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Effects and remediation of heavy metals contamination in soil and vegetables from different areas: A review

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Abstract

Heavy metals are non-biodegradable and thus persist in the environment, potentially infiltrating the food chain via crop plants and accumulating in the human body through biomagnification. Due to their toxic nature, heavy metal poisoning poses a severe threat to human health and the environment. Consuming vegetables contaminated with heavy metals can lead to increased accumulation of these metals in the human body. This review discusses the risks of heavy metal contamination in various areas, as reported in some research studies, and the implications for human health.

Data obtained from several journals indicated that levels of lead (Pb) and cadmium (Cd)

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in vegetables were generally within permissible limits, though cadmium concentrations were found to be low in some studies. High concentrations of lead (Pb) can affect metabolic functions, growth, and photosynthetic activities. Cadmium (Cd) levels, which are lower than the permissible limit of 0.2 mg kg^{-1} set by WHO, can lead to chromosomal aberrations and sister chromatid exchanges in cells. Zinc (Zn) levels were within permissible limits except in lettuce and spinach in some findings. Low zinc content in vegetables impacts human health, plant health, and agricultural productivity. Addressing zinc deficiency requires integrated approaches such as soil management, crop biofortification, and dietary diversification. Ensuring adequate zinc levels is essential for improving public health and achieving sustainable agricultural practices.

Addressing heavy metal contamination in vegetables requires a combination of remediation and preventive strategies. Implementing soil and water management practices can mitigate these risks and ensure the safe production of vegetables.

Introduction

The polluted water absorbed by various vegetables during the agricultural process results in the vegetables becoming contaminated, which are then consumed by humans and other animals. Once these contaminated vegetables are ingested, the heavy metal contents exhibit poisonous effects on the body. Heavy metals like lead, cadmium, manganese, and arsenic can enter the body through the gastrointestinal system when affected vegetables are consumed. The bulk of bodily heavy metals are transferred from the blood to tissues (Sankhla *et al.* [1]). Cadmium first binds to blood cells and albumin, then to metallothionein in the kidneys and liver. It is later carried through the blood to the lungs. Manganese vapor disperses over the lung membrane to the central nervous system (CNS). Water-soluble inorganic manganese ions are dispersed in the plasma and the kidneys for renal removal, while fat-soluble manganese salts are diffused in the colon for fecal removal. Arsenic accumulates in the heart, lungs, liver, kidneys, muscles, neural tissues, skin, nails, and hair, passing through the circulation.

According to Järup [2], heavy metals are defined as those metals with a specific density greater than 5 g/cm^3 that negatively impact both the environment and living organisms. While these metals are needed in extremely low concentrations for various physiological and biochemical processes, they become harmful when these quantities are exceeded. Despite the known long-term negative health impacts of heavy metal exposure, it continues to occur and worsen in many regions of the world. Common heavy metals present in wastewater include arsenic, copper, cadmium, chromium, lead, nickel, and zinc, all of which are highly toxic and pose potential risks to human health and the environment (Lambert *et al.* [3]).

Soil is a natural resource that constitutes the Earth's outermost layer. It is composed of minerals, organic matter, water, and air, and it promotes plant life by supplying nutrients, water, and a substrate for root growth. Understanding and protecting soil health is critical for environmental sustainability, agricultural output, and climate change mitigation. Soil is vital for the environment as it supports plant development, water filtration, carbon sequestration, and provides habitat for numerous organisms. Soil is classified based on its primary particle size, which can be sandy, clay, silty, or loam. Soil properties include texture, structure, pH, and fertility.

Heavy metals in soil are metals or metalloids that can be toxic to plants, animals, and humans in large amounts. Lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), and nickel (Ni) are some of the heavy metals present in soil. In agricultural and urban soils, heavy metal contamination is caused by various human activities. Contamination from a single dominant source, such as a metal smelter, can significantly impact soils, plants, and potentially the health of the local population, especially in countries with lax emission controls and soil quality standards. Industrial soils can contain a variety of heavy metal contaminants, depending on the industry, raw materials, and products.

