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12. Soil Pollution: Emerging Threat to Agriculture

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Abstract:

Soil pollution, resulting from various sources including agricultural practices, heavy metals, industrial and domestic waste, and radioactive materials, presents a pressing environmental challenge globally. This book chapter explores the diverse origins, types, and consequences of soil pollution, delineating the adverse effects on agriculture, ecosystems, and human health. Agricultural activities, industrial processes, and improper waste disposal practices contribute significantly to soil contamination, altering soil composition and fertility, reducing crop yields, and posing risks to food safety. Heavy metal pollutants, based on their persistence and toxicity, disrupt soil ecosystems and pose long-term threats to both environmental and human health. Radioactive materials, originating from human activities like nuclear power generation and nuclear accidents, pose severe risks, contaminating vast soil areas and disrupting ecological balance. Domestic and municipal waste, alongside industrial effluents, further compound soil pollution, necessitating stringent waste management strategies for mitigation. Signs of soil contamination range from visible signs like discolored soil patches to subtle indicators such as reduced biodiversity, underscoring the importance of regular soil testing for accurate detection. Soil pollution's detrimental impacts on agriculture encompass nutrient imbalances, reduced soil quality, contaminated crops, and economic losses for farmers. Effective remediation strategies involve a multifaceted approach, combining physical, chemical, and biological techniques, tailored to specific contaminants and soil conditions. Addressing soil pollution requires a paradigm shift towards sustainable practices and stringent environmental regulations to safeguard soil health and ecosystem integrity.

Keywords:

soil pollutants, heavy metals, agriculture, radioactive materials, soil health.

12.1 Introduction:

Pollution represents an unwelcome alteration in the physical, chemical, and biological attributes of our air, water, and soil, potentially endangering life and creating health risks for all living organisms. It occurs when substances from various origins infiltrate our natural environment, profoundly impacting both plant and animal life due to the resultant changes brought about by these pollutants. Soil pollution specifically refers to the presence of hazardous chemicals—pollutants or contaminants—in soil, reaching concentrations that pose threats to human health and the broader ecosystem (Mirsal 2008). These pollutants can stem from two primary sources: anthropogenic activities, driven by human actions, and natural occurrences within the environment. Anthropogenic causes encompass a broad spectrum of human activities, including industrial processes, agricultural practices, improper waste disposal, and the extensive use of chemical fertilizers and pesticides. These activities introduce pollutants into the soil, disrupting its composition and fertility. On the other hand, natural causes of soil pollution involve occurrences such as volcanic eruptions, erosion, and the release of chemicals from natural deposits within the Earth. While these causes are innate to the environment, their intensity and impact can still contribute significantly to soil contamination.

Beyond these causes, soil pollution can result from a variety of pollutants, including heavy metals, pesticides, petroleum hydrocarbons, and other harmful chemicals. Their presence in the soil not only affects the health and growth of plants but also seeps into the food chain, potentially endangering human health and the balance of entire ecosystems. The consequences of soil pollution are multifaceted, extending beyond direct impacts on agriculture to encompass environmental degradation, reduced biodiversity, compromised water quality, and health risks to both humans and wildlife. Understanding the origins, types, and consequences of soil pollution is crucial in devising effective strategies to mitigate its effects and safeguard the integrity of our environment and food systems.

12.2 Sources of Soil Pollution:

12.2.1 Agricultural Practices:

Agricultural practices significantly contribute to soil pollution through various means, often unintentionally (Upadhyay *et al*., 2020). Some of the primary ways in which agriculture contributes to soil pollution include:

A. **Pesticide and Herbicide Use**: The widespread use of chemical pesticides and herbicides in agriculture is a major contributor. These chemicals, while effective in controlling pests and weeds, can accumulate in the soil over time, leading to soil contamination. Improper application or excessive use can result in the runoff of these chemicals into nearby soil, affecting its quality and fertility.
B. **Fertilizer Application**: The excessive use or improper application of chemical fertilizers introduces high levels of nutrients, such as nitrogen and phosphorus, into the soil. While these nutrients are essential for plant growth, their overuse can lead to nutrient imbalances, soil acidification, and eutrophication in water bodies when they leach into water systems.
C. **Soil Erosion**: Intensive farming practices, including monoculture and over-tilling, can contribute to soil erosion. When topsoil is eroded, it often carries with it valuable nutrients and can expose deeper, less fertile layers. This erosion results in reduced soil quality and productivity.

