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Role of Earthworms and Radish for the Remediation of Pesticides and Heavy Metals in Contaminated Soil

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Abstract

Soil contamination with pesticides and heavy metals due to excessive agricultural and industrial activities. Moreover, soil contamination has become an increasing environmental and public health concern. Effective remediation strategies are essential to restore soil health, reduce toxicity, and promote sustainable agriculture. The role of earthworms and radish (*Raphanus sativus*) in the phytoremediation of co-contaminated soils, specifically focusing on their abilities to mobilize and accumulate heavy metals and pesticides. Furthermore, earthworms, particularly *Eisenia fetida* and *Pheretima posthuma*, are ecological engineers; their activities enhance soil quality and facilitate the bioavailability of contaminants. Through bioturbation and organic matter processing, earthworms increase the accessibility of heavy metals and pesticides to plants, thus boosting phytoremediation potential. Vermitechnology, including vermicomposting, has significantly reduced metal toxicity, enhanced soil enzyme activity, and promoted

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microbial diversity. Radish plants, known hyperaccumulators, have demonstrated a substantial capacity to absorb metals such as cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As), as well as pesticides like triazophos and chlorpyrifos, with concentrations highest in the roots and shoots. Findings reveal that combined applications of earthworms and phytoremediation plants can improve the efficiency of contaminant uptake. Specifically, *E. fetida* exhibited superior performance in increasing metal and pesticide bioavailability to radish compared to *P. posthuma*. This study suggests that earthworm-assisted phytoremediation using radish is a viable, eco-friendly approach for mitigating soil contamination. Future studies should concentrate on field trials, the influence of different soil kinds, and additional synergistic plant and earthworm species to optimize bioremediation methods.
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Introduction

