Journal of Health and Rehabilitation Research 2791-156X JHRR

For contributions to JHRR, contact at email: editor@jhrlmc.com

Narrative Review

Soil Contamination and Human Health: Exploring the Heavy Metal Landscape: A Comprehensive Review

Muhammad Zaib[1*], Ali Zeeshan[2], Humaira Akram[2], Sunila Hameed[2], Ammara Wakeel[2], Samreen Qasim[2], Saira Aslam[2]

[1]University of Sargodha, Sargodha

[2]University of Veterinary and Animal Sciences, Lahore

[*]*Corresponding Author: Muhammad Zaib; Email: zaibch767@gmail.com*

Conflict of Interest: None.

Zaib M., et al. (2023). 3(2): 351-356. DOI: 10.61919/jhrr.v3i2.123

ABSTRACT

Background: Composting, a cost-effective and efficient method for managing solid waste rich in organic matter, faces challenges when contaminants, particularly heavy metals, are present. These contaminants can significantly impact various environmental aspects and human health.

Objective: This study aims to provide a comprehensive review of the effects of heavy metal contamination in compost, focusing on its impact on soil quality, plant growth, aquatic ecosystems, and human health.

Methods: An extensive examination of current literature was conducted to analyze the consequences of heavy metal presence in compost. This involved reviewing studies on soil microbial activity, plant health, the accumulation of metals in the food chain, and the resultant effects on animal and human health, as well as on aquatic systems.

Results: Elevated levels of heavy metals in compost were found to be toxic to soil microorganisms, vital for numerous soil processes, leading to a reduction in their abundance and functionality. Plants exposed to these metals showed disrupted physiological processes and compromised growth. The absorption of heavy metals by plants leads to their entry into the food chain, posing risks to animal and human health. In aquatic environments, these contaminants contribute to oxidative stress, negatively affecting aquatic life.

Conclusion: The presence of heavy metals in compost presents significant environmental and health risks. It is crucial to ensure the absence of such contaminants in compost intended for agricultural use. This study underscores the need for sustainable waste management practices and stringent monitoring of compost quality to safeguard environmental health and human well-being.

Keywords: Heavy metals, Compost contamination, Soil health, Plant growth, Food chain, Aquatic ecosystems, Human health, Environmental impact.

INTRODUCTION

Composting, facilitated by aerobic microorganisms, represents an advanced approach to organic waste management. This process encompasses three distinct phases: the mesophilic phase, the thermophilic phase, and the cooling phase, also known as the compost stabilization stage (1). During these phases, organic waste undergoes a series of transformations, fostering a biological environment conducive to the efficient breakdown of materials. This culminates in the production of nutrient-rich compost, a process capable of reducing solid waste volume by an impressive 40-50% (2). The thermophilic phase plays a crucial role in pathogen elimination through metabolic heat generation, while also facilitating the decomposition of a significant proportion of hazardous organic pollutants. The resulting product is an environmentally friendly soil amendment or fertilizer (3). However, elevated levels of heavy metals in the final compost can undermine soil stability and resilience, impacting soil chemistry, physics, and biology, and thereby affecting plant growth and development (4).

Heavy metals, including copper, nickel, cadmium, zinc, chromium, and lead, pose significant environmental challenges due to their diverse nature (5). While some metals like iron, zinc, calcium, and magnesium are essential for human physiology, others like arsenic, cadmium, lead, and methylated mercury are non-essential and potentially toxic even at low concentrations (6). The presence of heavy metals in soil can disrupt the complex and dynamic ecosystems of soil microorganisms, affecting microbial diversity, population size, and overall activity levels (7). Lead (Pb) contamination, for example, can adversely affect soil productivity and plant physiological functions (8). The absorption of heavy metals by plants is a crucial factor in the transmission of these contaminants through the food chain, posing significant health risks (9). Agricultural runoff containing heavy metals also threatens aquatic ecosystems (10).

