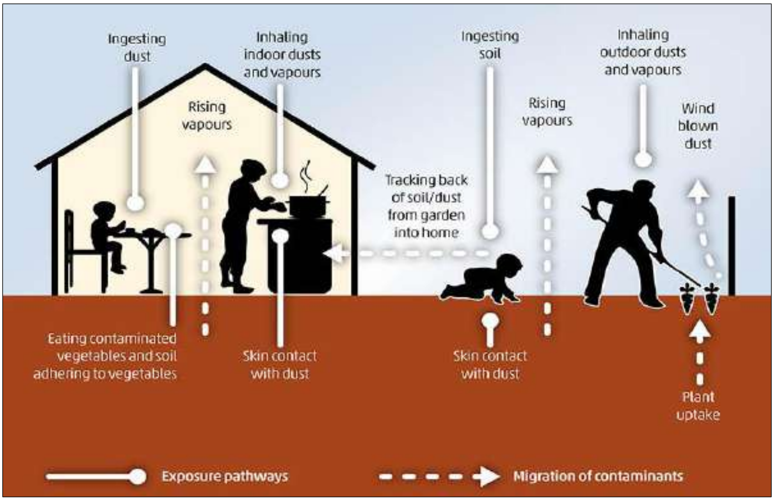


Fig 5: Routes of exposure pathways to soil pollution

Contamination or pollution of soil can directly impact human health through various pathways (Figure 5). Direct contact with contaminated soil or inhalation of soil-borne contaminants in vaporized form can pose risks. Furthermore, infiltration of soil pollution into groundwater aquifers used for human consumption, even in seemingly remote areas, can present significant threats. These exposures can lead to the development of pollution-related diseases. The health consequences resulting from exposure to soil contamination can vary depending on the type of pollutant, the route of exposure, and the vulnerability of the exposed population. Chronic exposure to certain substances found in contaminated soil, such as chromium, lead, petroleum, solvents, pesticides, and herbicides, can have carcinogenic properties, cause congenital disorders, or result in other chronic health conditions. Even naturally occurring substances, like nitrate and ammonia from agricultural operations, when present in industrial or concentrated forms, have been identified as health hazards in soil and groundwater. Benzene, when chronically exposed to at sufficient concentrations, is known to be associated with a higher incidence of leukaemia. Mercury and cyclodienes have been linked to increased kidney damage and certain irreversible diseases. PCBs and cyclodienes are associated with liver toxicity. Organophosphates and carbonates can trigger a series of responses leading to neuromuscular blockage. Chlorinated solvents can induce liver and kidney changes, as well as depression of the central nervous system. Additionally, a range of other health effects may occur, including headaches, nausea, and various neurological symptoms. Soils also host pathogen organisms, which may pose a serious risk to human health and the environment, exacerbated by imbalances in soil health (Oliver and Gregory, 2015). WHO estimates that around of 24 percent of the global population is affected by soil-transmitted helminths (parasitic worms), affecting primarily poorest communities without sanitary measures. In 2015, about 12 percent of the global population (892 million people) had no access to water, sanitation and hygiene (WASH) services and practiced open defecation in water courses and land, releasing human pathogens into the environment (WHO and UNICEF, 2017). The soils are the ideal environment for survival of human pathogens, from which these can be transferred to other hosts in contact with contaminated soil (Holcomb *et al.,* 2020; Julian, 2016; Pickering *et al.,* 2012). The specific health risks and symptoms depend on the particular pollutants involved, the route and duration of exposure, and individual susceptibility. Implementation of appropriate measures to manage and remediate contaminated soil is crucial to mitigate these health risks and protect human well-being.

