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Review Article

Beneath the Surface: Unmasking the Global Crisis of Soil Pollution

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Abstract: Soil pollution is an escalating global crisis with profound implications for environmental health, agricultural productivity, and food security. Driven by industrial emissions, intensive agriculture, urbanization, and poor waste management, pollutants such as heavy metals, pesticides, microplastics, and emerging contaminants persist in the soil, disrupt its biological functions, and enter the food chain. These toxicants degrade soil microbial communities, reduce crop yields, and impair biodiversity and ecosystem resilience. The impacts extend beyond the farm, contributing to climate change and posing chronic risks to human health through bioaccumulation and biomagnification. Despite its critical importance, soil pollution remains under-monitored, and remediation is often constrained by technical, financial, and institutional challenges. This review synthesizes the sources, classifications, pathways, and ecological impacts of soil contaminants, while critically examining current remediation strategies and policy frameworks. It underscores the urgent need for integrated soil health management, robust legal regulations, enhanced public awareness, and innovative sustainable practices to restore and protect this vital resource.

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1. Introduction

Soil, often termed the "living skin of the Earth," is fundamental to terrestrial ecosystems, providing essential services such as supporting plant growth, regulating water cycles, sequestering carbon, and sustaining biodiversity. Despite its ecological and economic importance, soil remains a neglected resource, suffering progressive degradation and contamination worldwide. Among various forms of degradation, soil pollution has emerged as a critical but underrecognized global crisis, characterized by the accumulation of toxic substances that disrupt soil functions and threaten environmental and human health. (Alloway, 2013; Wuana & Okieimen, 2011). Contaminants such as heavy metals, pesticides, and industrial waste infiltrate soils through diverse sources—industrial discharges, mining, agricultural inputs, urbanization, and improper waste disposal. Unlike air or water pollution, soil contamination often lacks immediate visibility, with impacts becoming apparent only after prolonged exposure. These pollutants can persist in soils for decades, remaining bioavailable and toxic, entering the food chain via plant uptake or leaching into groundwater. (Cheng et al., 2019).

The nature and extent of soil pollution vary globally. Developed countries often grapple with legacy contamination from industrial activities and intensive agrochemical use, while developing regions face increasing pollution from unregulated industries, poor waste management, and excessive fertilizer and pesticide applications. For instance, India's Indo-Gangetic plains show elevated levels of arsenic, cadmium, and lead, raising concerns over food safety and public health.

Polluted soils undermine agricultural productivity, food quality, and ecological stability. Toxic elements interfere with nutrient uptake, impair microbial functions, reduce crop yields, and ultimately affect food security and human well-being. Soil pollution also disrupts biodiversity, diminishes carbon sequestration potential, and compounds the impacts of climate change (Lehmann et al., 2011). Yet, global monitoring frameworks remain inadequate, and remediation efforts are often costly, site-specific, and technologically demanding. This study explores the sources, contaminants, ecological and health impacts, and remediation strategies related to soil pollution, while emphasizing the urgent need for integrated management, policy interventions, and sustainable soil practices.

2. Soil Pollution: Concepts and Classifications

Soil pollution refers to the presence of chemical substances (inorganic and organic) or other agents in soil at concentrations harmful to ecosystem and human health (Alloway, 2013). Both natural (e.g., geogenic) and anthropogenic inputs contribute, but the latter driven by industrialization, intensive agriculture, and improper waste disposal is most concerning (Nagajyoti et al., 2010).

Inorganic contaminants, such as heavy metals (e.g., lead, cadmium, arsenic), metalloids, and salts, are persistent, non-biodegradable substances with high retention potential (Wuana & Okieimen, 2011). Organic contaminants include pesticides/herbicides, petroleum hydrocarbons, solvents, polycyclic aromatic hydrocarbons (PAHs), and persistent organic pollutants (POPs). Their persistence varies; some undergo microbial degradation while others accumulate (Nagajyoti et al., 2010; Khan et al., 2013).

Industrial emissions from sources like smelters, chemical plants, tanneries, and battery recycling contribute significantly to soil pollution (Alloway, 2013). Agricultural inputs, including agrochemicals, manures, and biosolids, introduce pesticides, nitrates, and heavy metals (Zhao et al., 2015). Urban and municipal waste from landfills, sewage sludge, and e-waste contribute metals, persistent organics, and microplastics (Li et al., 2019). Mining and oil spills lead to the liberation of heavy metals, hydrocarbons, and acid mine drainage (Rodrigues et al., 2021).

