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Toxic Air, Contaminated Water, and Degraded Soil: The Health Burden of Pollution

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Abstract

Healthy soil is essential for human well-being as it plays a crucial role in food production, sustains ecosystems, and provides vital ecological services like pollination. It helps in water storage, flood prevention, and carbon sequestration, which helps mitigate climate change. However, soil pollution poses a significant and growing threat to human health. Soil can become contaminated with heavy metals, pesticides, biological pathogens, and micro/nano plastic particles. Pollution hampers the soil's ability to produce food, leads to crop contamination, and causes diseases. Pollutants in the soil can also leach into rivers, contributing to water pollution. Deforestation accelerates soil erosion, releases stored pollutants, and generates airborne dust. Pollution in air, water, and soil is responsible for at least 9 million deaths annually, with over 60% of pollution-related deaths attributed to cardiovascular diseases.

Recognizing the impact of pollution on health, the European Commission and the EU Action Plan for 2050: A Healthy Planet for All, have stressed the need to reduce pollution in air, water, and soil to levels that no longer harm human or ecosystem health. Achieving a toxic-free environment and ensuring a safe operating space for humanity are vital for sustaining the planet's health for future generations. This review article summarizes the current understanding of the connection between soil health and human health and explores the key soil pollutants and their health effects.

Key-words: Pollution, Toxic, Air, Health

Introduction

Healthy soil is crucial for human health, yet it is often overlooked in medical discussions. Soil is a fundamental part of the planet's infrastructure, directly supporting human survival. It is essential for producing safe and sufficient food, supporting diverse ecosystems, and providing critical services such as pollination. Additionally, healthy soil stores water, protects waterways, prevents flooding, and plays a significant role in mitigating climate change by capturing carbon.

However, pollution of air, water, and soil poses a growing threat to global health. According to the Lancet Commission on Pollution and Health, pollution is the leading environmental cause of disease and premature death worldwide. Pollution-related diseases were responsible for an estimated 9 million premature deaths in 2015, accounting for 16% of global deaths. Additionally, pollution led to the loss of 268 million disability-adjusted life years (DALYs) in the same year.

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Despite the significant impact of pollution, the Global Action Plan for the Prevention and Control of Non-Communicable Diseases (NCDs) does not adequately address chemical pollutants or other environmental stressors, such as mental stress, noise exposure, and climate change, all of which contribute to health risks [1].

Epidemiological data suggest that environmental risk factors, including pollution, are major contributors to non-communicable diseases, particularly cardiovascular diseases, as well as metabolic and mental health conditions like hypertension, stroke, diabetes, and depression. Soil pollution, although less visible than air pollution, poses serious risks to human health, contributing to various diseases, including cardiovascular problems.

Soil is crucial for human health in many ways. It is the foundation of the global food system, with approximately 78% of the average per capita calorie intake derived from crops grown in soil. Soil also serves as a natural filter, removing contaminants from water. Beyond food production, soil supports biodiversity, which is essential for nutrient cycling, pest control, and the development of pharmaceuticals. Healthy soils contribute to carbon sequestration and water retention, supporting agricultural productivity even during dry periods.

Threats to soil health include pollution from heavy metals, pesticides, deforestation, and plastic waste. These pollutants reduce the soil's ability to support food production, harm ecosystems, and pose significant health risks. Soil pollution is not always easily observable, and its impacts on human health are not fully understood or quantified, particularly in relation to cardiovascular disease.

This review article aims to summarize the current knowledge on the relationship between soil pollution and human health, focusing on its role in the development of cardiovascular diseases and the broader implications for public health [2].

MECHANISMS OF SOIL AND WATER CONTAMINATION BY HEAVY METALS, PESTICIDES, AND BIOACTIVE TOXICANTS: IMPACTS AND IMPLICATIONS

Toxic substances, including heavy metals, metalloids, and pesticides, commonly found in contaminated soil, are known to induce oxidative stress, which is recognized as a key initiating factor for various non-communicable diseases (NCDs). Epidemiological and experimental studies suggest that heavy metals such as cadmium, lead, and arsenic can trigger cardiovascular diseases. Cadmium, for instance, contributes to vascular damage, endothelial dysfunction, and atherosclerosis through oxidative mechanisms, such as replacing iron and copper in sulfur complexes and promoting Fenton reactions, disrupting antioxidant responses, and inhibiting nitric oxide-mediated vasodilation. Additionally, there is evidence indicating that heavy metals and metalloids can influence the epigenetic regulation of gene expression.

Lead, similarly, induces oxidative stress, inflammation, endothelial dysfunction, and vascular cell proliferation, leading to adverse effects on heart rate variability. Both lead and cadmium exhibit similar biological effects that contribute to cardiovascular issues. Other toxic soil pollutants, including polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers, perfluoro carboxylic acids, and bisphenol A (BPA), are also associated with negative health impacts. These chemicals can enter the soil through industrial processes or pesticide applications and have been linked to various health problems, including cancer, endothelial dysfunction, atherosclerosis, neurodegenerative diseases, and cardiometabolic disorders. Pesticide exposure, in particular, is a major health concern for agricultural workers, with millions affected annually by pesticide poisoning. Exposure to these chemicals has been connected to chronic diseases such as diabetes, cancer, asthma, and ischemic heart disease, including complications like myocardial infarction, arrhythmias, heart failure, and severe hypertension during pregnancy [3].

