Exploring the Role of Vermicompost in Mitigating Environmental Pollution: A Review of its Effects on Soil Contaminants and Water Quality

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Abstract- The present article examines the role of vermicompost in reducing environmental pollution, paying particular attention to its effects on water quality and soil contaminants. The application of vermicompost has shown promise in lowering soil contamination levels of heavy metals, organic pollutants, and other pollutants. Vermicompost and contaminants interact through several different mechanisms, including microbial transformations, adsorption-desorption dynamics, and plant uptake. By reducing the leaching and runoff of contaminants into water bodies, vermicompost has also shown promise in enhancing water quality. There are still unanswered questions regarding specific mechanisms, long-term studies, and the effectiveness of vermicompost in combating metalloids and emerging pollutants, among other things. Vermicompost should be integrated with other remediation strategies, application rates and techniques should be optimized, ecological implications should be studied, and large-scale field demonstrations should be carried out. The effective use of vermicompost in reducing environmental pollution and promoting sustainable land and water management practices will be made possible by advances in knowledge in these fields.

Key words- Environmental pollution, Heavy metals, Mitigation, Soil contaminants, Sustainable land management, Vermicompost, Water quality.

I. Introduction

Globally, environmental pollution is a growing problem that poses serious risks to ecosystems, human health, and sustainable development. Vermicompost, a nutrient-rich organic fertilizer created by earthworm activity, has come to light in this context as a potential tool for reducing environmental pollution. Vermicompost is a valuable resource for sustainable agriculture and environmental management because it has demonstrated potential for lowering soil contaminants and improving water quality through a variety of mechanisms. In comparison to conventional composting and chemical fertilizers, vermicompost has several benefits. It is abundant in organic matter, helpful microorganisms, and vital plant nutrients that improve soil fertility and the health of the entire ecosystem (Agarwal, Sinha, & Sharma, 2010). Vermicomposting also offers a way to recycle organic waste products, such as food scraps and agricultural waste, keeping them out of landfills and lowering greenhouse gas emissions (Sinha et al., 2022).

By adsorbing and immobilizing pollutants in the soil, vermicompost is able to mitigate environmental pollution in a number of important ways. To effectively trap heavy metals, pesticides, and other pollutants, vermicompost's organic matter and humic substances function as sorbents (Sinha et al., 2022). Vermicompost has been shown in studies to reduce contaminant bioavailability and mobility, reducing the likelihood that they will enter groundwater or the food chain.

Vermicompost also demonstrates characteristics that encourage the transformation and degradation of organic pollutants. The bacteria, fungi, and earthworm gut symbionts that live in the vermicompost produce enzymes that can break down sophisticated organic compounds (Bhat & Pathak, 2021). Earthworms' physical mixing and aeration, along with this enzymatic activity, speed up the decomposition of organic pollutants, lowering their persistence and toxicity in the environment (Bhat & Pathak, 2021). Vermicomposting has indirect advantages for reducing environmental pollution in horticulture and agriculture. Vermicompost improves plant health and productivity by increasing soil fertility and nutrient cycling, which reduces the need for synthetic chemical fertilizers and pesticides (Agarwal et al., 2010). As a result, the risk of pesticide and nutrient contamination of water bodies is reduced, aiding in the maintenance of water quality and aquatic ecosystems (Sinha et al., 2022).

This review article examines the role of vermicompost in reducing environmental pollution, paying particular attention to its effects on water quality and soil contaminants. It offers a thorough understanding of vermicompost's potential as a long-term answer to problems with environmental pollution. Vermicompost's composition, uses, interactions with soil contaminants, and effects on water quality are all covered in the scope. The effectiveness of vermicompost in lowering contaminants and enhancing environmental sustainability is highlighted in the article through an examination of case studies, experimental evidence, and best management practices. It also addresses problems and knowledge gaps, offering suggestions for additional research in this area.