D. **Livestock Farming:** Animal farming, particularly in concentrated animal feeding operations (CAFOs), generates large amounts of manure. Improper disposal or excessive accumulation of manure can lead to nutrient runoff, contaminating nearby soils and water bodies with high levels of nitrogen and phosphorus. Additionally, livestock medications and hormones used in animal agriculture can enter the soil through manure, impacting soil quality.

E. **Industrial Agriculture Practices:** Large-scale industrial agriculture involves the use of machinery, which can lead to soil compaction. Compacted soil reduces its ability to absorb water and nutrients, affecting plant growth. Moreover, the release of agricultural waste, such as plastics, into the environment can further contribute to soil pollution.

Addressing soil pollution stemming from agricultural practices requires a shift towards sustainable farming methods. Adopting practices like crop rotation, agroforestry, reduced pesticide and fertilizer use, proper manure management, and conservation tillage can help minimize soil pollution while maintaining agricultural productivity and ecosystem health. Additionally, promoting organic farming and integrated pest management techniques can reduce reliance on chemical inputs, mitigating the negative impact on soil quality. Based on their persistence in soil (Table 12.1), pesticides can be categorized as below:

- Non-persistent pesticides: These break down relatively quickly in the environment. They have a short lifespan in soil, often days to a few weeks, and degrade through various processes like microbial action, sunlight (photodegradation), or chemical reactions. They don’t tend to accumulate in the environment and have less long-term impact.
- Moderately persistent pesticides: These pesticides take a longer time to break down compared to non-persistent ones. They can remain in the soil for several weeks to months before being degraded. While they might not persist for years, their presence over extended periods can still impact the environment and organisms.
- Persistent pesticides: These pesticides have a high resistance to degradation and can remain in the soil for years, or even decades. They pose a higher risk of accumulation in the environment, potentially causing long-term harm to ecosystems, wildlife, and even human health through bioaccumulation in the food chain.

Table 12.1: Non-Persistent, Moderately Persistent and Persistent Pesticides in Soil.

Non persistent (half-life < 30 days)	Moderately persistent (half-life>30 days but <80 days)	Persistent (>100 days)
Aldicarb	Aldrin	Bromacil
Captan	Atrazine	Chlordane
Dalapon	Carbaryl	Paraquat
Malathion	Diazinon	Trifluralin
2,4-D	Glyphosate	Lindane
2,4,5-T	Parathion	Picloram
Methyl parathion	Simazine	

Table 12.2: Partition Coefficient of Some Pesticides in Soil.

Pesticide	Partition Coefficient
Aldicarb	10
Carbofuran	29
2,4-D	32
Simazine	158
Atrazine	172
Propazine	207
Carbaryl	229
Malathion	1778
Parathion	7161
DDT	243,000

Additionally, when pesticides are used on crops, they can inadvertently spread beyond their intended target due to factors like spray drift or water runoff. Consequently, a portion of the pesticide ends up in the soil, where some adheres to soil colloids while the rest remains in a soluble form within the soil solution (Table 12.2) (Renaud *et al.*, 2004).

The partition coefficient represents the ratio between the concentration of the pesticide that's adsorbed onto the soil and the concentration that remains in the solution phase.

12.2.2 Heavy Metal Pollutants:

Heavy metals are metallic elements characterized by their high atomic weights and densities. Examples include lead, cadmium, mercury, arsenic, and chromium, among others. While some heavy metals are naturally present in the Earth's crust, human activities such as industrial processes, mining, agricultural practices, and improper disposal of waste contribute significantly to their presence in the environment. When released into the soil through various means like industrial runoff, atmospheric deposition, or improper waste disposal, these metals can persist and accumulate (Table 12.3) (Das 1996). Heavy metal pollution in soil occurs as these elements don't biodegrade, causing long-term contamination. Their presence interferes with the soil's natural composition and functions, disrupting the balance required for healthy plant growth and microbial activity.