The mechanisms by which toxic soil pollutants induce oxidative stress are varied but largely involve P450 chemistry, redox cycling, inhibition of antioxidant enzymes, and disruption of mitochondrial function. These mechanisms have been extensively studied. Additionally, chronic exposure to heavy metals has been shown to affect circadian rhythms, contributing to conditions like "cadmium chrono toxicity," where disturbances in

circadian rhythms are linked to oxidative stress. Antioxidant therapies may mitigate some of these effects. Research has also highlighted the impact of environmental organic chemicals on circadian pathways, with studies showing that exposure to endocrine-disrupting chemicals, such as BPA, leads to dysregulation of the circadian clock, especially in liver tissues. Disruption of circadian rhythms is associated with various diseases, including cardiovascular conditions. Experimental and clinical evidence strongly supports a connection between circadian misalignment, commonly observed in shift workers, and an increased risk of cardiovascular diseases [4].

CLINICAL STUDIES ON SOIL AND WATER CONTAMINATION WITH HEAVY AND TRANSITION METALS

In India, soil and water contamination with heavy metals, pesticides, and other toxic substances has become a growing public health concern. Studies have shown that heavy metal contamination, including arsenic, cadmium, and lead, is prevalent in several regions due to industrial activities, improper waste disposal, and agricultural practices. For example, areas in Punjab, Uttar Pradesh, and West Bengal have been found to have high levels of arsenic in groundwater, leading to serious health issues such as cardiovascular diseases, cancers, and developmental disorders.

A study conducted on Indian agricultural workers highlighted the significant health risks posed by pesticide exposure. Approximately 25 million agricultural workers in India are affected by pesticide poisoning annually. These workers face an increased risk of chronic diseases, including cardiovascular problems, respiratory disorders, and neurological issues. Furthermore, pesticide exposure is linked to acute conditions such as dizziness, nausea, skin irritation, and headaches.

The contamination of soil and water by heavy metals is also associated with the consumption of contaminated food. India's reliance on rice, vegetables, and fruits that can absorb heavy metals from polluted soil poses a direct threat to public health. This problem is exacerbated by the rapid globalization of food supply chains, which facilitates the movement of contaminated produce across regions. The risks of consuming such contaminated food can include cardiovascular diseases, cancer, and kidney damage, among others [5].

In addition to soil pollution, airborne dust is a significant health risk in India, especially in regions affected by desert dust storms, agricultural activities, and deforestation. Dust particles, especially those smaller than 10 µm in diameter, can cause severe respiratory issues, including asthma, pneumonia, and lung cancer. In urban areas, dust from construction sites and unpaved roads also contributes to air pollution, exacerbating cardiovascular diseases and other chronic illnesses.

Studies have shown that the impact of environmental pollutants on cardiovascular health is significant in India, where the prevalence of heart disease is rising. In particular, the increased levels of particulate matter (PM), lead, and other toxic chemicals in the air have been linked to higher rates of acute myocardial infarction, strokes, and other heart-related issues. This trend underscores the importance of addressing soil, water, and air pollution in India to mitigate their effects on public health.

The global nature of environmental pollution means that countries like India, with extensive agricultural activity and industrial growth, are increasingly vulnerable to the cross-border effects of soil and water contamination. The impact of heavy metals, pesticides, and airborne pollutants on human health underscores the need for stricter regulations and policies aimed at reducing pollution and ensuring public health protection in India [6].

IMPACT OF NANO- AND MICROPLASTIC CONTAMINATION ON WATER, AIR, AND SOIL

The rapid rise in plastic production, from 2.3 million tons in 1950 to 448 million tons by 2015, reflects the global scale of plastic usage and waste. As production is expected to double by 2050, the environmental impact becomes increasingly dire, especially in countries like India, where industrialization and urbanization are rapidly increasing. Plastic waste, especially nano- and microplastics, has become a major environmental concern. It is estimated that every year, around 8 million tons of plastic waste enter the oceans from coastal nations, equating to five garbage bags of waste for every meter of coastline

worldwide. India, with its vast coastline of about 7,500 km, is one of the nations most affected by this plastic influx, particularly in coastal cities like Mumbai, Chennai, and Kolkata [7].

In India, improper waste management systems and lack of efficient recycling infrastructure exacerbate plastic pollution. In addition to conventional plastic waste, emerging sources of pollution, such as tire-wear particles, microplastics from synthetic carpets, and clothing fibers, contribute significantly to environmental degradation. These microplastics often originate from household products and industrial activities, including textile manufacturing, which is a major industry in India. As these particles degrade, they can find their way into the air, soil, and water bodies, posing significant health risks.