5. Impairment of natural ecosystems due to soil pollution

Soil pollution has significant impacts on both above-ground and below-ground biodiversity through two main mechanisms. Firstly, the presence of contaminants can lead to a reduction in the number of organisms, as they may be negatively affected by the toxic effects of these pollutants. Additionally, changes can occur at the community level, where certain tolerant or resistant organisms may thrive compared to those that are more sensitive to the contaminants. Studies have indicated that exposure to certain trace elements can even induce resistance in soil microorganisms and contribute to antimicrobial resistance (Heydari, 2020). Furthermore, soil contaminants have the potential to enter the food chain, causing diseases and mortality in various organisms residing in the soil, as well as terrestrial and aquatic ecosystems. The loss of biodiversity and biomass due to soil pollution results in a decline in organic matter and alters nutrient inputs and cycling processes. As a consequence, the primary productivity of both natural and agricultural ecosystems is affected, leading to an overall decline in the provision of soil ecosystem services. Moreover, polluted soils can act as a source of contamination for groundwater, as contaminants can leach through the soil layers. Additionally, wind and water erosion can transport these pollutants off-site, affecting freshwater systems and ultimately reaching the marine environment. It is important to note that these changes can occur gradually over time or remain relatively inert until a tipping point is reached, resulting in severe degradation of the soil ecosystem (Baudrot *et* *al.,* 2018). The composition of soil encompasses solid, liquid, gaseous, and living components. As a result, the quality of soil is not solely determined by the presence and impact of pollution in each of these components, but rather by the complex interactions among them (Bünemann *et al.,* 2018).

Changes in soil properties that influence its capacity to buffer and filter contaminants can result in a decline in protective mechanisms. Consequently, the soil may transition from acting as a safeguard to becoming a potential source of contamination, potentially releasing pollutants into other environmental compartments such as water, air, and organisms (Biswas *et al.,* 2018). This pollution-induced degradation of soil can initiate a self-reinforcing cycle of deterioration (Figure 6). Ultimately, these processes can lead to the loss of valuable ecosystem services, as illustrated in Figure 7. Soil microorganisms, such as bacteria, archaea, and fungi, constitute the predominant biomass within soil and play a crucial role in delivering essential ecosystem services (FAO *et al.,* 2020). However, the presence of soil contaminants can have adverse effects on the biomass and specific enzymatic activities of these microorganisms, leading to alterations in soil communities (Zhang *et al.,* 2015).

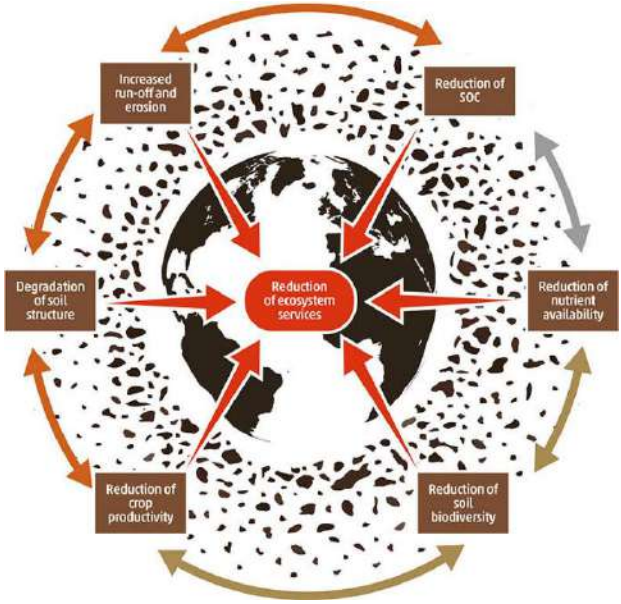


Fig 6.: Pollution causes a chain of degradation processes in soil, jeopardizing soil's ability of providing key ecosystem services

Source: adapted from FAO, 2015

Fig 7: Impacts of soil pollution on soil ecosystem services

6. Soil pollution control and amelioration measures

This chapter provides an overview of tools, technologies, and strategies for remediating contaminated soil and groundwater, as well as managing and adapting to soil pollution risks. Both soil and groundwater are considered due to potential contaminant migration within the groundwater, which can further disperse pollutants in the soil. Risk assessment serves as the basis for determining the need for remediation or risk mitigation measures. Remediation aims to eliminate or isolate the pollution source, while management and adaptation strategies focus on blocking exposure pathways or removing receptors from harm's way. Various approaches exist for risk assessment, considering factors such as receptor characteristics, contaminant type and quantity, and exposure duration (Aven, 2016). The methodology employed depends on site-specific conditions.