Contaminants are categorized based on their soil residence time and movement. Persistent and immobile contaminants include lead and mercury. An example of a persistent and mobile contaminant is arsenic in groundwater. Non-persistent but leachable contaminants include nitrates and certain pesticides. Volatile organics, such as those that migrate through soil air-gaps to groundwater or air, also contribute to pollution (FAO & UNEP, 2021). Contaminants can be classified by their hazard potential. Human toxicants include carcinogens and neurotoxins (e.g., benzene, cadmium, asbestos). Ecotoxicants are substances that harm plants, microbes, and fauna (e.g., chlorinated solvents, PAHs). Secondary pollutants are by-products of contaminant transformation (e.g., methylmercury). Soil quality focuses on chemical aspects, such as contaminant thresholds and pH. In contrast, soil health integrates biological and physical functions; indicators include microbial biomass, organic matter, and porosity (Cheng et al., 2019).

3. Sources of Soil Pollution

(i) Industrial emissions- Metal smelters release arsenic, lead, and cadmium, leading to chronic contamination near their sites (Alloway, 2013). Tanneries are a source of chromium pollution in soils and water bodies (Khan et al., 2013). Battery and e-waste recycling processes contribute lead, mercury, and brominated flame retardants; artisanal e-waste sites are particularly problematic hotspots (Li et al., 2019).

(ii) Agricultural chemicals- Pesticides, such as organochlorines (e.g., DDT), are banned but persist for decades and act as endocrine disruptors (Nagajyoti et al., 2010). Overuse of fertilizers leads to nitrate leaching and eutrophication; phosphate-based fertilizers can introduce cadmium and uranium trace contaminants (Zhao et al., 2015). Animal manure and biosolids can concentrate copper, zinc, antibiotics, and antibiotic-resistance genes (Li et al., 2019).

(iii) Waste Disposal- Landfills leach heavy metals and persistent organic molecules into the soil (Rodrigues et al., 2021). Sewage sludge contains pharmaceuticals, pathogens, and trace metals; its application on farmland can transfer pollutants (FAO & UNEP, 2021). Construction demolition activities can release asbestos, leaded paint chips, and silica dust (Cheng et al., 2019).

(iv) Mining and Oil Spillage- Mining activities produce tailings and acid mine drainage, which release low pH water with high metal concentrations, acidifying adjacent soils (Alloway, 2013). Oil spills involve hydrocarbon mixtures that degrade slowly and impact soil structure and microbial ecology (Rodrigues et al., 2021).

(v) Emerging Pollutants- Leaching of heavy metals (lead, cadmium), flame retardants (PBDEs), and rare earth elements occurs from landfills and informal recycling sites (Li et al., 2019). Microplastics from sludge, landfills, and wastewater biosolids are long-term soil contaminants affecting moisture and microbial function (Nagajyoti et al., 2010).

4. 1 Types of Soil Contaminants

(i) Heavy metals- The toxicity of lead, cadmium, arsenic, and mercury is well-documented. Their speciation and plant uptake, along with their chemical forms, influence their bioavailability. A notable case is arsenic contamination in Bangladesh through irrigation with contaminated groundwater, which has affected skin and increased cancer incidences (Peralta-Videa et al., 2009).

(ii) Organic substances- Pesticides, such as organochlorines (DDT, lindane), are banned but persist; organophosphates and neonicotinoids impact pollinators. PAHs originate from fossil fuel combustion and are toxic, mutagenic, and carcinogenic. Volatile organic compounds (VOCs), such as benzene and toluene, can contaminate soil and volatilize into indoor air, causing inhalation risks.

(iii) Microplastics- Sources and fragmentation in soil are understood, as are their interactions with heavy metals and hydrophobic organics. They affect soil aeration, moisture retention, and soil fauna (earthworms, nematodes).

(iv) Pathogens and Biohazards- These include sewage sludge–derived bacteria, viruses, and antibiotic-resistance genes. Agricultural runoff can also amplify zoonotic pathogens in soil.

(v) Emerging Pollutants- Per- and polyfluoroalkyl substances (PFAS), also known as "forever chemicals," from firefighting foams and industrial use, are persistent and bioaccumulative. Pharmaceutical residues, such as analgesics and antibiotics, can disrupt soil microbial networks (Cheng et al., 2019).