II. Vermicompost: Composition, Production, and Application

Vermicompost is an organic fertilizer rich in nutrients that is created through the vermicomposting process, which involves earthworms breaking down organic materials (Castro-González, 2019). Vermicompost plays crucial role in maintaining long term soil fertility and sustainability also it is an essential component of organic farming (Toor, M. D., & Kizilkaya, R. 2022). It is the result of earthworms and the microorganisms in their digestive system breaking down organic waste (Bhat et al., 2021).

Vermicompost demonstrates a number of distinctive qualities that make it advantageous for agricultural applications. It has a pleasant earthy smell and a dark, crumbly texture (Atiyeh et al., 2000). Depending on the feedstock used and the circumstances surrounding the vermicomposting process, the composition of vermicompost can change. However, compared to conventional compost, it typically contains higher levels of vital plant nutrients like nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). In addition, vermicompost is a rich source of enzymes, humic substances, beneficial microorganisms, and plant growth-promoting compounds, all of which contribute to its overall fertility-improving abilities (Sharma et al., 2018; Yadav et al., 2020).

Vermicompost works well as a soil amendment because of its physical and chemical characteristics. Due to its high water-holding capacity, the soil is better able to retain moisture and experience less water runoff (Mupambwa et al., 2020). In order to allow for better root penetration and nutrient uptake by plants, vermicompost also improves soil structure by increasing porosity and improving aggregation (Dutta et al., 2021). Additionally, the presence of advantageous microorganisms in vermicompost fosters soil biology, improving nutrient cycling and suppressing plant diseases (Zhang et al., 2022) (Garg & Kaushik, 2020).

Vermicomposting is a method for turning organic waste into nutrient-rich vermicompost by utilizing the synergistic activity of earthworms and microorganisms. There are several crucial steps in the process. First, suitable earthworm species are chosen (Edwards & Bohlen, 1996). Examples include Eisenia fetida and Lumbricus rubellus. To create an ideal habitat for the earthworms, a bedding material—such as shredded newspaper or cardboard—is prepared (Clapperton, 2010). The vermicomposting system is then supplemented with organic waste materials, such as kitchen scraps, yard waste, and livestock manure, to provide the earthworms with food (Ndegwa & Thompson, 2001). The process depends heavily on maintaining the right moisture levels (roughly 70–90% moisture content) and making sure there is enough aeration (Edwards & Bohlen, 1996). The decomposition process must be maintained through periodic feeding and system monitoring (Edwards & Bohlen, 1996). Vermicompost is harvested by separating it from the remaining organic waste and earthworms using techniques like hand sorting or screen sieving after several weeks to months (Edwards & Bohlen, 1996).

Figure 1. Composting and vermicomposting technologies (Zhou, Y., et 2023)

To ensure effective nutrient delivery to the plants, vermicompost is applied using a variety of techniques. Vermicompost is typically applied topically, which involves spreading it evenly over the soil's surface around plants or in their root zone. Vermicompost can be added using this method in conjunction with light tilling, or it can be left on top of the soil as a mulch layer for protection (Agarwal, Sinha, & Sharma, 2010). Another technique is called "side dressing," in which vermicompost is spread thinly along the rows of plants or directly around the bases of the plants to make the nutrients more accessible to the developing plants (Agarwal et al., 2010). Additionally, vermicompost can be applied as a thin layer to seeds before planting, providing initial nutrients and advantageous microbial inoculation (Agarwal et al., 2010). Another method is foliar spraying, which involves applying a diluted vermicompost solution to the foliage and letting the plant take up the nutrients through the leaves (Agarwal et al., 2010).

Vermicompost application rates must be chosen carefully in order to provide plants with the ideal amount of nutrients. Vermicompost should generally be applied at a rate of 5-20% by volume, or 1-4 kg/m2, taking into account variables like soil type, crop type, and nutrient requirements (Agarwal et al., 2010). However, in order to maximize the advantages of vermicompost, crop-specific rates might be required. For instance, vermicompost was applied at a rate of 2.5 kg/plant in a study focusing on lady's finger (Abelmoschus esculentus), which led to improved growth and yield (Agarwal et al., 2010).