Heavy metals (HMs) and harmful environmental contaminants seriously threaten ecosystems and human health. Cadmium (Cd), Lead (Pb), chromium (Cr), arsenic (As), and other metals are classified as having a high atomic weight and a density of more than 5 g/cm³. Although certain heavy metals, including manganese (Mn), zinc (Zn), and copper (Cu), are vital for biological functions at very trace levels, excessive concentration in the environment can be detrimental. In agricultural soils, particularly those irrigated with contaminated wastewater, the accumulation of these metals presents a serious challenge to food safety and quality, posing possible health hazards to customers (Verma, 2018). Many anthropogenic activities, such as mining, sewage sludge application, industrial discharge, and excessive use of chemical fertilizers and pesticides, can introduce heavy metals into soil. Because they are not biodegradable, metals remain in the soil and build up over time, adversely affecting its physical, chemical, and biological properties. Studies have indicated that heavy metal contamination can lead to soil acidification, reduced nutrient availability, reduced microbial activity, and changed soil composition, which might negatively affect crop output and plant growth. Furthermore, the transfer of heavy metals presents serious health dangers to humans through the food chains they accumulate in edible parts of plants and enter the human body, leading to several health issues, including neurotoxicity, carcinogenicity, and chronic diseases. In Pakistan, the use of pesticides is widespread, particularly in the agricultural heartland of Punjab, where intensive farming practices have become the norm. The reliance on chemical pesticides to manage pests and diseases has resulted in increased agricultural productivity but has also led to significant environmental and health issues (Naqvi et al., 2024a). The overuse of these chemicals has been linked to acute poisoning incidents or chronic health problems in farming communities, including respiratory issues, skin diseases, and cancer. Pesticide remains have been detected in water, soil, and crops, raising concerns about food safety and environmental sustainability (Kanwal et al., 2024; Ali et al., 2024a; Ali et al., 2024b). Furthermore, the overreliance on pesticides has contributed to the decline of beneficial insect populations, essential for pollination and pest control, ultimately threatening agricultural biodiversity. One potential solution to mitigate the negative impacts of heavy metals and pesticide residues in agricultural soils is mulching. To preserve soil moisture, mulching comes from the German term "molsch," which means easily decomposable involves covering the soil's surface with organic or inorganic materials, regulating temperature, and enhancing soil health. Organic mulches, such as straw, grass clippings, and wood chips, can improve soil structure, boost microbial activity, and encourage the decomposition of organic contaminants, such as pesticide residues. Research has indicated that using organic amendments like straw mulch can significantly enhance microbial diversity and activity in the soil, leading to improved degradation rates of pesticides. A member of the Brassicaceae family, the radish (*Raphanus sativus*) is particularly noteworthy for its potential in phytoremediation an eco-friendly approach to eradicate, transfer, or use plants to stabilize environmental contaminants. Radishes are known for their ability to accumulate heavy metals, particularly cadmium (Cd), manganese (Mn), and zinc (Zn). This characteristic makes them suitable candidates for phytoremediation strategies to rehabilitate contaminated soils. Research has demonstrated that radishes can effectively absorb heavy metals from the soil, reducing their availability for uptake by other crops and potentially lowering the danger of metal buildup in the food chain. Phytoremediation works through several mechanisms, including phytoextraction, where plants absorb and collect heavy metals in their tissues; phytodegradation, in which plants decompose organic pollutants; and phytostabilization, in which plants immobilize pollutants in the rhizosphere, such as pesticides, through metabolic processes. Organic amendments, such as straw mulch, can play a crucial role in enhancing these processes' efficiency by improving soil health and promoting beneficial microbial communities that facilitate pollutant degradation. Insecticides can degrade in soil through various methods, including bioremediation, chemical degradation, and phytoremediation. Microorganisms are used in bioremediation to break down or purify contaminants, while chemical degradation involves the chemical processes that break down substances. Phytoremediation, as mentioned earlier, relies on plants to absorb, accumulate, and transform pollutants. Various studies have highlighted the effectiveness of different plant species in degrading specific pesticides. For instance, certain species of the Brassicaceae family have demonstrated significant potential in degrading pesticides such as chlorpyrifos and parathion due to their metabolic capabilities (Niti, 2013; Eevers et al., 2017). This study aims to investigate the possibilities of mulching to enhance the degradation of pesticides and remediate heavy metals in contaminated soils, with a specific focus on the role of radish as an effective accumulator of contaminants. The interplay between organic amendments and plant species in mitigating the effects of contaminated heavy metals and pesticide residues in agricultural soils is crucial for developing sustainable agriculture practices. Heavy metals and persistent insecticides affect the ecosystem and human health, necessitating the exploration of eco-friendly solutions for soil and water remediation and seriously threatening biodiversity. One promising research avenue involves using earthworms with plants for soil remediation. Earthworms, such as *Lumbricus terrestris* and Eisenia fetida, have shown promise in degrading specific pesticides and remediating heavy metals due to their unique enzymatic activities and gut microbial processes. Earthworms enhance soil structure and aeration and make it easier for nutrients and water to flow, all contributing to healthier soils. Furthermore, the gut microbiota of earthworms can play a vital role in the breakdown of organic pollutants, including pesticides (Sinha et al., 2008; Adie, 2022). The combined use of plants and earthworms offers a viable approach for restoring contaminated soils, as it leverages the strengths of both organisms to enhance pollutant degradation and improve soil health. This synergistic relationship can lead to improved rates of bioremediation and increased resilience of agricultural systems to contamination. Understanding the interactions between plants, earthworms, and microbial communities in contaminated soils is essential for optimizing remediation strategies and promoting sustainable agricultural practices. In conclusion, the challenges posed by heavy metal contamination and pesticide residues in agricultural soils require innovative and sustainable solutions. This research seeks to address these challenges by investigating the potential of mulching with organic amendments to enhance the breakdown of insecticides and make heavy metal remediation easier using radish as a key plant species. The results of this investigation will aid in creating environmentally friendly approaches for managing contaminated soils, ultimately promoting food safety and environmental health.