6.1 Short-term risk mitigation strategies for soil pollution

While comprehensive investigations and the formulation of a remediation strategy are underway, it is crucial to promptly implement emergency risk reduction measures to protect public health and the environment. These measures should be straightforward and swiftly executable. Nevertheless, a preliminary risk assessment should be conducted to mitigate the potential risks of additional exposure during their implementation. Some examples of such measures include:

- Implementing measures to prevent further release of contaminants into the soil.
- Applying an impermeable layer to cover the contaminated area, preventing the release of vapors and minimizing the runoff of rainwater and leaching.
- Conducting informative sessions for local communities to raise awareness about the risks associated with the site.
- Erecting visible warning signs to alert individuals about the potential hazards.
- Securing the site, such as installing a fence, to restrict access for the public and livestock.
- Imposing restrictions on land use, specifically prohibiting food production on the affected area.
- Advising the public against consuming crops or livestock products from the contaminated site and imposing restrictions accordingly.

- Providing an alternative and safe water supply to ensure access to clean water.

6.2 Bioremediation

Bioremediation is an in situ biological treatment method that harnesses the activity of soil microorganisms to remediate contaminated sites. Its primary focus is on the degradation of organic pollutants, such as petroleum hydrocarbons, solvents, and pesticides, as well as the transformation of trace element species to reduce their availability. Bioremediation can be carried out under aerobic or anaerobic conditions, with different treatment methods tailored to specific contaminants and operating conditions. In aerobic biological treatment, atmospheric oxygen is utilized, sometimes introduced into the soil to stimulate aerobic microorganisms. On the other hand, anaerobic biological treatment involves excluding oxygen and often involves the addition of reducing agents to stimulate microbial activity. While certain contaminants can be degraded by both approaches, aerobic biological treatment is typically employed for non-chlorinated or slightly chlorinated hydrocarbons, whereas anaerobic biological treatment is more suitable for highly chlorinated hydrocarbons.

6.3 Microbiological remediation

Microbiological remediation of soil contaminated with trace elements primarily involves the immobilization and reduction of these elements, thereby decreasing their bioavailability. While microorganisms cannot degrade trace elements, they can facilitate their conversion into alternative forms that possess less hazardous physical and chemical properties. For instance, aerobic and anaerobic microorganisms have the ability to transform hexavalent chromium into its trivalent state, which is less toxic and exhibits lower mobility (Sumikura and Shiiba, 2016; Thatoi *et al.*, 2014). Combining phytoremediation and microbial bioremediation techniques can synergistically enhance biodegradation processes (Lucas García *et al.*, 2013).

6.4 Bioventing and biosparging

Bioventing and biosparging are similar techniques employed to enhance the biodegradation of aerobically degradable compounds by injecting air directly into the soil. Bioventing is conducted in the unsaturated zone above the water table (vadose zone), while biosparging takes place in the saturated zone below the water table. The controlled injection of air at low rates is designed to stimulate and sustain the existing soil microorganisms responsible for biodegrading organic contaminants. The objective of maintaining a low air flow rate is to minimize the volatilization and release of organic compounds into the atmosphere, making it particularly suitable for treating soil contaminated with less volatile hydrocarbons. If volatile contaminants are present, additional measures such as vapor extraction and treatment using techniques like activated carbon filtration or catalytic oxidation may be necessary. Bioventing and biosparging are commonly applied to remediate soil polluted with less volatile petroleum hydrocarbons, as they result in minimal emissions of volatile vapours.