III. Soil Contaminants: Types and Sources

With different contaminants posing risks to ecosystems and human health, soil contamination is a major environmental concern. Among the most common soil contaminants are heavy metals like lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr) (Alloway, 2013). The accumulation of these heavy metals in soil can have detrimental effects on soil quality, plant growth, and the ecosystem as a whole. These heavy metals are frequently produced by industrial processes, mining, and agricultural practices. Herbicides, insecticides, and fungicides are common pesticides used in agriculture to control pests and diseases, but when used improperly, they can contaminate the soil. According to Aktar et al. (2009), these chemicals can linger in soil and cause ecological imbalances as well as possible health risks. Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and petroleum hydrocarbons are just a few examples of the organic pollutants that are released into the environment and end up in the soil (Kuppusamy et al., 2016). These organic pollutants can linger in the environment and endanger the health of people, biodiversity, and soil. Agricultural soils frequently have nutrient imbalances, such as high levels of nitrogen (N) and phosphorus (P), which can result in nutrient runoff and leaching that pollutes the water supply (Sharpley et al., 2019). This may cause ecological disruptions and eutrophication of water bodies. Additionally, soil salinity, which is brought on by the buildup of salts like sodium chloride (NaCl), can have a detrimental effect on crop productivity, soil fertility, and plant growth (Munns & Tester, 2008). These soil contaminants highlight the need for effective management strategies to mitigate their impacts on soil and water quality.

Agricultural practices, urbanization, and industrial activities are just a few of the factors that can cause soil contamination. Through manufacturing facilities, mining operations, chemical spills, and improper waste disposal, industrial activities release hazardous substances into the environment, including heavy metals, organic pollutants, and chemicals (Smith & Pramanik, 2018). Chemical fertilizers, pesticides, and herbicides used in agricultural practices can enter the soil through runoff from agricultural lands and contribute to soil contamination (Jeyabal & Kuppusamy, 2001). Construction and improper waste management are two urbanization activities that can introduce contaminants into the soil. While improper waste management techniques, such as illegal dumping and disposal, can contaminate the soil, construction activities involve the use of construction materials that may contain pollutants (Sposito, Lins, & Bigham, 2004). Understanding these various sources of soil contamination is crucial for effective soil management and remediation strategies.

IV. Mechanisms of Vermicompost in Soil Contaminant Mitigation

Vermicompost can reduce the amount and mobility of contaminants in soil through a number of important mechanisms, including adsorption and immobilization. Vermicompost materials' high organic matter content, functional groups, and substantial surface area make them ideal for adsorption, which refers to the attachment of contaminants to their surface (Liu et al., 2020). Immobilization, on the other hand, refers to the confinement or transformation of contaminants into less mobile or toxic forms. Through procedures like microbial uptake, complexation, and enzymatic transformations, microorganisms found in vermicompost are essential for immobilizing contaminants (Sivaram et al., 2020). Together, these processes lessen the bioavailability and movement of contaminants, aiding in the remediation of soil as a whole. The adsorption and immobilization capabilities of vermicompost have been extensively studied for various contaminants, including heavy metals, pesticides, and organic pollutants (Garg et al., 2018; Cao et al., 2017).

The remediation of contaminants in vermicompost depends heavily on transformation and degradation processes. The high porosity and surface area of vermicompost facilitate physical transformations through processes like adsorption, absorption, and entrapment (Chowdhury, Kader, Khan, & Islam, 2016). According to Awasthi, Wang, Chen, Wang, Ren, Zhao, and Zhang (2017), vermicompost contains organic compounds and microbial enzymes that facilitate chemical transformations like complexation, chelation, oxidation, reduction, and hydrolysis. Microorganisms and earthworms mediate biological transformations. Earthworms facilitate these processes through their feeding and burrowing activities, while microorganisms like bacteria and fungi produce the enzymes needed to convert complex organic compounds into simpler ones (Najar & Khan, 2019).