Pesticide contamination in soil

Insects, weeds, fungi, bacteria, and other organisms that can harm crops, plants, and animals are all considered pests (Rehman et al., 2023; Iftikhar et al., 2024; Naqvi et al., 2024b). Pesticides are chemical compounds that are used to manage and remove these pests. They are frequently employed to safeguard crops, manage unwanted pests, and preserve public health and household members. Pesticides can be divided into groups based on the pests they are intended to control and their chemical makeup. The principal categories are insecticides intended to manage and get rid of insects. Herbicides are used to eradicate or control undesirable plants and weeds. The purpose of fungicides is to treat or prevent fungal diseases that harm plants, crops, and preserved food. Rodenticides manage rodents like rats and mice (Nayak & Solanki, 2021). Because pesticides persist in the ecosystem and permeate it, they accumulate via the food chain and produce more harmful health issues. Lung cancer, renal failure, heart failure, and osteoporosis are among the acute and chronic illnesses that these pollutants can cause in humans (Alengebawy et al., 2021). Although Pakistan has used pesticides extensively to control pests, like other nations, it has started to have environmental issues in the region. Pesticides have been proven to have contaminated groundwater in several areas of Pakistan, and this contamination is ongoing. Numerous pieces of evidence point to the misuse and overuse of pesticides by farmers, especially in the regions that cultivate cotton. According to biological monitoring studies, farmers are more prone to suffer both acute and long-term health effects from pesticide exposure at work. Additionally, cotton pickers and field laborers are at higher risk (Tariq et al., 2007). Pests that are resistant to pesticides may also arise from the overuse of pesticides. According to a study, Punjab and Sindh farmers had elevated blood levels of organochlorine pesticides (OCPs) (Saeed, 2017). Research on the environmental impacts of the life cycle of using pesticides in Punjab's rice-wheat cropping system was examined. According to the study, pesticides greatly influence the ecosystem (Brar et al., 2022). The Punjab province has the highest pesticide application rate, followed by Sindh, Khyber Pakhtunkhwa, and Balochistan. Approximately 70–85% of the pesticides used in Pakistan are used on cotton crops and other crops like fruits, vegetables, rice, tobacco, maize, wheat, and sugarcane. Pakistani soils and streams in different areas have been shown to have residues of several pesticide families, especially organochlorine. Pesticide properties, destiny, and soil penetration are all influenced by the physical and chemical properties of the soil. Every year, more than 500,000 Pakistanis experience agrochemical poisoning, with 10,000 of them dying as a result (Shahid et al., 2016). The study's findings demonstrated that the locals in Vehari District had little understanding of the dangers and proper use of pesticides. Moreover, farm laborers' blood samples exhibited the highest OCP residues, suggesting they are frequently exposed to this class of pesticides. Respondents have substantial levels of bioaccumulation following direct exposure to these chemicals (Saeed, 2017). The study's objective was to quantify the levels of pesticides, such as bifenthrin, spirotetramat, pyriproxyfen, imidacloprid, and diafenthiuron, in soil and plant residue at specific cotton fields in Pakistan's Multan District. It was noted that pesticide residue (0–15 cm) was present in all samples taken from chosen fields. It was found that the total carcinogenic risk estimations for a few pesticides ranged from 10^{-6} to 10^{-2}, indicating that the residents of the research region have a low to high chance of developing cancer (Parveen et al., 2023). Additionally, the results showed that indirect exposure poses a significant health risk to the populations of the research areas. Environmentally common pesticides infiltrate the biosystem and accumulate inside the organisms. Both humans and animals have had fatal and non-lethal consequences from the bioaccumulation and biomagnification of pesticides. Alternatives to crop protection agents include genetically modified organisms (GMOs), organic farming, dietary modifications, and advancements in food technology. Pesticide use must be more controlled and safer through risk analysis, testing, or licensing. The preservation of agriculture, aquaculture, fisheries, and ecosystems can only be achieved by encouraging farmers and users to embrace safe farming practices (Gupta & Gupta, 2020).