Following the industrial and agricultural revolutions, chemicals became widely used to boost production in various fields. This was supported by a sharp increase in demand for goods and services due to rapid population growth. Furthermore, rising population expansion has driven up the demand for industrial resources. High industrial productivity has also been linked to increased levels of effluents, including heavy metals and other pollutants. This has significantly impacted many receiving environments and their valuable resources. As a result, environmental contamination by heavy metals has continuously degraded the ecosystem, diminishing its ability to support life and rendering its intrinsic values useless (Masindi [4], Mavhungu *et al.* [5]).

Healthy Soil as the Foundation of Productive and Sustainable Agriculture

Healthy soil is the foundation of productive, sustainable agriculture. Maintaining soil health is essential for achieving agricultural productivity and sustainability, requiring a balanced supply of essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients. These nutrients are vital for plant growth and development. Good soil structure enhances aeration and water infiltration, allowing roots to penetrate deeply and access water and nutrients. It also helps prevent soil compaction, which can restrict root growth and reduce the efficiency of water and nutrient uptake. Healthy soil maintains an optimal balance of water retention and drainage.

Disease Suppression of Healthy Soil

Healthy soil supports a diverse community of microorganisms that help suppress soil-borne diseases. Beneficial microbes outcompete harmful pathogens for resources and can produce natural antibiotics, reducing the need for chemical pesticides.

Healthy soil is indispensable for productive, sustainable agriculture. It ensures that crops receive the necessary nutrients, water, and support to grow optimally, leading to high yields and quality produce. By adopting practices that enhance soil health, farmers can build resilient agricultural systems that support long-term productivity and environmental stewardship. Maintaining soil health is crucial not only for current agricultural productivity but also for the sustainability of food systems for future generations.

Soil pollution is a major environmental concern with severe consequences for ecosystems, human health, and agricultural productivity. It disrupts the delicate balance of ecosystems, kills soil microorganisms, plants, and animals, and leads to the loss of biodiversity and ecosystem services. Exposure to heavy metals is dangerous to human health and the environment. Addressing soil contamination is essential to safeguard these critical areas.

The present study was conducted as a preliminary investigation into vegetable and soil pollution in industrial areas. The aim of this review is to investigate the effect of heavy metals in the soil and vegetables based on findings from five different reputable research journals. It seeks to identify the heavy metals present in vegetables and soil, investigate the effects of these metals on humans and the environment, and state the permissible limits of these heavy metals.

Heavy Metals in Vegetables

The concentration of heavy metals in the edible parts of vegetables was investigated, and the results found that the bioaccumulation of metals in all the vegetables is not similar. The health risk to humans from the consumption of vegetables may be due to heavy metal uptake from contaminated soils via plant roots, as well as the direct deposition of contaminants from the atmosphere onto plant surfaces (McBride [6]). Dietary intake is the main route of exposure to heavy metals for most people (Tripathi *et al.* [7]). Information about the concentration of heavy metals in different types of vegetables and their dietary intake is very important for assessing their risk to human health. Heavy metals in the nutrient cycle have seriously threatened health and environmental integrity; therefore, the problem of heavy metal contamination in vegetables requires detailed study to develop central strategies.

In Challawa, irrigation relies on river water flowing through Challawa Goje Dam, which accumulates industrial sewage from nearby industries. The crops grown are predominantly consumed by local residents. While industrialization advances development and improves living conditions, many industries discharge waste materials into the environment, polluting aquatic bodies, soil, and air (Adam *et al.* [8]). Using industrial wastewater for irrigation can have detrimental effects not only on plants and animals but also on human health. Consuming fruits and vegetables contaminated with heavy metals can lead to various short-term and long-term diseases. For instance, lead (Pb) exposure can impair the intellectual development of children, increase blood lead levels, and contribute to hypertension and cardiovascular disease (Ekong *et al.* [9]).

Heavy metal contamination in soil is a critical environmental issue with significant implications for human health, agriculture, and ecosystem stability. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), and nickel (Ni) are particularly concerning due to their toxicity and persistence in the environment. These metals enter the soil through both natural and anthropogenic processes. Natural sources include weathering of rocks and volcanic activity, while anthropogenic sources are more widespread and impactful, including mining, smelting, and various manufacturing processes (Jung and Thornton [10]).