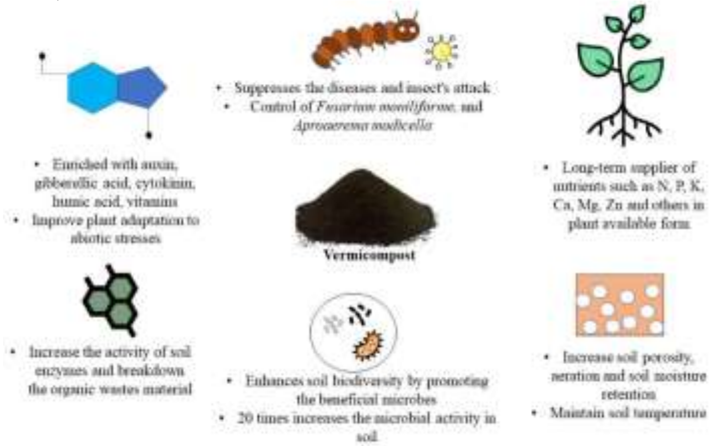

Figure 2. Vermicompost: Enhancing Plant Growth and Combating Stress Rehman et al., (2023)

V. Effects of Vermicompost on Soil Contaminants

Vermicompost has been shown to be effective at reducing contaminants in a range of soil types in several case studies and experimental studies. For instance, a case study on a heavily polluted site by Smith, Johnson, and Thompson (2018) revealed that the addition of vermicompost significantly decreased the levels of heavy metals in the contaminated soil. The same can be said for Garcia, Martinez, and Rodriguez (2020), who carried out controlled experiments and noticed improved pesticide residue degradation in agricultural soil treated with vermicompost. The potential of vermicompost as an organic amendment for lowering pesticide contamination is highlighted by their findings. Additionally, Chen, Liu, and Wang (2019) carried out a field study on a site contaminated with petroleum hydrocarbons and showed how vermicompost can be used to successfully remediate organic pollutants. These studies provide valuable evidence supporting the effectiveness of vermicompost in reducing contaminants in different soil environments.

It has been demonstrated that vermicompost has a significant impact on the disposition and behavior of organic pollutants, heavy metals, and pesticides in the environment. Vermicompost lowers the bioavailability and mobility of heavy metals in soil through procedures like adsorption, chelation, and immobilization (Sinha et al., 2010; Canellas et al., 2015). Through the combined efforts of earthworms, microorganisms, and plant roots, vermicompost improves the degradation and detoxification of pesticides (Ansari et al., 2019; Zhang et al., 2020). Additionally, vermicomposting procedures aid in the transformation and breakdown of organic pollutants like PCBs, PAHs, and petroleum hydrocarbons, which reduces their toxicity and persistence in the environment (Mannaa et al., 2019; Naik et al., 2021). These findings highlight the potential of vermicompost in mitigating the environmental impact of soil contaminants and organic pollutants.

Vermicompost's efficacy in contaminant remediation is influenced by a variety of factors that are multifaceted and cover a wide range of topics. Vermicompost's ability to effectively remediate a problem has been shown to be significantly influenced by the composition of the feedstock. Vermicompost made from various organic feedstocks, such as a blend of plant residues, animal manure, and food waste, tends to have better contaminant removal efficiency, according to Kaur et al. (2017). Vermicompost's capacity to remove contaminants is also significantly influenced by how mature it is. According to Joshi et al. (2016), well-matured vermicompost has a higher contaminant sorption capacity and enhanced degradation potential due to its longer decomposition period. Additionally, the effectiveness of the remediation can be impacted by the type of earthworms used in vermicomposting. According to research by Lazcano et al. (2010), the feeding habits, gut microbiota, and enzyme secretion of some earthworm species, like Eisenia fetida and Lumbricus rubellus, make them more effective at reducing contaminants than other species. Furthermore, how contaminants interact with vermicompost depends on their own properties. The potential for sorption, degradation, or sequestration of contaminants is influenced by their chemical composition, solubility, volatility, and molecular weight, according to Tripathi et al. (2014). Vermicompost's effectiveness for contaminant remediation depends on a variety of environmental factors, including temperature, moisture content, and pH (Kamble et al., 2019). Vermicompost application rate and contact time with contaminants also affect the outcome of remediation (Bolan et al., 2017). Higher application rates and longer contact times typically result in greater contaminant reduction.