6.5 Phytoremediation

Phytoremediation is an in-situ technology that harnesses the natural abilities of plants to remediate polluted soils. It serves two primary purposes in soil remediation: stabilizing contaminants to reduce their mobility and availability, and removing contaminants either through degradation or transfer to other media (Salt *et al.*, 1995). Phytoremediation has been widely employed for the remediation of soils contaminated with trace elements, but it has also demonstrated effectiveness in facilitating the removal and biodegradation of organic contaminants (Huang *et al.*, 2005). Phytoremediation encompasses various techniques depending on the specific plant mechanisms involved and the type of contaminants being addressed, each of which is explained in brief below.

a) **Phytostabilization** is a technique that employs plant species capable of tolerating contaminants to stabilize and immobilize polluted soils, effectively preventing the dispersal of contaminants through erosion by wind and water. The plants' evapotranspiration process helps reduce soil moisture and leachate flow, thereby minimizing the migration of contaminants deeper into the soil and protecting groundwater from contamination.

b) **Phytoextraction** is a remediation process that involves the direct uptake of both inorganic and organic contaminants from soil into plants. The extent and rate of contaminant transfer from the plant roots to the aboveground parts depend on the specific contaminant and the plant species involved. While organic contaminants can serve as a carbon and energy source for soil microorganisms and may undergo biodegradation, trace elements are non-biodegradable and cannot be chemically eliminated. Instead, they have the potential to enter the tissues of living organisms, leading to their accumulation (bioaccumulation) and concentration (biomagnification) within the food chain (Wu *et al.*, 2010).

c) **Phytodegradation** is a process in which plants facilitate the degradation of organic contaminants in the soil. Through various mechanisms, plants can enhance the breakdown of organic pollutants, converting them into less harmful forms or mineralizing them into simpler compounds. This natural degradation process occurs primarily through the action of enzymes produced by plants and associated microorganisms. Phytodegradation can be an effective approach for remediating contaminated sites, as it harnesses the natural abilities of plants and their associated microbial communities to detoxify and degrade organic pollutants present in the soil.

d) **Rhizodegradation** refers to the decomposition of organic contaminants in soils facilitated by the activity of fungi and microorganisms present in the root zone (Singh and Ward, 2004). This process relies on the interaction between plants and these microorganisms, with the root exudates released by the plants playing a crucial role. These exudates can enhance the activity and diversity of microorganisms, enabling the biotransformation of organic contaminants through co-metabolism. A notable example of this process involves the cultivation of Phragmites australis in dredged sediments, where the plant acts as a biostimulation agent, accelerating the degradation of polycyclic aromatic hydrocarbons (PAHs). Through rhizodegradation, *Phragmites australis* promotes the oxidation of PAHs, facilitating their breakdown and removal from the environment (Di Gregorio *et al.*, 2014).

e) **Phytovolatilization** is a remediation process that involves the use of specialized plant enzymes to transform and volatilize both inorganic and organic contaminants within the plant-microorganism-soil system. In this process, the contaminants are transferred from the soil into the plants, where they undergo transformation and subsequent release into the atmosphere. This technique has been successfully employed for the remediation of soils contaminated with inorganic and organic mercury. In such cases, the plants have the ability to reduce Hg^{2+} to elemental mercury, which is less toxic, and then release it into the air (Heaton *et al.*, 1998). However, as the contaminants are transferred between different mediums, thorough risk assessments must be conducted to ensure the suitability and effectiveness of this approach.

Conclusion

Despite significant advancements in understanding the behaviour of soil contaminants, it remains challenging to provide precise quantitative assessments of the impacts of soil pollution on ecosystems and human health. This difficulty arises from the lack of standardized methodologies and a centralized mechanism for sharing and implementing scalable solutions. To overcome this deficiency, there is an urgent need for long-term monitoring programs that combine demographic studies, phenotypic and genetic analyses, and selection assays to evaluate the effects of soil pollution on plant and animal populations in contaminated habitats. Integrative studies are necessary due to the limitations of extrapolating laboratory data from a few model organisms to predict the responses of complex microbial, plant, and animal communities. Additionally, establishing causal relationships between soil pollution and human health outcomes poses significant challenges. Therefore, it is crucial to conduct comprehensive epidemiological studies and implement health surveillance systems, starting with highly polluted areas and extending to the general population. This can be achieved by collecting easily accessible biological samples such as urine, blood, and breast milk, allowing for rapid intervention and minimizing risks to the population. Harmonizing methodologies for epidemiological studies and considering exposure to multiple contaminants should be prioritized to protect human health in the context of soil pollution. Soil pollution, resulting from unsustainable human activities, poses a significant threat to human development and well-being. The international community must recognize the prevention and mitigation of soil pollution as a crucial prerequisite for achieving the Sustainable Development Goals (SDGs) outlined in the 2030 Agenda. Collecting, mapping, monitoring, and reporting data on soil pollution are essential for ensuring public access to information, promoting environmental justice, and minimizing the socioeconomic impacts of soil pollution on all stakeholders.