Heavy Metals Contamination

Due to their non-degradability, bioaccumulation, hyper toxicity, and excessive release by industries, animal husbandry, and agriculture, among other things, heavy metals are adversely affecting people, the environment, and other living things. As a result, they have gained global attention. Wastewater has recently emerged as the primary method for dispersing millions of tons of heavy metals, and their annual release rate is rising (Singh et al., 2011). Pests resistant to pesticides may also emerge due to excessive pesticide use. The natural and anthropogenic sources of heavy metals are industrial wastewater, urban runoff, natural depletion of the earth's crust, mining, sewage discharge, soil erosion, insecticides and pesticides used for crops or plants, etc. (Mahurpawar 2015). In Vehari, the concentration of Cd is 0.02 mgL^{-1} in wastewater samples (Sarwar et al., 2020). In Lahore, the Cd concentration in wastewater samples is 0.002 to 0.09 mgL^{-1} at "River Ravi" (Ahmad et al., 2022). These concentrations exceeded the permissible limit of Pakistan's National Environmental Quality Standard (NEQS-Pak). (Tong et al., 2020) emphasized how serious the health dangers of heavy metals were in China's cities between 2003 and 2009. The decreasing order of the concentration trends of HM was as follows: Punjab > Khyber Pakhtunkhwa > Sindh > Baluchistan > Gilgit Baltistan. It was determined that the daily intake of metalloids from HM Cd and Se had the lowest usage, while Fe had the highest. The highest hazard quotient values for As and Cd were observed in the Punjab and Khyber Pakhtunkhwa provinces, exceeding the threshold limit (<1). The findings indicated that children have increased exposure to carcinogenic and noncarcinogenic risks (Jehan et al., 2022). According to a study on the hazards of heavy metals on human health, the results showed that absorption was the primary mode of exposure with detrimental effects on human health. It is believed that exposure to heavy metals can cause health issues in both adults and children. The study aimed to examine any potential dangers to human health from consuming agricultural crops tainted with harmful heavy metals. Surface soils had a higher-than-allowable concentration of lead (Pb), chromium (Cr), and cadmium (Cd) than food crops and irrigation water. In many food crops, Manganese (Mn) and lead (Pb) have accumulation factors (AF) greater than 1. The Health Risk Index (HRI) for lead in all food crops irrigated with wastewater and tube well water was higher than 1. All the food crops and soil samples have shown a high contamination level (Khan et al., 2013) Singh et al., 2011). Over 200 items were looked at. The analysis includes studies describing the occurrence of diabetic mellitus due to heavy metal pollution of fruits, drinking water, and pesticides. According to a 2011 WHO estimate, there are Currently, 12.9 million individuals have diabetes mellitus, and that figure is steadily rising. In Pakistan, water contamination poses a serious hazard to public health. Most people in Pakistan are exposed to pesticides and arsenic through their food, vegetables, fruits, and other edibles or drinking water (Bahadar et al., 2014). Pesticides and heavy metals negatively impact human health. Heavy metals can cause serious problems for adults and children when consumed, breathed, or absorbed through the skin. It is feasible to conclude that the harmful health impacts of heavy metal exposure include neurological disorders, musculoskeletal conditions, and imbalances in reproductive hormones. Hazardous consequences from pesticide exposure include asthma, ovarian cancer, lung tumors, soft tissue sarcoma, and endocrine disruption. Additionally, they harm genetics. They also have a significant impact on sperm DNA damage and the promotion of Parkinson's disease. We also recommend more research on novel strategies for bioremediation and phytoremediation of environmental pollutants (Alengebawy et al., 2021).