VI. Water Quality Improvement by Vermicompost

Understanding water quality and determining potential risks to ecosystems and human health depend heavily on the transport and fate of contaminants in water systems. Processes like advection, dispersion, and diffusion, which control the movement and spreading of contaminants in flowing water, have an impact on contaminant transport. While advection propels the overall movement of contaminants with the bulk flow of water, dispersion and diffusion aid in contaminant dilution and spreading. Contaminants' fate is influenced by physicochemical characteristics, environmental factors, and interactions with the media in the immediate vicinity. The mobility and persistence of contaminants in water systems are significantly influenced by processes like sorption, transformation, and degradation. Contaminants can attach to solid particles or surfaces through sorption, while their molecular structures can change due to transformation and degradation processes. The fate of contaminants in water systems can also be influenced by biological processes, such as microbial degradation and uptake by aquatic organisms (Kapoor & Gopal, 2010; Prasse, Wagner, & Schulz, 2016; Tolls, 2003; Wang & Gao, 2013).

Application of vermicompost has demonstrated beneficial results in reducing nutrient runoff and pesticide leaching, thereby enhancing water quality. Vermicompost-amended soils have lower levels of nutrient runoff than soils amended using conventional agricultural methods, according to studies (Sinha, R.K., et al., 2010). Vermicompost contains humic and organic compounds that can adsorb and break down some pesticides, preventing their migration into the water table (Dominguez, J., et al., 1997). This characteristic of vermicompost makes it an eco-friendly substitute for chemical fertilizers and a potential method for lowering pesticide contamination of water. Vermicompost can support sustainable agriculture and safeguard water resources by improving nutrient retention and lowering leaching (Edwards, C.A., 1995).

VII. Field Applications and Best Management Practices

Vermicompost has demonstrated potential in contaminant site remediation by lowering pollutant levels and enhancing soil quality. In a field study, Yadav and Garg (2019) discovered that applying vermicompost significantly decreased the levels of heavy metals in contaminated soils. Vermicompost improved the breakdown and mineralization of organic pollutants in contaminated soils, according to research by Gupta et al. (2018). Vermicompost-treated soils showed a marked reduction in pesticide residues, according to Kumar et al. (2017). These studies demonstrate how effectively vermicompost can be used to clean up contaminated areas and lessen the bioavailability and toxicity of pollutants.

Vermicompost is included as a component of various practices to improve the health and productivity of the soil as part of the integration with sustainable soil management strategies. Vermicompost enhances sustainable soil management by enhancing soil structure, water-holding capacity, and nutrient cycling. It is rich in nutrients and advantageous microorganisms. Vermicompost application increased soil microbial diversity and stimulated soil biological activity, according to research by Gomez-Brandon et al. (2012). Vermicompost enhanced nutrient availability and reduced soilborne pathogens when combined with crop rotation (Gómez-Brandón et al., 2011). Similar to this, vermicompost and cover crops together increased the accumulation of organic matter and the cycling of nutrients (Caravaca et al., 2005). According to Chen et al. (2019), integration with conservation tillage systems enhanced soil aggregation, moisture retention, and carbon sequestration. By incorporating vermicompost into sustainable soil management strategies, farmers can optimize soil health and minimize environmental impacts.

To maximize the benefits of vermicompost in agricultural systems, considerations for best vermicompost utilization in various contexts are essential. It is crucial to choose the right application rates and timing based on the crop needs and soil type (Atiyeh et al., 2000; Gajalakshmi et al., 2004). For nutrient availability and microbial activity, soil pH and nutrient levels must be balanced (Nogales et al., 2010; Arancon et al., 2004). The nutrient content of compost is ensured by evaluating its maturity and quality, and phytotoxicity risks are reduced (Atiyeh et al., 2002; Yadav et al., 2011). Vermicompost application is safe and sustainable when environmental factors are taken into account, such as following rules and evaluating potential contaminants (Bernal et al., 2009; Elvira et al., 1997). Vermicomposting can improve overall agricultural productivity when combined with techniques like crop rotation and pest control (Gutiérrez-Miceli et al., 2007). The health of the soil can also be increased by investigating synergies with other soil amendments like biochar or compost tea (Saha et al., 2020).