References

1. Abrahams, P.W. (2002) Soils: their implications to human health. *Science of The Total Environment* 291(1), 1–32. https://doi.org/10.1016/S0048-9697(01)01102-0

2. Amini, M., Afyuni, M., Fathianpour, N., Khademi, H. and Flühler, H. (2005) Continuous soil pollution mapping using fuzzy logic and spatial interpolation. *Geoderma* 124(3-4), 223-233.

3. An, N., Cui, Y.J., Conil, N., Talandier, J. and Conil, S. (2020) Soil–atmosphere interaction in the overburden of a short-lived low and intermediate level nuclear waste (LLW/ILW) disposal facility. *Computers and Geotechnics* 124, 103610. https://doi.org/10.1016/.2020.103610

4. Apiratikul, R., Pongpiachan, S. and Hashmi, M.Z. (2020) Health risk assessment of polycyclic aromatic hydrocarbons in coastal soils of Koh Samed Island (Thailand) after the oil spill incident in 2013. *Marine Pollution Bulletin* 150, 110736.

5. Aven, T. (2016) Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research*, 253(1), 1–13. https://doi.org/10.1016/j.ejor.2015

6. Baudrot, V., Fritsch, C., Perasso, A., Banerjee, M. and Raoul, F. (2018) Effects of contaminants and trophic cascade regulation on food chain stability: Application to cadmium soil pollution on small mammals – Raptor systems. *Ecological Modelling*, 382, 33–42. https://doi.org/10.1016/

7. Biswas, B., Qi, F., Biswas, K.J., Wijayawardena, A., Khan, A.M. and Naidu, R. (2018) The fate of chemical pollutants with soil properties and processes in the climate change paradigm- A review. *Soil Systems* 2(3). https://doi.org/10.3390/soilsystems2030051

8. Brevik, E.C. and Burgess, L.C. (2013) Soils and human health. Boca Raton, FL, CRC Press. http://www.crcnetbase.com/isbn/9781439844557

9. Brevik, E.C. and Sauer, T.J. (2015) The past, present, and future of soils and human health studies. *SOIL* 1(1), 35–46. https://doi.org/10.5194/soil-1-35-2015

10. Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J.W. and Brussaard, L. (2018) Soil quality – A critical review. *Soil Biology and Biochemistry* 120, 105-125. https://doi.org/10.1016/j.soilbio.2018.01.030

11. BYJU'S (2020) Causes of soil pollution. https://byjus.com/biology/causes-of-soil-pollution/

12. Cappuyns, V. (2013) Environmental impacts of soil remediation activities: Quantitative and qualitative tools applied on three case studies. *Journal of Cleaner Production* 52, 145-154.

13. Chen, C., Zhang, X., Chen, J., Chen, F., Li, J., Chen, Y., Hou, H. and Shi, F. (2020) Assessment of site contaminated soil remediation based on an input-output life cycle assessment. *Journal of Cleaner Production* 263, 121422.

14. Chen, S., Shen, X., Hu, Z., Chen, H., Shi, Y. and Liu, Y. (2012) Effects

of simulated acid rain on soil CO_2 emission in a secondary forest in subtropical China. *Geoderma* 189-190, 65-71.