Effects of Heavy Metals

Human Health

The accumulation of heavy metals in plants from contaminated soil presents significant health risks. Cadmium (Cd) toxicity, for instance, affects vital organs and can lead to diseases such as cardiac failure and cancer (9, 10, 32, 33). Excessive zinc consumption can cause systemic dysfunctions and growth impediments (34). Copper (Cu), essential for physiological functions, can induce severe health issues when ingested in high amounts (35). Nickel (Ni) exposure can result in skin irritation, respiratory issues, and even cancer in certain contexts (6). Lead (Pb) exposure can cause dysfunction in multiple organ systems and is particularly harmful to the central and peripheral nervous systems (36). Chromium (Cr), especially in its hexavalent form, is a potent carcinogen (38, 40). Mercury, with no known function in human biochemistry, can cause severe neurological and gastrointestinal disorders (6). Arsenic toxicity can lead to fatal outcomes and mimic autoimmune disorders like Guillain-Barre syndrome (6).

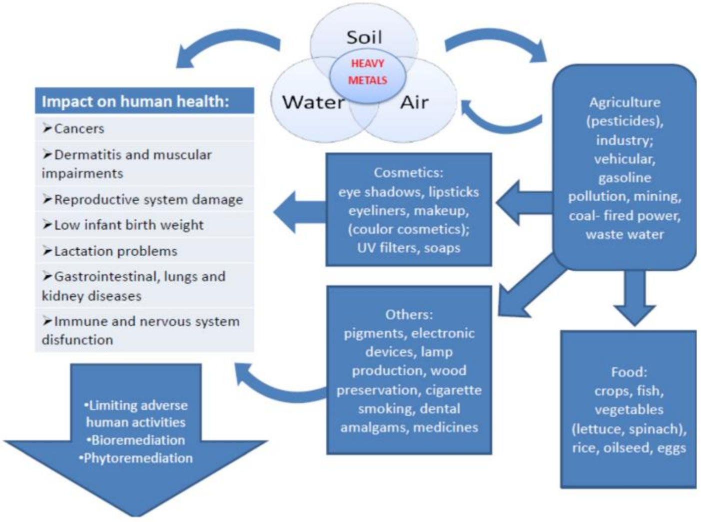

Figure 1 Illustrates the various routes of exposure to toxic metals, the negative impact they have on human health, and ways to limit the risk caused by contact with these elements (indicated by the large arrow on the left). The adverse effects of toxic metals can occur due to direct exposure to them in the environment or indirectly due to human activity.

Soil

Soil contamination by heavy metals is a critical issue globally, particularly in industrialized regions where human activities significantly contribute to metal pollution (11). These contaminants not only compromise plant growth in terms of quality and quantity but also induce profound changes in soil microbial communities' size, composition, and activity (12). Heavy metals, including copper (Cu), nickel (Ni), cadmium (Cd), zinc (Zn), chromium (Cr), and lead (Pb), are key agents of soil pollution, each exhibiting unique distribution patterns and ecological impacts (11). Studies have elucidated the detrimental effects of heavy metals on soil's biological and biochemical attributes, underscoring the complex interactions between these metals and soil components. Soil properties such as organic matter content, clay composition, and pH levels significantly influence the extent of metal impacts on the soil ecosystem (13). Understanding these interactions is essential in formulating effective strategies for soil pollution mitigation and remediation, vital for preserving soil health, biodiversity, and agricultural productivity in the context of escalating global industrialization.

The introduction of heavy metals into soil ecosystems significantly alters enzymatic dynamics by disrupting microbial communities responsible for enzyme production. This leads to a disturbance in vital microbial processes and a decrease in the abundance and functionality of soil microorganisms (14, 15, 16). Chromium, for instance, exists in soil in two forms: Cr (III) and Cr (VI), with Cr (VI) being highly toxic and detrimental to soil microbial populations (7, 14, 18). The impact of heavy metals on soil microbial communities and enzyme activities is diverse, with different metals affecting enzyme activities in varying degrees. For instance, cadmium (Cd) shows higher toxicity to enzymes compared to lead (Pb) (14). This table summarizes these impacts, providing a detailed understanding of the complex effects of heavy metal pollution on soil ecosystems.