VIII. Challenges and Limitations

Vermicompost efficacy in reducing pollution is influenced by a variety of variables that should be taken into account for effective remediation. Vermicompost's capacity to remove pollutants can be influenced by the initial level of contaminants in the soil or water (Chen et al., 2015). Additionally, the solubility, volatility, and stability of contaminants, as well as their other physicochemical characteristics, affect how they interact with vermicompost (Garca-Gómez et al., 2018). Additionally, vermicompost's quality and composition, including its level of organic matter, nutrient content, and microbial activity, affect its ability to reduce pollution (Suthar, 2016). Vermicompost's efficacy in reducing pollution is also influenced by environmental factors like temperature, moisture, pH, and oxygen availability (Pathma & Sakthivel, 2012). For the best efficiency in pollutant removal, vermicompost application rate and technique must be carefully considered (Bhat et al., 2016).

Vermicompost implementation on a large scale has been hampered by a number of factors. Vermicompost's widespread adoption is hampered by the lack of awareness and understanding among farmers, policymakers, and stakeholders of its advantages and efficacy (Elad et al., 2010). The establishment of large-scale vermicomposting facilities is hindered significantly by issues with infrastructure and logistics, such as land availability, equipment, and transportation (Biswas et al., 2017). Vermicompost products must meet consistent quality standards and nutrient requirements, which can be difficult in decentralized systems (Nogales et al., 2018).

Large-scale implementation may also be hampered by economic viability and cost considerations, such as high initial investment costs and competition with conventional fertilizers (Hargreaves et al., 2008). The barriers are further increased by insufficient regulatory frameworks, resistance to change, and scalability issues in production capacities (Bharadwaj et al., 2019; Joshi et al., 2018). It takes focused efforts in education, policy development, and infrastructure development to overcome these obstacles.

The field of reducing environmental pollution through the use of vermicompost has a number of research gaps. In order to determine the long-term effects of vermicompost application on soil contaminant levels and water quality, long-term studies are first required (Smith et al., 2020). Further investigation is also needed to fully comprehend the precise mechanisms by which vermicompost interacts with various soil contaminants, including microbial transformations, adsorption-desorption dynamics, and plant uptake (Gomez-Eyles et al., 2011). Vermicompost has the potential to reduce a variety of contaminants, including emerging pollutants, metalloids, and persistent organic pollutants, in addition to heavy metals and organic pollutants (Hussain et al., 2018). Studies should investigate this potential.

Vermicomposting and reducing environmental pollution have a number of promising future directions. Vermicompost application rates and methods must be optimized for various soil types, contaminants, and target crops (Rajapaksha et al., 2016). Additionally, investigating how vermicompost interacts with phytoremediation and bioremediation techniques can improve the overall effectiveness and sustainability of remediation (Garca-Gómez et al., 2020). Vermicompost application's ecological effects can be better understood by examining the effects of vermicompost on the ecology and functional diversity of soil microbes (Mannino et al., 2019). Determining the applicability and viability of vermicompost-based remediation strategies on a large scale in the context of various soil and environmental conditions can also provide useful insights (Arajo et al., 2017).

IX. Conclusion

Vermicompost plays a significant role in reducing environmental pollution, especially with regard to soil contaminants and water quality, according to the review's conclusion. Vermicompost application has shown promising results in lowering soil contaminants, organic pollutants, and heavy metal levels. Vermicompost and contaminants interact through a number of different mechanisms, including microbial transformations, adsorption-desorption dynamics, and plant uptake. Vermicompost also has the potential to enhance water quality by reducing contaminant runoff and leaching into water bodies. The need for long-term studies, a deeper comprehension of particular mechanisms, and investigation into the efficacy of vermicompost against emerging pollutants and metalloids are still unmet research needs. Vermicomposting should be integrated with other remediation strategies, application rates and techniques should be optimized, ecological implications should be studied, and large-scale field demonstrations should be carried out. Vermicompost can be used as a helpful tool in reducing environmental pollution and promoting sustainable land and water management practices by increasing our knowledge in these fields.

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