Additionally, heavy metals are toxic to living organisms, impacting plants, animals, and microorganisms by inhibiting essential biological processes. Plants can absorb these metals, leading to reduced growth and potentially entering the food chain, posing health risks to animals and humans. Furthermore, heavy metals can leach into groundwater or be carried away by runoff, extending their environmental impact beyond the initial contaminated area. Managing heavy metal pollution necessitates proper waste disposal methods, remediation efforts to clean up contaminated sites, and stringent regulations to minimize their release into the environment. Permissible limit of these heavy metals as per Indian standards are mentioned in Table 4 (Sharma *et al.*, 2006).

Table 12.3: Extremely, moderately and less poisonous heavy metals in soil.

ELEMENT	POISONOUS
Cd, As	Extremely
Hg, Pb, Ni	Moderately
Cu, Zn, Mn	Lower

Some of the Heavy Metals in Soil Are:

A. Cadmium:

- Alters soil microbial activity.
- Tends to accumulate in leafy vegetables.
- Highly toxic to plants (phytotoxic).
- Elevated levels of Cd in soil can disrupt nutrient equilibrium.
- Availability diminishes with rising pH and increased CaCO3.
- Consumption of cadmium-contaminated rice in Japan led to Itai-itai disease.

B. Lead:

- Soil-bound lead is largely inaccessible to plants.
- Introduced into soil through sewage and industrial waste.
- Availability decreases in the presence of organic matter.
- Liming reduces lead availability and its uptake by plants.

C. Mercury:

- Its control involves adsorption and desorption processes.
- Binds with ligands such as OH-, Cl, and organic anions.
- Affinity to soil organic matter reduces its availability.
- Typically, not readily taken up by plants from soil unless in the methyl mercury form.

D. Nickel:

- Influences microbial communities.
- Ni^{2+} is the prevailing form.
- Increased pH diminishes its mobility.
- Forms stronger chelates with organic matter.

E. Chromium:

- Exists as Cr (III) and Cr (VI).
- Plant roots act as a primary barrier against chromium entry.
- Soil levels may surpass 10,000 mg/kg.

F. Arsenic:

- Occurs as (III) (toxic form) and as (V).
- Wetland rice under irrigation is highly susceptible to arsenic toxicity.
- Behavior in soil resembles that of phosphate.

Table 12.4: Permissible Limit of Heavy Metals as Per Indian Standards.

Heavy Metal	Permissible Limit for Indian Standards (Ug/G)
Zn	300-600
Cd	3-6
Cu	135-270
Cr	1-1000
Pb	250-500
Ni	75-150

12.2.3 Radioactive Materials:

Radioactive materials serve as a significant source of soil pollution, arising predominantly from human activities like nuclear power generation, industrial processes, mining, and nuclear accidents. These materials, including isotopes of elements like uranium, thorium, and radium, emit ionizing radiation that can persist in the environment for extended periods, posing serious health and environmental risks. When radioactive substances find their way into soil, they can contaminate vast areas, leading to long-term ecological disturbances (Mirsal and Mirsal 2008). Accidental spills, improper disposal of nuclear waste, or fallout from nuclear events contribute to this contamination. Radioactive elements, once in the soil, can be taken up by plants, entering the food chain and potentially causing health concerns for organisms, including humans, as they bio accumulate. Effective containment and management strategies for radioactive materials are critical to prevent further soil pollution and mitigate the far-reaching consequences on ecosystems and human health.

12.2.4 Domestic and Municipal Wastes:

Domestic and municipal wastes serve as significant contributors to soil pollution, encompassing a broad range of materials generated from households, businesses, and public areas. These wastes comprise organic matter, plastics, paper, glass, metals, and various hazardous substances like batteries, chemicals, and pharmaceuticals. Improper disposal practices, including open dumping, unregulated landfills, and inadequate waste management systems, lead to the direct deposition of these wastes into the soil. Organic waste, while biodegradable, can contribute to soil pollution when it decomposes anaerobically in landfills, generating methane and leachate that can contaminate soil and groundwater. Plastics and non-biodegradable materials persist in the soil for extended periods, fragmenting into microplastics that can disrupt soil structure and affect microbial activity. Hazardous components within domestic waste, such as heavy metals from electronic devices or toxic chemicals from cleaning products, pose serious risks.