15. Chung, B.Y., Song, C.H., Park, B.J. and Cho, J.Y. (2011) Heavy metals in brown rice (*Oryza sativa* L.) and soil after long-term irrigation of wastewater discharged from domestic sewage treatment plants. *Pedosphere* 21(5), 621-627. http://dx.doi.org/10.1016/S1002-0160(11)60164-1

16. Di Gregorio, S., Gentini, A., Siracusa, G., Becarelli, S., Azaizeh, H. and Lorenzi, R. (2014) Phytomediated biostimulation of the autochthonous bacterial community for the acceleration of the depletion of polycyclic aromatic hydrocarbons in contaminated sediments. *BioMed Research International* 2014: 1–11. https://doi.org/10.1155/2014/891630

17. FAO (2015) Soil functions. Paper presented at International Year of Soils, 2015, Rome, Italy. https://www.fao.org/resources/infographics/infographics-details/en/c/284478/

18. FAO, ITPS, GSBI, CBD and EC. (2020) State of knowledge of soil biodiversity - Status, challenges and potentialities. Rome, Italy, *Food and Agriculture Organization of the United Nations*. 616 pp. https://www.fao.org/documents/card/en/c/cb1928en

19. Gyamfi, E., Appiah-Adjei, E.K. and Adjei, K.A. (2019) Potential heavy metal pollution of soil and water resources from artisanal mining in Kokoteasua, Ghana. *Groundwater for Sustainable Development* 8, 450-456.

20. He, D., Luo, Y., Lu, S., Liu, M., Song, Y. and Lei, L. (2018) Microplastics in soils: Analytical methods, pollution characteristics and ecological risks. TrAC *Trends in Analytical Chemistry* 109, 163-172. https://doi.org/10.1016/j.trac.2018.10.006

21. Heaton, A.C.P., Rugh, C.L., Wang, N. and Meagher, R.B. (1998) Phytoremediation of mercury and methylmercury polluted soils using genetically engineered plants. *Journal of Soil Contamination* 7(4), 497–509. https://doi.org/10.1080/10588339891334384

22. Heydari, A. (2020) Resistance of environmental bacteria to heavy metals and antibiotics in selected New Zealand soils: A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Health Sciences at *Massey University, Wellington, New Zealand*. Massey University. (Thesis). https://mro.massey.ac.nz/handle/10179/15831

23. Holcomb, D.A., Knee, J., Sumner, T., Adriano, Z., de Bruijn, E., Nalá, R., Cumming, O., Brown, J. and Stewart, J.R. (2020) Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. *International Journal of Hygiene and Environmental Health* 226: 113496. https://doi.org/10.1016/j.ijheh.2020.113496

24. Huang, X.D., El-Alawi, Y., Gurska, J., Glick, B.R. and Greenberg, B.M. (2005) A multi-process phytoremediation system for decontamination of persistent total petroleum hydrocarbons (TPHs) from soils. *Microchemical Journal*, 81(1), 139–147. https://doi.org/10.1016/j.microc

25. Hudak, P.F., Wachal, D.J. and Hunter, B.A. (1999) Managing subsurface property hazards: Reactive soils and underground storage tanks. *Urban Water* 1(3), 237-241.

26. Ji, W., Yang, T., Ma, S. and Ni, W. (2012) Heavy metal pollution of soils in the site of a retired paint and ink factory. *Energy Procedia* 16(A), 21-26.

27. Julian, T.R. (2016) Environmental transmission of diarrheal pathogens in low and middle income countries. *Environmental Science*: *Processes and Impacts* 18(8), 944–955. https://doi.org/10.1039/C6EM00222F

28. Komonweeraket, K., Cetin, B., Benson, C.H., Aydilek, A.H. and Edil, T.B. (2015) Leaching characteristics of toxic constituents from coal fly ash mixed soils under the influence of pH. *Waste Management* 38, 174-184.

29. Krcmar, D., Tenodi, S., Grba, N., Kerkez, D., Watson, M., Roncevic, S. and Dalmacija, B. (2018) Preremedial assessment of the municipal landfill pollution impact on soil and shallow groundwater in Subotica, Serbia. *Science of The Total Environment* 615, 1341-1354.

30. Li, B., Kong, J., Yang, L., Zhang, L., Zhang, Z. and Li, C. (2020b) Direct detection of chemical warfare agent simulants in soil by thermal desorption-low temperature plasma-mass spectrometry. *International Journal of Mass Spectrometry* 451, 116320. https://doi.org/10.1016/j.ijms.2020.116320

31. Li, Y., Hu, J., Liu, H., Zhou, C. and Tian, S. (2020a) Electrochemically reversible foam enhanced flushing for PAHs-contaminated soil: Stability of surfactant foam, effects of soil factors, and surfactant reversible recovery. *Chemosphere* 260, 127645.