Composting Process

Heavy metals profoundly influence the composting process by altering microbial diversity. Microorganisms, essential for organic matter degradation during composting, are affected by heavy metals in terms of reproductive capacity, morphological characteristics, and physiological functions (41). These metals can inhibit microbial enzymes, disrupting essential enzymatic reactions and metabolic processes (42). For example, higher concentrations of copper (Cu) and zinc (Zn) have been shown to decrease dehydrogenase activity during vermicomposting (43). The oxidative stress induced by heavy metals leads to the generation of reactive oxygen species, further damaging proteins (44). In vermicomposting systems, high levels of Cu and Zn can affect earthworm populations, necessitating careful monitoring (43). This table outlines the varied impacts of heavy metals, especially lead

(Pb), copper (Cu), and zinc (Zn), on microbial diversity and composting processes, emphasizing the critical need for vigilant monitoring in sustainable composting practices.

Plants

Figure 2 Diagrammatic explanation about heavy metals in the environment

In the context of plants, heavy metals like lead (Pb), cadmium (Cd), arsenic (As), selenium (Se), and mercury (Hg) are non-essential and potentially harmful (9). Conversely, elements such as manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), nickel (Ni), cobalt (Co), and molybdenum (Mo) are vital for plant growth but can become toxic when present in excessive concentrations. The use of compost in agriculture requires careful consideration of these elements, especially in vegetable cultivation where there is a direct path for heavy metal transfer to humans (9). The absorption and accumulation of heavy metals in plants vary with environmental factors, as demonstrated in studies on Beta vulgaris (Spinach), where seasonal variations influenced the uptake of various metals (21, 22). This complex accumulation process depends on plant species and environmental conditions, affecting essential physiological functions and potentially leading to reduced plant growth, chlorosis, and other adverse effects (7, 8, 10, 23). Heavy metal stress in plants typically inhibits growth, with essential elements showing a Gaussian curve of tolerance and non-essential elements displaying a plateau-like phase (Figure 2).

Aquatic Environment

Heavy metals in aquatic environments pose significant threats to marine organisms due to their enduring nature and capacity to induce oxidative stress (24).

Table 1 Impact of Heavy Metals on Microbial Diversity and Composting Processes.

Heavy Metal	Effect on Microorganisms and Composting Processes
General Impact	Heavy metals have a profound influence on composting by altering microbial diversity, impacting the degradation of organic matter, and modifying heavy metal mobility for plants. Their presence impedes microbial enzymes, hindering enzymatic reactions and complex metabolic processes (41).
Phosphatase Synthesis	The synthesis of phosphatase, crucial in composting, is diminished in the presence of heavy metals, affecting organic matter degradation (42).
Lead (Pb)	Toxic lead in Pb-contaminated substrates suppresses microbial growth and activity, posing challenges to microorganisms during composting (41).
Copper (Cu) and Zinc (Zn)	Cu and Zn influence dehydrogenase and protease activity during vermicomposting. Higher Cu and Zn dosages result in decreased dehydrogenase activity, impacting the composting process (43).
Enzyme Deactivation	Heavy metals can deactivate enzyme reactions through complexation with the substrate, reacting with protein-active enzyme groups, or interacting with the enzyme-substrate complex, hindering microbial processes (41).
Oxidative Damage	Copper and cadmium induce oxidative damage to proteins during composting by triggering oxidative stress and generating reactive oxygen species like hydroxyl or superoxide radicals (44).
Impact on Vermicomposting	Elevated Cu and Zn levels impact vermicomposting systems, accumulating in worm tissue and reducing juvenile production. Monitoring Cu and Zn levels is crucial for maintaining a healthy earthworm population in vermicomposting with Eisenia fetida earthworm (43).

These metals resist bacterial degradation, thus persisting in marine ecosystems (24). Heavy metal contamination in rivers disrupts aquatic biodiversity and increases overall pollution levels (25). Metals bind with particulate matter in water, settling into sediments and affecting organisms like aquatic macrophytes (26). Even in areas where water quality criteria are met, metal contamination can still degrade the environment (27). Diatom communities in rivers are particularly sensitive to micropollutant levels (28, 29).