When these substances leach into the soil, they can contaminate the surrounding environment, affecting plant growth, soil fertility, and the health of organisms within the ecosystem.

Moreover, leachate from improperly managed landfills can contain a cocktail of pollutants that seep into the soil, potentially contaminating groundwater, rivers, and streams nearby. This not only impacts the immediate area but also poses risks to broader ecosystems and human health through the food chain.

To mitigate soil pollution from domestic and municipal wastes, effective waste management strategies are crucial.

These include waste segregation at the source, recycling and composting programs, proper landfill management with liners and leachate collection systems, and the implementation of advanced technologies for waste treatment and disposal. Education and awareness campaigns also play a pivotal role in promoting responsible waste disposal practices among the public to minimize the detrimental impact of domestic and municipal waste on soil quality and environmental health.

12.2.5 Industrial Wastes:

Improper waste disposal practices significantly contribute to soil contamination, introducing harmful chemicals and pollutants into the environment. These contaminants adversely impact both plant and animal species, disrupting ecosystems and posing risks to local water supplies and drinking water sources.

The consequences extend beyond immediate soil pollution, affecting broader environmental health. Additionally, regulated landfills, meant to contain waste, can emit toxic fumes containing chemicals that, when released into the atmosphere, contribute to acid rain.

Acid rain, upon descending to the earth's surface, can cause damage to the soil profile, altering its composition and fertility. This phenomenon is further exacerbated by various industrial effluents categorized into distinct types, each presenting specific challenges to soil health.

For instance, effluents from distilleries and paper mills can increase the soil's electrical conductivity (EC), organic carbon (OC), and the presence of exchangeable sodium (Na), nitrogen (N), phosphorus (P), and potassium (K). Conversely, effluents from tanneries and textile industries can reduce soil porosity and hydraulic conductivity, affecting the soil's ability to retain water and support healthy plant growth. However, among the most detrimental are effluents from metal furnishing industries, notorious for introducing heavy metals into the soil, posing severe risks to ecological balance and human health. These industrial effluents compound the challenges of soil pollution, necessitating comprehensive strategies for waste management and stricter regulations to mitigate the detrimental impacts of these contaminants on soil quality and ecosystem stability. Efforts to monitor and control these sources of pollution are crucial in safeguarding soil health and ensuring sustainable environmental practices.

12.3 Signs of Soil Contamination:

- Indicators of soil contamination encompass various observable signs that can signal potential issues within the soil ecosystem. These signs include the presence of discolored or stained soil patches, often indicating the infiltration of pollutants altering its natural appearance.
- Additionally, a foul odour emanating from the soil might suggest the presence of contaminants affecting its quality.
- Moreover, the absence or scarcity of insects and worms, crucial components of a healthy soil ecosystem, can signal disturbances due to pollution. Similarly, a lack of diverse plant life or stunted growth in vegetation might indicate soil degradation caused by pollutants hindering plant development.
- Elevated erosion rates in affected areas can serve as another warning sign, indicating weakened soil structure and resilience due to contamination.
- However, sometimes contamination might not exhibit visible signs, making it imperative to conduct soil testing in specialized laboratories to detect and analyze any underlying pollutants accurately. Soil testing provides essential insights into potential contaminants, allowing for targeted remediation measures and the restoration of soil health.

12.4 How Does Soil Pollution Cause Threat to Agriculture?

Soil pollution poses a significant threat to agriculture by directly impacting soil health, reducing crop productivity, and potentially contaminating food sources.