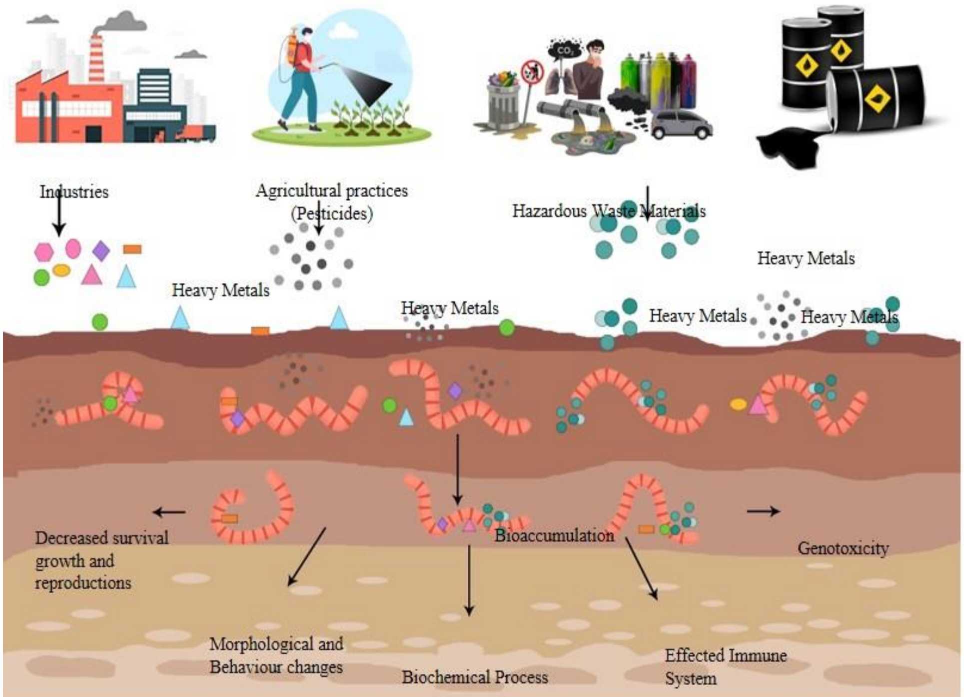

Figure 1. Effects of Hazardous material like metals and Pesticide on the growth of Earthworms

Role of earthworms in phytoremediation

Due to improper land use and poor soil management, the natural resources are limited and very vulnerable to deterioration. The entire planet desperately needs a healthy ecosystem that produces food, clean water, fertile soil, and other natural resources. The contamination of land has increased as a result of anthropogenic activity. Our natural resources are becoming scarcer in nearly every aspect due to the intensification of industrial and agricultural practices, particularly the use of pesticides. Earthworms play various roles that support numerous ecosystem functions that promote the sustainability of agrosystems (Table 1) (Datta et al., 2016). The utilization of hyperaccumulating plants with large biomass improves phytoextraction performance. The rhizosphere has been the focus of much recent research, nonetheless, the drilosphere compartment (the soil region impacted by earthworm secretions and castings) has received less attention. Nonetheless, earthworms are vital to their surroundings because they are ecological engineers. The kind of earthworm, the metal, and the soil's physical and chemical properties affect how heavy metals and earthworms interact. The speciation of soil metals is influenced by earthworms, which changes the metals' bioaccessibility to other living organisms, such as plants (Jusselme et al., 2015). The remaining pesticides and metals in soils have become an increasingly major environmental concern because of their widespread application in practices. There are various defense mechanisms that organisms in contaminated soils have against the toxicity of contaminants. Remediating co-contaminated soils with microorganisms and/or plants is a process known as bioremediation, which is efficient and promising (Zhang et al., 2020). The authors looked at how ryegrass developed and accumulated copper in Cu-contaminated pot soils in connection to the addition of corn straw, earthworms (*Metaphire guillelmi*), and combinations of corn straw and earthworms. The experiment consisted of four treatments and four amounts of Cu addition (0, 100, 200, and 400 mg kg−1). Treatments included control (CK), earthworm additions to soil only (E), straw mulching alone (M), and straw mulching plus earthworm additions (ME). There were three copies of every treatment. After 30 days, each container contained ten ryegrass (Lolium multiflorum) seeds, which were then collected. Furthermore, earthworm activity and straw mulching were observed to increase plant uptake of copper along with the concentration of copper in the roots and shoots of plants. In soil with low to medium levels of Cu contamination, earthworm activity, straw mulching, and how they interact could be crucial to increasing the effectiveness of phytoextraction (Dandan et al., 2007). *N. reynaudiana* might accumulate more heavy metals if exposed to EDTA and earthworms. The application of EDTA and earthworms together maximized the impact on absorption by *N. reynaudiana* absorption and heavy metals uptake. As a result, the findings of this study supported the theory that earthworm activity enhances soil qualities, increases nutrients available in the soil, and boosts. By causing soil disturbance, N. reynaudiana biomass in polluted soil raises soil porosity, encouraging EDTA and rhizosphere