4.2 Why Key Soil Contaminants Are Problematic

The nature and severity of soil pollution depend largely on the type of contaminant involved. Many pollutants are toxic, persistent, and capable of bioaccumulating in the food chain, posing serious threats to environmental and public health. Below is a concise overview of the major contaminants and the reasons they are particularly hazardous:

- **Lead (Pb):**

A potent neurotoxin especially harmful to children, impairing cognitive development and reducing IQ. It binds strongly to soil particles, remaining bioavailable for decades.

- **Cadmium (Cd):**

Accumulates in crops like rice and leafy vegetables. Causes kidney damage, bone demineralization, and is classified as a carcinogen. More mobile in acidic soils.

- **Arsenic (As):**

Linked to cancers and skin lesions. Commonly found in contaminated irrigation water, especially in rice fields. Highly mobile in groundwater and bioavailable under reducing conditions.

- **Mercury (Hg):**

Highly toxic in its methylated form. Affects the nervous system and can biomagnify through the food web. Often emitted from coal burning and industrial waste.

- **Pesticides (e.g., DDT, organophosphates, neonicotinoids):**

Persistent pesticides like DDT act as endocrine disruptors. Organophosphates affect nerve transmission, while neonicotinoids harm pollinators and beneficial soil fauna.

- **Polycyclic Aromatic Hydrocarbons (PAHs):**

Derived from fossil fuel combustion, these are carcinogenic and mutagenic. They degrade slowly and disrupt microbial activity in soil.

- **Volatile Organic Compounds (VOCs):**

Compounds like benzene and toluene can vaporize from soil to air, posing serious inhalation risks. Benzene is a known carcinogen.

- **Microplastics:**

Alter soil porosity and moisture retention. Serve as carriers for other toxic substances and interfere with microbial and faunal activity.

- **Per- and Polyfluoroalkyl Substances (PFAS):**

Also known as “forever chemicals,” these are highly persistent, bioaccumulative, and linked to hormone disruption, immune dysfunction, and cancer.

- **Pharmaceuticals and Antibiotics:**

Commonly introduced via sewage sludge or livestock manure. Disrupt microbial networks and promote the development of antibiotic-resistant genes in soil ecosystems.

Understanding the specific risks associated with each contaminant is crucial for developing targeted remediation strategies and prioritizing regulatory actions.

5. Mechanisms and Pathways of Soil Contamination

Soil pH, organic matter, texture, and cation exchange capacity affect contaminant binding. Chemical speciation dictates mobility and risk (Alloway, 2013). Gravitational infiltration redistributes soluble ions and contaminants, with nitrates and arsenic moving down soil profiles. Rain events mobilize pollutants into streams and rivers, and heavy metals adsorbed to soil particles are transported. VOCs and certain pesticides transition to the air–soil interface, leading to inhalation risks. Roots absorb contaminants, leading to biomagnification through trophic levels. Examples include cadmium in rice and mercury in root vegetables (Cao et al., 2018). Heavy metals are strongly adsorbed to clay and organic matter, becoming stabilized but potentially remobilizing under pH changes.

6. Impact of Soil Pollution on Soil Health and Functions

Soil health refers to the ongoing capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (Doran & Zeiss, 2000). Contaminated soils compromise key soil functions such as nutrient cycling, organic matter decomposition, water retention, and root penetration, thereby reducing productivity and environmental services.

(i) Effects on Soil Microbes- Microorganisms are critical for soil ecosystem functioning, including nitrogen fixation, phosphorus solubilization, and decomposition of organic matter. Heavy metals such as cadmium, lead, and arsenic reduce microbial diversity and enzymatic activities (Giller et al., 2009). Studies report declines in microbial biomass and shifts toward metal-tolerant but less functionally diverse communities (Cheng et al., 2019). Soil enzyme activity, such as dehydrogenase, phosphatase, and urease, is frequently used as a biomarker of soil health. Pollution with copper, zinc, and nickel has been associated with enzyme inhibition and functional decline (Wang et al., 2009).

(ii) Effects on Soil Structure - Organic contaminants like petroleum hydrocarbons disrupt soil aggregates and hydrophobicity, reducing water infiltration and increasing erosion risk (Muratova et al., 2003). Heavy metal contamination can alter soil particle interactions and reduce structural stability.

(iii) Nutrient Cycling- Contaminants impair microbial-driven biogeochemical cycles. For instance, nitrification and denitrification processes are inhibited by cadmium and lead, leading to nitrogen imbalance (Zhang et al., 2010). Similarly, mycorrhizal fungi, crucial in phosphorus uptake, are particularly sensitive to metal toxicity.