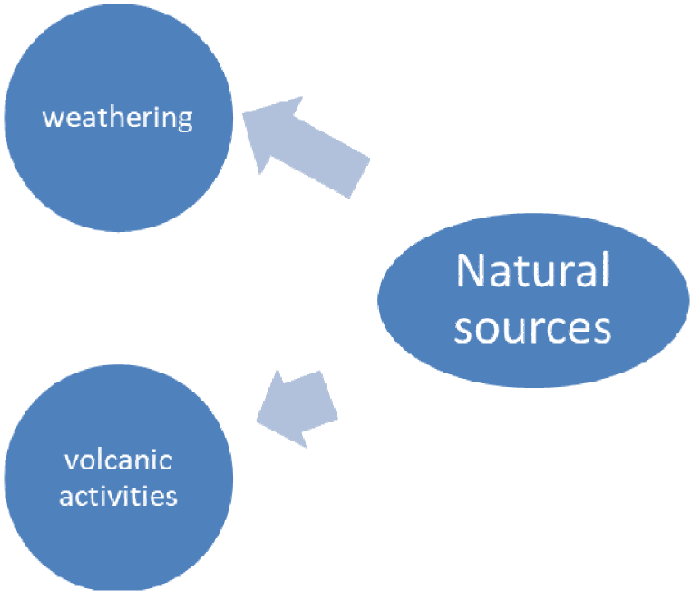

Figure 1. Natural source of soil contamination.

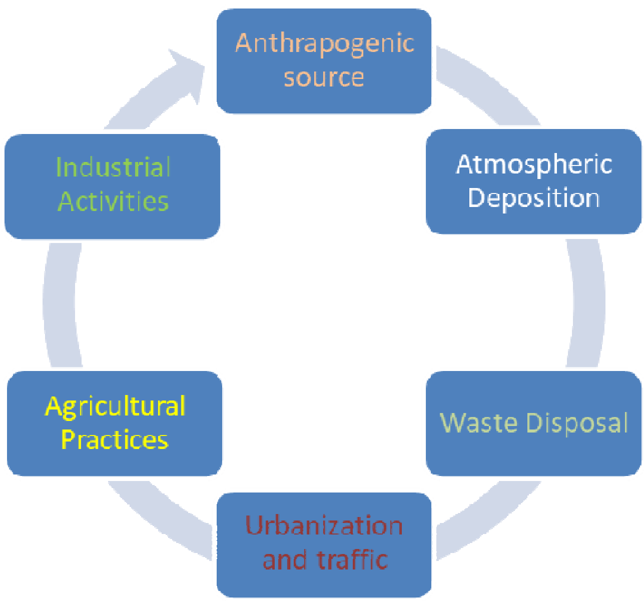

Figure 2. Anthropogenic source of soil contamination.

In agricultural practices, the use of phosphate fertilizers, sewage sludge, and pesticides contributes to heavy metal accumulation in soils. Studies have shown elevated levels of Cd and Zn in soils treated with sewage sludge (McBride [6]). Urbanization and traffic, such as emissions from vehicles, construction activities, and improper waste disposal, are significant urban sources of heavy metals, particularly Pb and Cd (Jaradat *et al.* [10]). Assessing soil contamination involves determining the concentration and bioavailability of heavy metals. Soil Sampling and Analysis: Standard methods involve collecting soil samples and analyzing them using techniques like atomic absorption spectroscopy (AAS), inductively coupled plasma mass spectrometry (ICP-MS), and X-ray fluorescence (XRF) (Alloway [11]). Bioavailability Assessments: Understanding the bioavailability of heavy metals is crucial for assessing their potential impact. Techniques such as sequential extraction procedures help determine the fraction of metals available for uptake by plants and microorganisms (Tessier *et al.* [12]). Risk Assessment Model. Models like the Hazard Quotient (HQ) and Total Environmental Risk Index (TERI) are used to evaluate the potential risks to human health and the environment (USEPA [13]). Heavy metal contamination of soils is a pervasive issue with serious implications for environmental and human health. Research has identified various sources of contamination, from industrial activities to agricultural practices, and has elucidated the complex effects of heavy metals on soil health, plant growth, and human well-being. Assessment methods and remediation strategies continue to evolve, offering hope for mitigating the impacts of heavy metal pollution. Continued interdisciplinary research and innovative approaches are essential to effectively address this ongoing environmental challenge.