The accumulation of heavy metals in fish and their subsequent movement up the food chain raises concerns for human health, especially due to the biomagnification of these contaminants (25). Reactive oxygen species generated by these metals can cause extensive damage to aquatic organisms, impacting their physiology and ecosystem dynamics (24). Fish, as a primary source of human consumption, are at risk due to their potential heavy metal contamination, with mercury (Hg) being of particular concern (30). Benthic macroinvertebrates, important in lotic food webs, serve as indicators of metal contamination, yet their role in transferring these pollutants through the food chain needs further assessment (31).

CONCLUSION

The utilization of compost enriched with heavy metals poses significant risks to soil health, agricultural productivity, and environmental integrity. The absorption of these metals by plants from contaminated soils disrupts their physiological processes, leading to diminished crop yields and reduced agricultural efficiency. This concern is further magnified by the potential for biomagnification, where heavy metals accumulate in human tissues through the food chain, presenting substantial health risks. The implications of heavy metal contamination extend beyond plant and soil health, influencing human healthcare systems and health policy.

Heavy metals in compost contribute to soil pollution, altering soil's physical, chemical, and biological characteristics. This alteration not only impairs plant growth but also impacts the soil microbial ecosystem, essential for nutrient cycling and soil fertility. The consequences of these changes have far-reaching implications for agricultural practices and policies. To address these challenges, health policies must focus on stringent regulations for compost quality, particularly for agricultural use. This includes the development of guidelines and standards to limit heavy metal content in compost, ensuring it is free from pathogens and toxic elements.

The entry of heavy metals into the food chain through plant uptake is a critical concern for public health. This necessitates a revision in health policies to include regular monitoring of food products for heavy metal contamination, reinforcing the importance of food safety. In healthcare, the emphasis should be on awareness and prevention strategies, educating the public about the risks associated with consuming produce grown in contaminated soils. Health practitioners should be equipped with the knowledge to identify and manage health issues related to heavy metal exposure.

Furthermore, the runoff from agricultural fields contaminated with heavy metals poses a significant threat to aquatic ecosystems. This requires attention in environmental policies, ensuring that agricultural practices do not detrimentally impact aquatic life. Strategies such as buffer zones and the use of phytoremediation plants can be effective in mitigating the transfer of heavy metals from agricultural fields to water bodies. Therefore, the presence of heavy metals in compost has wide-ranging implications, from soil and plant health to human healthcare and environmental policy. Addressing these challenges requires a multi-faceted approach involving stringent regulation of compost quality, increased monitoring of food safety, public health education, and the implementation of environmentally responsible agricultural practices. By adopting these measures, we can ensure the sustainable use of compost in agriculture without compromising the health of ecosystems and the well-being of human populations.

REFERENCES

1. Neklyudov AD, Fedotov GN, Ivankin AN. Intensification of Composting Processes by Aerobic Microorganisms: A Review. Appl Biochem Microbiol. 2008;44(1):6–18.

2. Zorpas AA, Vassilis I, Loizidou M, Grigoropoulou H. Particle Size Effects on Uptake of Heavy Metals from Sewage Sludge Compost Using Natural Zeolite Clinoptilolite. J Colloid Interface Sci. 2002;250:1–4.

3. Cai QY, Mob CH, Wu QT, Zenga QY, Katsoyiannis A. Concentration and speciation of heavy metals in six different sewage sludge-composts. J Hazard Mater. 2007;147:1063–1072.

4. Wong JWC, Selvam A. Speciation of heavy metals during co-composting of sewage sludge with lime. Chemosphere. 2006;63:980–986.

5. Karaca A, Cetin SC, Turgay OC, Kizilkaya R. Effects of Heavy Metals on Soil Enzyme Activities. In: Sherameti I, Varma A, editors. Soil Heavy Metals. Heidelberg: Soil Biology; 2010. p. 237-265.

6. Duruibe JO, Ogwuegbu MOC, Egwurugwu JN. Heavy metal pollution and human biotoxic effects. Int J Phys Sci. 2007;2(5):112-118.

7. Ashraf R, Ali TA. Effect of heavy metals on soil microbial community and mung beans seed germination. Pakistan J Bot. 2007;39(2):629-636.