(iv) Decline in Organic Matter and Carbon Sequestration- Persistent contaminants reduce microbial respiration and decomposition, slowing organic matter turnover and leading to the accumulation of undecomposed litter (Lehmann et al., 2011). Moreover, contaminated soils exhibit lower carbon sequestration capacity, exacerbating climate change feedbacks.

7. Linking Soil Health Impairment to Broader Ecological Consequences

Soil pollution compromises core biological, chemical, and physical functions of soil. These disruptions not only reduce soil productivity but also cascade into wider ecological imbalances. The following points illustrate how impaired soil health translates into broader environmental consequences:

- **Disruption of Microbial Communities → Impaired Ecosystem Functioning**

Soil microbes drive nutrient cycling, organic matter decomposition, and detoxification. Heavy metal toxicity and pesticide residues reduce microbial biomass and diversity, leading to inefficient nutrient turnover and loss of ecosystem services.

- **Loss of Soil Fauna → Breakdown of Food Webs**

Contaminants like lead, arsenic, and hydrocarbons adversely affect soil fauna such as earthworms and nematodes. Their decline reduces soil aeration, litter decomposition, and prey availability, disturbing predator-prey relationships and initiating trophic cascades.

- **Altered Soil Structure → Increased Erosion and Habitat Degradation**

Organic pollutants and heavy metals disrupt soil aggregation and porosity. Poor structure reduces water infiltration, increases runoff and erosion, and degrades nearby aquatic habitats through sedimentation and pollutant loading.

- **Decline in Vegetation and Plant Biodiversity → Reduced Habitat Complexity**

Phytotoxic effects such as stunted growth, chlorosis, and poor germination reduce plant cover and diversity. Loss of vegetation alters habitat structure, affects pollinators and herbivores, and destabilizes ecosystems reliant on native plant communities.

- **Reduced Carbon Sequestration → Amplification of Climate Change**

Soil contamination impairs microbial decomposition and carbon stabilization, reducing soil's carbon sink function. This contributes to higher atmospheric CO_2 levels, accelerating global warming and altering climatic feedback loops.

- **Bioaccumulation and Biomagnification → Threats to Wildlife and Human Health**

Contaminants absorbed by plants are transferred to herbivores and higher trophic levels. Toxic metals and persistent organic pollutants accumulate in wildlife, impairing reproduction, immunity, and survival—affecting biodiversity and posing long-term risks to human consumers.

- **Aquatic Ecosystem Contamination via Leaching and Runoff**

Pollutants such as nitrates, phosphates, and heavy metals leach into groundwater or are carried by surface runoff into rivers and lakes, causing eutrophication, fish kills, and degradation of aquatic biodiversity.

- **Reduced Ecosystem Resilience and Adaptive Capacity**

Polluted soils are less able to recover from environmental shocks such as droughts, floods, or pest outbreaks. This lowers the resilience of entire landscapes to climate change and anthropogenic pressures.

8. Impacts on Agricultural Productivity and Food Security

(i) Reduction in Crop Yield and Quality: Soil contamination affects the germination, growth, and productivity of crops. Cadmium, lead, and arsenic inhibit root elongation, reduce chlorophyll synthesis, and disrupt nutrient uptake (Clemens et al., 2013). Multiple field studies have reported significant yield declines in cereals, pulses, and vegetables grown in polluted soils (Zhao et al., 2015).

(ii) Crop Contamination and Food Chain Entry: One of the most alarming effects of soil pollution is the entry of contaminants into the food chain. Arsenic in rice, cadmium in leafy vegetables, and lead in tubers are documented globally, including in South Asia and Sub-Saharan Africa (Cao et al., 2018; Srivastava et al., 2020). Bioaccumulation and translocation depend on crop species, pollutant type, and soil conditions. For example, leafy vegetables accumulate more heavy metals than grains due to higher surface exposure and transpiration-driven uptake.

(iii) Soil Fertility Decline and Increased Inputs: Contaminated soils require more fertilizers to achieve target yields due to impaired microbial and enzymatic functions. This increases input costs and risks further pollution if not managed sustainably (Zhang et al., 2010).

(iv) Economic Implications: Loss of productivity, market rejection due to contamination, and reduced land value impose significant economic burdens on farmers and governments. Clean-up costs and food recalls further amplify economic losses (FAO & UNEP, 2021).