The transfer of nano- and microplastic particles from polluted seawater and soil into the atmosphere is another growing concern. In India, the urban air quality is already a critical issue, with cities like Delhi and Mumbai experiencing hazardous levels of air pollution. These airborne plastic particles are now becoming a significant component of household air pollution, particularly from synthetic products like carpets, clothing, and industrial by-products. With India being one of the world's largest producers and consumers of textiles, the contribution of microplastics from clothing and carpets is substantial [8].

The health implications of nano- and microplastic pollution are far-reaching. Studies have shown that these small plastic particles can enter the human body through inhalation, ingestion, and skin contact, leading to various health problems such as respiratory disorders, cardiovascular diseases, and potential neurotoxicity. In a country like India, where air pollution is already a major public health issue, the presence of microplastics in the air exacerbates the risk, especially for vulnerable populations, including children, the elderly, and those with pre-existing health conditions [9] [10].

Additionally, these particles accumulate in water bodies, which, in India, often suffer from contamination due to industrial discharge and improper waste disposal. Rivers like the Ganga and Yamuna, as well as numerous smaller rivers and lakes, are significantly polluted by plastics, including microplastics, which pose threats to aquatic life and can enter the food chain, impacting human health [11].

Addressing the issue of nano- and microplastic contamination in India requires a multifaceted approach. This includes improving waste management systems, increasing awareness about the dangers of plastic pollution, and encouraging the use of alternatives to plastics, particularly in the textile and automotive industries. Strict regulatory measures to monitor and reduce plastic production, use, and disposal are necessary to curb the increasing levels of pollution. Additionally, research into the effects of microplastics on human health, especially in urban and industrial areas in India, will be crucial to understanding the full extent of the impact and formulating effective public health interventions [12].

In conclusion, while plastic pollution is a global issue, its effects are particularly pronounced in rapidly developing countries like India, where industrial growth and population density create a perfect storm for environmental contamination. Addressing the health risks posed by nano- and microplastics will require coordinated efforts between government, industry, and the public to mitigate further damage to the environment and public health [13] [14].

IMPACTS OF DEFORESTATION ON SOIL HEALTH AND ECOSYSTEM SERVICES

Tropical forests play a crucial role in maintaining soil health, with long-term soil-vegetation feedbacks that provide vital ecosystem services. However, deforestation, which was occurring at an alarming rate of 5.5 million hectares annually between 2010 and 2015, has a significant impact on soil properties and functions. When forests are cleared, the soil undergoes substantial changes that can persist for decades, affecting both the topsoil and deeper subsoil layers. These changes disrupt essential functions such as nutrient cycling, carbon storage, greenhouse gas emissions, erosion resistance, and water storage, drainage, and filtration [15] [16] .

Reforestation efforts in tropical regions aim to reverse some of the effects of deforestation, particularly in the topsoil. However, these restoration processes can take decades, and even after reforestation, the soil properties may still differ from those found in undisturbed natural

forests. Additionally, better management of soil organic matter in land areas that have been converted for other uses can help mitigate the negative ecological impacts of deforestation on soil health.

This highlights the critical role of soil science not only in understanding the processes of deforestation and reforestation but also in the development of policies and incentives that can help reduce deforestation and improve soil management for long-term sustainability [17] [18].

Conclusion

The growing pollution of air, water, and soil, particularly in developing nations like India, poses severe threats to human health and ecosystems. Soil, often neglected in discussions of environmental health, plays a fundamental role in food production, carbon sequestration, and ecosystem services. However, pollution from heavy metals, pesticides, and plastics has compromised its ability to support life, leading to a range of adverse health outcomes, including cardiovascular diseases, cancers, and respiratory issues.

In India, industrial activities, improper waste disposal, and intensive agricultural practices have significantly contributed to the contamination of soil and water. Heavy metals like arsenic, cadmium, and lead, along with pesticide residues, are prevalent in various regions, posing serious risks to public health, especially among agricultural workers and communities that rely on contaminated water sources. Moreover, the increasing presence of microplastics in water, air, and soil further exacerbates health problems, from respiratory conditions to potential neurotoxic effects.

Deforestation also contributes to soil degradation, altering its structure and functionality, with lasting consequences on nutrient cycling, carbon storage, and water management. While reforestation and soil management practices can mitigate some of these impacts, the recovery process is slow and cannot completely reverse the damage caused by deforestation.

To address these pressing issues, a multi-pronged approach is required, combining stricter pollution control regulations, improved waste management infrastructure, and better agricultural practices. Public awareness campaigns, along with technological advancements in waste disposal and recycling, are vital to curbing pollution. Furthermore, there is an urgent need for research into the long-term health effects of soil, water, and air contamination, especially in relation to emerging pollutants like microplastics.

Ultimately, reducing pollution in all its forms is essential for safeguarding human health and the environment. It requires coordinated efforts across governments, industries, and communities to create a sustainable future. Effective policies, incentivizing the protection and restoration of soil and ecosystems, are key to ensuring a healthier planet for future generations.

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