32. Liu, B. and Lui, R. (1997) Electrokinetic remediation of contaminated soil. In: *Nonlinear Analysis: Theory, Methods and Applications* 30(6), 3391-3398.

33. Lucas García, J.A., Grijalbo, L., Ramos, B., Fernández-Piñas, F., Rodea-Palomares, I. and Gutierrez-Mañero, F.J. (20130 Combined phytoremediation of metal-working fluids with maize plants inoculated with different microorganisms and toxicity assessment of the phytoremediated waste. *Chemosphere* 90(11), 2654–2661. https://doi.org/10.1016/j.chemosphere.2012.11.042

34. Nič, M., Jirát, J., Košata, B., Jenkins, A. and McNaught, A., eds. (2009) *International Union of Pure and Applied Chemistry (IUPAC) Compendium of Chemical Terminology*: Gold Book. 2.1.0 edition. Research Triagle Park, NC, IUPAC. http://goldbook.iupac.org/

35. Oliver, M.A. (2008) Soil and human health: A review. *European Journal of Soil Science* 48(4), 573–592. https://doi.org/10.1111/j.1365-2389.1997.tb00558.x

36. Oliver, M.A. and Gregory, P.J. (2015) Soil, food security and human health: A review: Soil, food security and human health. *European Journal of Soil Science* 66(2), 257–276. https://doi.org/10.1111/ejss.12216

37. Pérez-Mayán, L., Ramil, M., Cela, R. and Rodríguez, I. (2020) Multiresidue procedure to assess the occurrence and dissipation of fungicides and insecticides in vineyard soils from Northwest Spain. *Chemosphere* 261, 127696. https://doi.org/10.1016/j.chemosphere.2020.127696

38. Pickering, A.J., Julian, T.R., Marks, S.J., Mattioli, M.C., Boehm, A.B., Schwab, K.J. and Davis, J. (2012) Fecal Contamination and Diarrheal Pathogens on Surfaces and in Soils among Tanzanian Households with and without Improved Sanitation. *Environmental Science and Technology* 46(11), 5736–5743. https://doi.org/10.1021/es300022c

39. Pope, C.J., Peters, W.A. and Howard, J.B. (2000) Thermodynamic driving forces for PAH isomerization and growth during thermal treatment of polluted soils. *Journal of Hazardous Materials* 79(1-2), 189-208. https://doi.org/10.1016/s0304-3894(00)00267-3

40. Qisse, N., EL Alouani, M., EL Azzouzi, L., EL Fadil, I., Saufi, H., EL Belghiti, M.A., Zrineh, A. and EL Azzouzi, M. (2020) Adsorption of Imazalil herbicide onto Moroccan agricultural soils: Kinetic and

isotherm adsorption studies. *Groundwater for Sustainable Development* 11, 100468.

41. Rao, M.N., Sultana, R., Kot, S.H. (2017) Chapter 7 - *Soil remediation technologies*. Solid and Hazardous Waste Management. *Science and Engineering*. pp. 243-260.
42. Salam, M. and Varma, A. (2019) Bacterial community structure in soils contaminated with electronic waste pollutants from Delhi NCR, India. *Electronic Journal of Biotechnology* 41, 72-80.
43. Salt, D.E., Blaylock, M., Kumar, N.P., Dushenkov, V., Ensley, B.D., Chet, I. and Raskin, I. (1995) Phytoremediation: A novel strategy for the removal of toxic metals from the environment using plants. *Bio/Technology (Nature Publishing Company)* 13(5), 468–474. https://doi.org/10.1038/nbt0595-468
44. Shaltami, O.R. (2014) Characteristics of heavy metals in soil at Al Qawarishah village, NE Libya. *Trace Elements in the Environment* 13, 16-19.
45. Singh, A. and Ward, O.P., eds. (2004) Applied Bioremediation and Phytoremediation. *Soil Biology*. Berlin Heidelberg, Springer-Verlag. https://www.springer.com/gp/book/9783540210207
46. Sudoma, M., Pestalova, N., Bilkova, Z., Sedlacek, P. and Hofman, J. (2021) Ageing effect on conazole fungicide bioaccumulation in arable soils. *Chemosphere* 262, 127612.
47. Sumikura, M. and Shiiba, K. (2016) Insolubilization of hexavalent chromium in highly alkaline cement sludge by anaerobic bioremediation. *Bioremediation Journal* 20(3), 209–216. https://doi.org/10.1080/10889868.2016.1148008
48. Tao, H., Liao, X., Li, Y., Xu, C., Zhu, G. and Cassidy, D.P. (2020) Quantifying influences of interacting anthropogenic-natural factors on trace element accumulation and pollution risk in karst soil. *Science of The Total Environment* 721, 137770.
49. Thatoi, H., Das, S., Mishra, J., Rath, B.P. and Das, N. (2014) Bacterial chromate reductase, a potential enzyme for bioremediation of hexavalent chromium: A review. *Journal of Environmental Management* 146, 383–399. https://doi.org/10.1016/j.jenvman.2014.07.014
50. Wang, S. and Mulligan, C.N. (2004) An evaluation of surfactant foam