(v) Food Security and Nutrition: Reduced availability and quality of food directly affect household food security. Chronic exposure to toxicants in food causes malnutrition, growth stunting in children, and long-term health impacts in vulnerable communities (Jaishankar et al., 2014).

9. Remediation Strategies and Technologies

Soil remediation involves the removal, immobilization, or detoxification of pollutants to restore the functional integrity of soil. Given the diversity of contaminants and soil properties, remediation must be tailored to specific site conditions. Broadly, remediation techniques are categorized into physical, chemical, and biological approaches, with increasing emphasis on eco-friendly and sustainable methods.

(i) Physical Remediation: Techniques Soil excavation and removal is effective but expensive and disruptive, often used for highly toxic sites (Alkorta et al., 2004). Thermal desorption volatilizes organic pollutants using heat (e.g., for hydrocarbon-contaminated soils) but consumes high energy (Khan et al., 2004). Soil washing employs surfactants or water to separate contaminants; it is useful for heavy metals but generates large volumes of secondary waste (Mulligan et al., 2001).

(ii) Chemical Remediation: Stabilization/solidification (S/S) involves mixing binding agents (e.g., lime, cement) to immobilize contaminants. It is effective for heavy metals but may alter soil structure. Chemical oxidation (e.g., using Fenton's reagent, ozone, or persulfate) transforms organic contaminants into less harmful substances. Electrokinetic remediation uses electric fields to mobilize charged contaminants, particularly metals from fine-grained soils (Acar & Alshawabkeh, 1993).

(iii) Biological Remediation (Bioremediation): Microbial bioremediation involves indigenous or introduced microbes to degrade organic contaminants like petroleum hydrocarbons, pesticides, and PAHs (Vidali, 2001). Bioventing and biosparging enhance microbial degradation via controlled air or nutrient injection into soil.

(iv) Phytoremediation: Phytoremediation uses plants and associated rhizosphere microbes to extract, degrade, or stabilize contaminants. Phytoextraction involves hyperaccumulator plants (e.g., Brassica juncea, Thlaspi caerulescens) that absorb heavy metals (Ali et al., 2013). Phytostabilization refers to plants immobilizing metals in roots or rhizosphere (e.g., Vetiveria zizanioides). Rhizodegradation is the microbial degradation of organic pollutants stimulated by plant root exudates. Limitations include long remediation times and plant sensitivity to contamination, but the method is cost-effective and environmentally benign.

(v) Emerging Technologies: Biochar and nanomaterials (e.g., nano-iron, nano-hydroxyapatite) immobilize metals and enhance microbial activity (Beesley et al., 2011; Mukherjee et al., 2014). Integrated approaches, such as combining phytoremediation with biochar amendment or microbial consortia, offer improved outcomes.

10. Policy Frameworks and Global Regulations

The Global Soil Partnership (GSP), coordinated by FAO, promotes sustainable soil management (FAO, 2021). UN Sustainable Development Goal (SDG 15.3) targets land degradation neutrality by 2030, recognizing soil health's role in ecosystem resilience. In the European Union, the EU Soil Strategy (2021) aims for all EU soils to be in healthy condition by 2050, and the REACH regulation restricts hazardous chemicals. In the United States, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates clean-up of hazardous waste sites under EPA oversight (Gibbs, 1982). India lacks a unified soil pollution law. Relevant frameworks include the Environment Protection Act (1986), which provides authority to regulate industrial emissions and waste, and the Hazardous and Other Wastes (Management and Transboundary Movement) Rules (2016). The National Action Plan on Soil Health Management (2015) focuses primarily on nutrient management. There is an urgent need for a dedicated soil protection law, a national-level contaminant inventory, and the integration of soil quality into land-use policies. Significant gaps and challenges exist, including poor enforcement of existing regulations, a lack of standardized soil quality indicators and thresholds, fragmentation across ministries and regulatory bodies, and low public awareness and community engagement.