8. Bhattacharyya P, Chakrabarti K, Chakraborty A, Tripathy S, Powell MA. Fractionation and bioavailability of Pb in municipal solid waste compost and Pb uptake by rice straw and grain under submerged condition in amended soil. Geosci J. 2008;12(1):41–45.

9. Jordao CP, Nascentes CC, Cecon PR, Fontes RLF, Pereira JL. Heavy metal availability in soil amended with composted urban solid wastes. Environ Monit Assess. 2006;112:309–326.

10. Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ Pollut. 2008;152:686-692.

11. Hinojosa MB, Carreira JA, Ruız RG, Dick RP. Soil moisture pre-treatment effects on enzyme activities as indicators of heavy metal-contaminated and reclaimed soils. Soil Biol Biochem. 2004;36:1559–1568.

12. Yao H, Xu J, Huang C. Substrate utilization pattern, biomass and activity of microbial communities in a sequence of heavy metal-polluted paddy soils. Geoderma. 2003;115:139–148.

13. Speir TW, Kettles HA, Percival HJ, Parshotam A. Is soil acidification the cause of biochemical responses when soils are amended with heavy metal salts? Soil Biol Biochem. 1999;31:1953-1961.

14. Shun-hong H, Bing P, Zhi-hui Y, Li-yuan C, Li-cheng Z. Chromium accumulation, microorganism population and enzyme activities in soils around chromium-containing slag heap of steel alloy factory. Trans Nonferrous Met Soc China. 2009;19:241-248.

15. Mora AP, Calvo JJO, Cabrera F, Madejon E. Changes in enzyme activities and microbial biomass after ‘‘in situ’’ remediation of a heavy metal-contaminated soil. Appl Soil Ecol. 2005;28:125–137.

16. Chen GQ, Chen Y, Zeng GM, Zhang JC, Chen YN, Wang L, Zhang WJ. Speciation of Cadmium and Changes in Bacterial Communities in Red Soil Following Application of Cadmium-Polluted Compost. Environ Eng Sci. 2010;27(12):1019-1026.

17. Wang YP, Shi JY, Wang H, Li Q, Chen XC, Chen YX. The influence of soil heavy metals pollution on soil microbial biomass, enzyme activity, and community composition near a copper smelter. Ecotoxicol Environ Saf. 2007;67:75–81.

18. Garnier J, Quantin C, Martins ES, Becquer T. Solid speciation and availability of chromium in ultramafic soils from Niquelandia, Brazil. J Geochem Explor. 2006;88:206–209.

19. Garrido S, Campo GMD, Esteller MV, Vaca R, Lugo J. Heavy metals in soil treated with sewage sludge composting, their effect on yield and uptake of broad bean seeds (Vicia faba L.). Water Air Soil Pollut. 2002;166:303–319.

20. Rascio N, Izzo FN. Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? Plant Sci. 2011;180:169–181.

21. Sprynskyy M, Kosobucki P, Kowalkowski T, Buszewsk B. Influence of clinoptilolite rock on chemical speciation of selected heavy metals in sewage sludge. J Hazard Mater. 2007;149:310–316.

22. Sharma RK, Agrawal M, Marshall F. Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicol Environ Saf. 2007;66:258–266.

23. Guala SD, Vega FA, Covelo EF. The dynamics of heavy metals in plant–soil interactions. Ecol Model. 2010;221:1148–1152.

24. Woo S, Yum S, Park HS, Lee TK, Ryu JC. Effects of heavy metals on antioxidants and stress-responsive gene expression in Javanese medaka (Oryzias javanicus). Comp Biochem Physiol Part C. 2009;149:289–299.

25. Ayandiran TA, Fawole OO, Adewoye SO, Ogundiran MA. Bioconcentration of metals in the body muscle and gut of Clarias gariepinus exposed to sublethal concentrations of soap and detergent effluent. J Cell Anim Biol. 2009;3(8):113-118.

26. Peng K, Luo C, Luo L, Li X, Shen Z. Bioaccumulation of heavy metals by the aquatic plants Potamogeton pectinatus L. and Potamogeton malaianus Miq. and their potential use for contamination indicators and in wastewater treatment. Sci Total Environ. 2008;392:22-29.