soil mixing, and enhances EDTA's capacity to mobilize heavy metals. The findings offer a theoretical foundation for using EDTA and earthworms in phytoremediation techniques to improve plant growth in heavy metal-contaminated soils (Li et al., 2018). Although many other bioremediation methods have been developed, the most successful ones involve earthworms, such as vermitechnology, vermistabilization, and vermiremediation. Because earthworms can bioaccumulate a widespread range of compounds in their tissues, with organic pollutants like heavy metals like Pb, Hg, and Cu and polycyclic aromatic hydrocarbons (PAH), they aid in the conversion of contaminated soil into productive soil (Singh et al., 2020). Most organic wastes are managed by earthworms, which are also utilized to clean wastewater, restore soils contaminated by chemicals, boost soil fertility, and cultivate food. Some recent discoveries involve their use as raw materials for manufacturing industries and life-saving medications. With astounding results, It was evaluated in the following areas: vermicomposting "MSW," vermifiltration of "municipal & industrial wastewater," vermiremediation of chemically contaminated soils, and "cereal & vegetables crops." Wastewater BOD and TDSS decompose more than 75% more quickly, decrease by over 95%, and accelerate agricultural plant development by 30–40% compared to chemical fertilizers (Sinha et al., 2010). Common earthworms, or *Lumbricus terrestris* species, often known as the nightcrawler or dew worm, are widespread in temperate areas. Because they burrow, common earthworms are good for soil health (Lakhani & Satchell, 1970). These worms, or *Eisenia fetida* (Red Wigglers), are frequently employed in vermicomposting systems. They are smaller than *Lumbricus terrestris* and have a reddish-brown color. Red wigglers are frequently used to compost kitchen wastes because they are very effective at decomposing organic matter (Yao et al., 2020). *Lumbricus rubellus* (Red Earthworm) species resembles *Lumbricus terrestris* in appearance, but it is smaller and redder in hue. Red earthworms are common in forests and crucial to soil health (Azizi et al., 2013). As an anecic earthworm, *Pheretima posthuma* digs long, vertical tunnels in the soil and occasionally comes to the surface to ingest decomposing organic materials. Mixing and incorporating organic material into the soil is crucial (Patel et al., 2011). Numerous investigations have shown that regardless of the kinds of raw material used or the species of earthworms used, vermicomposting considerably reduces the accessible proportion of various metalloids and metals, including Cu, As, Cr, Cd, Ni, Zn, and Pb (Abadin et al., 2007). For 30 days, the earthworm *Eisenia fetida* was placed in soil contaminated with Sb, Cd, and their combination. Following this period, enzymatic assays and high-throughput sequencing of the 16 S rRNA genes were used to determine soil enzyme activity and bacterial populations. According to the findings, urease, neutral phosphatase, and protease activities were all considerably hindered by Cd at high treatment levels, On the other hand, earthworms might raise neutral phosphatase and urease activity by 1.46%–118.97% and 17.75%–121.91%, accordingly. However, while protease was unaffected by earthworms, catalase was inhibited. According to the Geometric Mean Index, the Earthworms improved the functioning of soil biochemistry (Xu et al., 2021).