11. Challenges in Soil Remediation and Policy Implementation

While advances in science and international recognition of soil pollution have grown, significant practical barriers continue to hinder effective remediation and policy enforcement. These challenges are multifaceted and interlinked: Soil pollution is highly site-specific, influenced by contaminant type, soil characteristics, and land use, making standardized remediation approaches ineffective. Many remediation technologies—such as phytoremediation and bioremediation—are time-intensive and limited by environmental conditions, while advanced techniques like thermal treatment or soil washing are cost-prohibitive and generate secondary waste. Compounding the technical issues is the complexity of mixed contamination, where multiple pollutants interact, complicating risk assessment and treatment. There is also a lack of universally accepted soil quality indicators or threshold values across regions, impeding systematic monitoring. Economically, remediation efforts demand substantial investments that are often beyond the capacity of small farmers and local governments. Public funding and incentives for sustainable practices remain limited, especially in low- and middle-income countries. From a governance standpoint, fragmented regulations and weak enforcement mechanisms are major obstacles. In countries like India, there is no unified soil pollution law, and responsibilities are divided across ministries, resulting in inefficiency. Monitoring infrastructure is underdeveloped, and institutional capacity remains inadequate for site assessment and enforcement. Societal challenges further exacerbate the issue. Public awareness is low, and contaminated site identification often faces resistance due to economic implications like land devaluation. Moreover, coordination between sectors—agriculture, industry, health, and environment—is lacking, making policy execution fragmented and ineffective. Emerging contaminants such as microplastics, PFAS, and pharmaceutical residues remain poorly regulated, and climate change intensifies the problem by altering pollutant mobility and degrading remediation effectiveness.

Overcoming these barriers requires a holistic and coordinated approach, involving robust legal frameworks, transdisciplinary research, sustainable financing, and strong public engagement. Only then can remediation efforts be scaled effectively and policy actions aligned with long-term environmental goals.

12. Future Directions and Sustainable Practices

Combating soil pollution requires integrated, actionable strategies that merge sustainable agriculture, technological innovation, and strong governance. The following consolidated directions offer practical pathways: Integrated Soil Health Management practices such as organic amendments (compost, biochar, and manure), cover cropping, and conservation tillage can restore microbial function and reduce contaminant mobility. For example, biochar from rice husks has been effectively used in Indian rice-wheat systems to immobilize cadmium and improve crop safety. Shifting toward green chemistry involves replacing synthetic agrochemicals with biopesticides and microbial biofertilizers (e.g., Trichoderma, neem-based products) and adopting controlled-release and low-toxicity fertilizers like nano-zinc or coated urea, which reduce nutrient leaching and chemical buildup. These have shown success in South Asia, improving crop nutrition and reducing residual toxicity. Enhanced soil monitoring systems are critical. Creating geo-referenced soil contaminant inventories, utilizing remote sensing and GIS, and expanding initiatives like digital soil health cards can help identify pollution hotspots and inform localized remediation. Platforms such as India's Bhuvan and the EU's EIONET-SOIL serve as practical models. Education and community engagement are essential for long-term impact. Programs like FAO's "Soil Doctors", farmer field schools, and citizen-led soil monitoring initiatives foster grassroots awareness and capacity-building. Incorporating soil health modules in school curricula can embed stewardship from a young age. Policy reform must prioritize the enactment of dedicated soil pollution laws, integrated land-use planning, and cross-sector coordination. Countries like China have pioneered such efforts with comprehensive soil pollution control legislation. Soil quality should also be incorporated into climate adaptation and disaster risk frameworks, recognizing its role in food and environmental security (FAO & UNEP., 2021).

Together, these measures present a roadmap for sustainable soil management that is ecologically sound, economically viable, and socially inclusive.

13. Conclusion

Soil pollution is a silent but formidable threat undermining the foundation of ecosystem health, food production, and human well-being. As contaminants accumulate and persist in the soil, they disrupt critical soil functions—nutrient cycling, microbial activity, water filtration, and carbon sequestration—leading to cascading ecological, agricultural, and health consequences. Heavy metals, persistent organic pollutants, microplastics, and emerging contaminants enter the food chain, degrade biodiversity, and impair soil fertility. The crisis is exacerbated by weak regulatory frameworks, limited remediation capacity, and fragmented policies. Despite its severity, soil pollution remains under-monitored and under-addressed compared to air and water pollution. The way forward demands an integrated and interdisciplinary approach—combining science, technology, policy, and public engagement. Sustainable soil management practices, green chemistry, improved monitoring, and strong legal instruments are essential to restore degraded soils and prevent future contamination. Equally important is the inclusion of soil health in national and global environmental strategies, including climate resilience and food security agendas. Tackling soil pollution is not only an environmental imperative but also a socio-economic and moral responsibility. As arable land shrinks and climate challenges intensify, protecting the integrity of our soils is central to ensuring a resilient, food-secure, and sustainable future for generations to come.

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