27. Gurrieri JT. Distribution of metals in water and sediment and effects on aquatic biota in the upper Stillwater River basin, Montana. J Geochem Explor. 1998;64:83–100.

28. Morin S, Vivas-Nogues M, Duong TT, Boudou A, Coste M, Delmas F. Dynamics of benthic diatom colonization in a cadmium/zinc-polluted river (Riou-Mort, France). Fundam Appl Limnol. 2007;168(2):179–187.

29. Jonge MD, Vijver BV, Blust R, Bervoets L. Responses of aquatic organisms to metal pollution in a lowland river in Flanders: A comparison of diatoms and macroinvertebrates. Sci Total Environ. 2009;407:615-629.

30. Soliman ZI. A Study of Heavy Metals Pollution in Some Aquatic Organisms in Suez Canal in Port-Said Harbour. J Appl Sci Res. 2006;2(10):657-663.

31. Iwasaki Y, Kagaya T, Miyamoto K, Matsuda H. Environmental Effects of Heavy Metals on Riverine Benthic Macroinvertebrate Assemblages With Reference to Potential Food Availability for Drift-Feeding Fishes. Toxicol Chem. 2002;28(2):354–363.

32. Sobha K, Poornima A, Harini P, Veeraiah K. A study on biochemical changes in the fresh water fish, catla catla (hamilton) exposed to the heavy metal toxicant cadmium chloride. Kathmandu Univ J Sci Eng Technol. 2007;1(4):1-11.

33. Lalor GC. Review of cadmium transfers from soil to humans and its health effects in the Jamaican environment. Sci Total Environ. 2008;400:162–172.

34. Stern BR, Solioz M, Krewski D, Aggett P, Aw TC, Baker S, Crump K, Dourson M, Haber L, Hertzberg R, Keen C, Meek B, Rudenko L, Schoeny R, Slob W, Starr T. Copper and human health: biochemistry, genetics, and strategies for modeling dose-response relationships. J Toxicol Environ Health Part B. 2007;10:157–222.

35. Argun ME, Dursun S, Ozdemir C, Karatas M. Heavy metal adsorption by modified oak sawdust: Thermodynamics and kinetics. J Hazard Mater. 2007;141:77–85.

36. Odum HT. Background of Published Studies on Lead and Wetland. In: Odum HT, editor. Heavy Metals in the Environment Using Wetlands for Their Removal. New York, USA: Lewis Publishers; 2000. p. 32.

37. Kazemipour M, Ansari M, Tajrobehkar S, Majdzadeh M, Kermani HR. Removal of lead, cadmium, zinc, and copper from industrial wastewater by carbon developed from walnut, hazelnut, almond, pistachio shell, and apricot stone. J Hazard Mater. 2008;150:322–327.

38. Shaffer RE, Cross JO, Pehrsson SLR, Elam WT. Speciation of chromium in simulated soil samples using X-ray absorption spectroscopy and multivariate calibration. Anal Chim Acta. 2001;442:295–304.

39. Jeyasingh J, Philip L. Bioremediation of chromium contaminated soil: optimization of operating parameters under laboratory conditions. J Hazard Mater B. 2005;118:113–120.

40. Huang S, Peng B, Yang Z, Chai L, Zhou L. Chromium accumulation, microorganism population and enzyme activities in soils around chromium-containing slag heap of steel alloy factory. Trans Nonferrous Met Soc China. 2009;19:241-248.

41. Huang DL, Zeng GM, Feng CL, Hu S, Zhao MH, Lai C, Zhang Y, Jiang XY, Liu HL. Mycelial growth and solid-state fermentation of lignocellulosic waste by white-rot fungus Phanerochaete chrysosporium under lead stress. Chemosphere. 2010;81:1091–1097.

42. García C, Moreno JL, Hernández T, Costa F. Effect of composting on sewage sludges contaminated with heavy metals. Bioresour Technol. 1995;53:13-19.

43. Malley C, Nair J, Ho G. Impact of heavy metals on enzymatic activity of substrate and on composting worms Eisenia fetida. Bioresour Technol. 2006;97:1498–1502.

44. Baldrian P. Interactions of heavy metals with white-rot fungi. Enzyme Microb Technol. 2003;32:78–91.