technology in remediation of contaminated soil. *Chemosphere* 57(9), 1079-1089.

51. WHO and UNICEF (2017) Open defecation global database. In: *Joint Monitoring Programme for Water Supply*, *Sanitation and Hygiene* (JMP). https://washdata.org/open-defecation

52. Wu, G., Kang, H., Zhang, X., Shao, H., Chu, L. and Ruan, C. (2010) A critical review on the bio-removal of hazardous heavy metals from contaminated soils: issues, progress, eco-environmental concerns and opportunities. *Journal of Hazardous Materials* 174(1–3), 1–8. https://doi.org/10.1016/j.jhazmat.2009.09.113

53. Xiao, R., Bai, J., Wang, J., Lu, Q., Zhao, Q., Cui, B. and Liu, X. (2014) Polycyclic aromatic hydrocarbons (PAHs) in wetland soils under different land uses in a coastal estuary: Toxic levels, sources and relationships with soil organic matter and water-stable aggregates. *Chemosphere* 110, 8-16. http://dx.doi.org/10.1016/j.chemosphere.2014.03.001

54. Yang, H., Wang, F., Yu, J., Huang, K., Zhang, H. and Fu, Z. (2021) An improved weighted index for the assessment of heavy metal pollution in soils in Zhejiang, China. *Environmental Research* 192, 110246. http://dx.doi.org/10.1016/j.envres.2020.110246

55. Zhang, H.B., Luo, Y.M., Wong, M.H., Zhao, Q.G. and Zhang, G.L. (2006) Distributions and concentrations of PAHs in Hong Kong soils. *Environmental Pollution* 141(1), 107-114.

56. Zhang, X., Liu, Z., Luc, N.T., Liang, X. and Liu, X. (2015) Dynamics of the biological properties of soil and the nutrient release of *Amorpha fruticosa* L. litter in soil polluted by crude oil. *Environmental Science and Pollution Research* 22(21), 16749–16757. https://doi.org/10.1007/s11356-015-4874-z

57. Zhang, Y., Wang, X. and Ji, H. (2020) Stabilization process and potential of agro-industrial waste on Pb-Contaminated soil around Pb-Zn mining. *Environmental Pollution* 260, 114069.

58. Zhou, Y., Sun, J., Wang, L., Zhu, G., Li, M., Liu, J., Li, Z., Gong, H., Wu, C. and Yin, G. (2021) Multiple classes of chemical contaminants in soil from an e-waste disposal site in China: Occurrence and spatial distribution. *Science of The Total Environment* 15(752), 141924. https://doi.org/10.1016/j.scitotenv.2020.141924

Cite this article: Titirmare, N.S., Gaikwad, A.S. and Margal, P.B. (2023) Soil Pollution and Environmental Health. In: S.A. Chaware et al. (Eds.), Advances in Soil Science 1(13), 267-307. Bright Sky Publications, New Delhi, India. http://dx.doi.org/10.5281/zenodo.8331094