The scientific community's growing attention to addressing heavy metal pollution in soils has spurred promising advancements in remediation technologies. Researchers are increasingly focusing on cost-effective and sustainable solutions, aiming to restore contaminated soils and enhance environmental health and food security. Continued innovation, supported by effective policies and public engagement, will be essential in translating these advancements into practical, large-scale applications.

Phytoremediation, contaminant immobilization, and soil washing are among the widely recognized approaches known for effectively restoring metal-polluted sites (Wuana and Okieimen [14]). Despite their affordability and environmental friendliness, these technologies are primarily applied in developed countries due to limited awareness and knowledge in developing regions. To mitigate risks associated with polluted soils, enhance food security, address land tenure issues, and promote agricultural use of contaminated lands in developing countries, there is a critical need for accessible, cost-effective, and sustainable remediation techniques.

Table 1. Heavy metals concentrations in vegetables according to different findings.

Vegetable	Heavy Metals mg kg^{-1}			References
	Zn	Cd	Pb	
Onion	20.80	0.93	3.50	Huang *et al*. [21]
Spinach	35.54	4.02	2.88	Huang *et al*. [21]
Lettuce	6.14	0.0004	0.17	Edogbo *et al*. [16]
Onion	11.7	2.81	0.14	Edogbo *et al*. [16]
Spinach	0.03	0.21	0.07	Hammed *et al*. [17]
Lettuce	4.17	0.11	0.08	Ali *et al*. [15]
Onion	1.00	0.007	0.009	Hodișan *et al*. [18]
Spinach	4.16	10.00	0.001	Wright *et al*. [19]
Lettuce	28.78-38.53	0.24-0.30	0.53-0.94	Najmi *et al*. [20]
	20-100	**0.50-30**	**0.01-2.4**	**WHO**

Discussion

Based on the results presented in Table 1, the concentrations of Lead (Pb), Zinc (Zn), and Cadmium (Cd) in spinach, lettuce, and spring onion were examined. The levels of lead in each sample were within permissible limits, except in two studies by Huang *et al*. [21], which reported higher concentrations. Elevated lead concentrations in primary producers can impact metabolic functions, growth, and photosynthetic activities.

The concentrations of cadmium, as reported by Edogbo [16] for lettuce, Hammed *et al*. [17] for spinach, and Edogbo *et al*. [16] for onion, were found to be below permissible levels. However, even low levels of cadmium can lead to chromosomal aberrations and sister chromatids in cells, underscoring the importance of understanding cadmium contamination pathways for effective mitigation strategies.

Zinc levels were generally below permissible limits, except in studies by Hong *et al.* [21] for onion and spinach reported by Edogbo *et al.* [16], as well as lettuce in the research by Najmi *et al.* [20]. Low zinc content in vegetables has significant implications for human health, plant health, and agricultural productivity. Addressing zinc deficiency requires integrated approaches such as soil management, crop biofortification, and dietary diversification. Ensuring adequate zinc levels in vegetables is crucial for improving public health and achieving sustainable agricultural practices.

Conclusion

From the results reparented in Figure 1: indicate that Zinc (Zn) has the higher value than cadmium (Cd) and lead (pb). This indicates the bioaccumulation value of heavy metals in the onion, spinach and onion in the descending order (Zn<Cd<Pb). Food poisonings may have their roots in the presence of these metals in plants from different locations. Heavy metals present significant health hazards. However, it is not advisable to dispose chemicals from industrial sludge, or effluents close to urban agricultural regions

Based on the results presented in Figure 1, Zinc (Zn) exhibited higher concentrations compared to Cadmium (Cd) and Lead (Pb) in onion, spinach, and lettuce, indicating a bioaccumulation pattern of heavy metals in the order of Zn < Cd < Pb. The presence of these metals in plants from various locations underscores the potential risk of food poisoning associated with heavy metal contamination.

Heavy metals pose significant health hazards. Therefore, it is crucial to avoid disposing of chemicals from industrial sludge or effluents near urban agricultural areas.

Recommendation

Adopting a holistic strategy that integrates safe agricultural practices, regulatory compliance, and effective land and water management is essential. By implementing these recommendations, we can significantly mitigate the risk of heavy metal contamination in vegetables. This approach not only safeguards human health but also promotes sustainable agricultural practices and protects the environment for future generations.

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