Here's how it affects agriculture:

- Nutrient Imbalance: Soil pollution can alter the nutrient composition of the soil, affecting its fertility. Heavy metals or chemical pollutants can disrupt the balance of essential nutrients, making them unavailable or toxic to plants. This imbalance can hinder plant growth and reduce crop yields.
- Reduced Soil Quality: Pollutants can degrade soil structure and decrease its ability to retain water and nutrients. This leads to soil compaction, decreased aeration, and impaired root development, negatively affecting plant growth.
- Contaminated Crops: Plants can absorb pollutants from contaminated soil, leading to the accumulation of toxic substances in their tissues. This contamination can render crops unsuitable for consumption or market sale due to health risks associated with consuming polluted food.
- Impact on Microbial Activity: Soil pollution can disrupt the balance of beneficial microorganisms crucial for nutrient cycling and maintaining soil health. This disturbance in microbial activity can further degrade soil quality and impact plant growth.
- Environmental Risks: Agricultural practices often involve the use of pesticides and fertilizers. When soil pollution combines with these inputs, it can lead to a cocktail of pollutants that pose environmental risks, potentially contaminating water sources and harming non-target organisms.

- Economic Losses: Reduced crop yields and contaminated produce can lead to financial losses for farmers. Additionally, soil remediation to restore polluted land can be costly and time-consuming.

Addressing soil pollution in agriculture requires implementing sustainable farming practices, proper waste disposal, reduced use of harmful chemicals, and adopting soil conservation techniques. Regular monitoring and soil testing are crucial to identify pollutants and mitigate their impact on agricultural productivity and food safety.

12.5 Remediation of Polluted Soil:

Remediating polluted soils involves several steps aimed at reducing or eliminating contaminants to restore soil health (Lombi and Hamon 2005). Here's an overview of the process:

- Assessment and Analysis: Identify the type and extent of contamination through soil testing and analysis. Understand the nature of pollutants, their distribution, and their potential impact on the environment.
- Containment and Prevention: Prevent further spread of contaminants by isolating the polluted area. Implement measures like barriers, covers, or liners to prevent leaching and spreading of pollutants to adjacent areas.

A. Physical Remediation Techniques:

- Excavation and Removal: For localized contamination, physically remove polluted soil and replace it with clean soil.
- Soil Venting: Utilize aeration to encourage the volatilization of volatile contaminants, allowing them to escape into the atmosphere.
- Soil Washing: Employ techniques such as flushing or washing the soil with solvents or surfactants to remove contaminants.

B. Chemical Remediation Techniques:

- Chemical Oxidation/Reduction: Use chemical agents to oxidize or reduce contaminants into less harmful forms.
- Phytoremediation: Employ plants to absorb, metabolize, or accumulate pollutants. Plants like sunflowers, willows, or poplars can extract heavy metals or organics from soil.

C. **Biological Remediation Techniques:**

- Bioremediation: Use microorganisms like bacteria or fungi to degrade pollutants into harmless substances. Bioaugmentation involves introducing specific microorganisms to enhance the process.
- Composting: Break down organic contaminants through controlled decomposition by microorganisms in a composting process.

- Stabilization and Immobilization: Modify the contaminants' chemical properties to reduce their mobility and toxicity. Techniques involve adding amendments that bind to pollutants, reducing their bioavailability.
- Monitoring and Post-Remediation Assessment: Regularly monitor the soil quality to ensure the effectiveness of remediation efforts. Conduct follow-up tests to assess the success of the remediation process and the restoration of soil health.

Environmental Management: Ensure proper waste disposal, manage runoff, and implement measures to prevent future contamination, emphasizing sustainable practices to maintain soil health. The choice of remediation technique depends on various factors, including the type and concentration of contaminants, soil type, site conditions, and available resources. Often, a combination of different remediation strategies may be most effective for comprehensive soil restoration.

12.6 Conclusion:

Soil pollution poses intricate challenges with wide-ranging impacts on agricultural productivity, ecological stability, and human well-being. The multifaceted origins of soil pollution demand comprehensive remediation strategies that address diverse pollutants and their distinct impacts on soil ecosystems. Understanding the complexities of soil contamination and its repercussions on agriculture underscores the urgent need for sustainable farming practices, responsible waste management, and stringent regulations. By adopting innovative remediation techniques and holistic approaches, we can mitigate soil pollution's adverse effects, restore soil health, and preserve the integrity of our environment. Regular monitoring, coupled with proactive measures and community engagement, is pivotal to safeguarding soil quality, ensuring food safety, and fostering resilient ecosystems for future generations.

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