Table 1. Role of Earthworm species in Phytoremediation.

Earthworm Species	**Common Name**	**Role in Phytoremediation**	**Notable Findings**	**Reference**
Eisenia fetida	Red Wigglers	Effective in organic waste decomposition, soil bioturbation, and bioaccumulation of contaminants.	Enhanced plant uptake of Cu in soil and increased soil enzyme activity, especially	Xu et al., 2021; Yao et al., 2020

			urease and phosphatase.	
Lumbricus terrestris	Nightcrawler/Dew Worm	Promotes soil health and enhances contaminant uptake through burrowing.	It effectively reduces metals like Cd, Pb, and Hg and improves soil porosity and fertility.	Lakhani & Satchell, 1970
Lumbricus rubellus	Red Earthworm	Essential in organic matter decomposition and metal bioavailability.	Common in forests, it aids in bioaccumulating heavy metals in contaminated areas.	Azizi et al., 2013
Pheretima posthuma	Earthworm	Vertical burrowing increases soil organic material mixing, facilitating contaminant accessibility.	It contributes to soil aeration and nutrient mixing, helping break down organic and chemical pollutants.	Patel et al., 2011

Phytoremediation of pesticides and heavy metals by Radish

Utilizing plants, phytoremediation purges the environment of contaminants. The most quickly evolving aspect of this low-cost, ecologically friendly technique is using metal-accumulating plants to purify contaminated soil and water (Raskin et al., 1997). The potential for Cr and Cd metal remediation in *W. globosa* was examined. The *W. globosa* was effective for lower concentrations of Cd and Cr metals, according to the adsorption isotherm mode l (Upatham et al., 2002) studied how *T. angustifolia* and *P. scrobiculatum* worked together to remediate wastewater from the textile sector. Along with other criteria, the plants investigated could extract As, Cr, Pb, and Cd metals up to 28-77%. (Chandanshive et al., 2017) studied metal uptake value in diverse aquatic macrophytes, including *P. stratiotes*, *T. angustifolia*, *E. crassipes*, *Phragmites karka, Schenoplectus litoralis*, and *Dichanthiumannulatum*, under varied concentrations of textile industry effluent. *According to the bio-concentration factor, P. stratiotes was the best heavy metal accumulator among the examined macrophytes* (Odjegba & Fasidi, 2004). Heavy metals and pesticides are thought to be hyper-accumulated in radish (*Raphanus sativus*). Certain plant species can absorb and accumulate important levels of metals or other pollutants in their tissues without showing any harmful effects, a phenomenon known as hyperaccumulation. Radishes and organic pollutants have been employed in investigations on phytoremediation for specific contaminants, such as some heavy metals like lead and cadmium. By absorbing these toxins, they have the potential to help with remediation. However, the effectiveness of radishes as phytoremediators may vary depending on several factors, such as the specific pollutant, the soil, and the duration of exposure (Marchiol et al., 2004). This study aimed to verify the efficacy of winter plant species in phytoremediation soil contaminated with sulfentrazone and fomesafen, using cucumber as an indicator species for residue presence. Four replications of each herbicide were used in the entirely randomized design of the experiment, which was set up in a 6 x 4 factorial format. Black oats, radish, and white lupine typically exhibited the greatest potential to phytoremediate soils contaminated with sulfentrazone and fomesafen at concentrations twice the allowable amounts of herbicides (Alves et al., 2019). The experiment described in this paper was conducted as a pot experiment to look into the basic potential of phytoextraction of radish (Raphanus sativus) and canola (Brassica napus) cultivated in soil contaminated with several metals. Chlorophyll concentrations and gas exchanges were assessed during the experiment. The phytoextraction coefficient for each element was determined after the phytoextraction effectiveness of radish and canola for heavy metals was also investigated. The studies show that both species can tolerate heavy metals moderately, but radish can tolerate them better than canola. These plants' ability to phytoremediate soils containing several pollutants was comparatively modest (Marchiol et al., 2004). The study's findings demonstrated that the brassicaceae family of plants, which includes mustard and radish, are hyper accumulators that can concentrate heavy metals in their various components, making them useful for cleaning up contaminated areas (Table 2). Research findings indicated that metal accumulator plants can extract metal from soil, but only to a limited extent. As metal concentration rises, The metal's bioaccumulation coefficient (BAC) or phytoextraction rate falls (Garg & Kataria, 2009). In a hydroponics investigation, the potential for Cd accumulation by three plant species—water spinach (*Ipomoea aquatica*), radish (*Raphanus sativus* L.), and arum (*Colocasia antiquorum*)—was investigated. Arum (*Colocasia antiquorum* L.) plants were cultivated for 60 days in a nutrient solution, whereas radish and water spinach plants were grown for 12 days in 0, 1.5, 2.5, 5, or 10 μM Cd. Radish and water spinach plant growth decreased with all Cd treatments (1.5–10 μM). However, arum growth only decreased at 50 μM Cd. When exposed to 10 μM Cd, arum's growth matched the control treatment's, suggesting it is more Cd-tolerant than water spinach and radish. When cadmium was added to the solution nutrient, the amounts of cadmium in all plant species' various plant sections dramatically rose. Arum and water spinach retained higher levels of Cd in their roots than in other plant parts, but radish had a higher concentration in its leaves (Kashem et al., 2008). The amount of polychlorinated biphenyls and organochlorine pesticides that radishes absorbed from the soil and air was assessed at a highly contaminated field site. The pollutants found in plants at the highest amounts were β-hexachlorocyclohexane, DDT, and its metabolites (Mikes et al., 2009). When the acceptable dosages of herbicides were black oats applied, white lupine and radish demonstrated the highest capacity for phytoremediation of soils contaminated with sulfentrazone and fomesafe. However, field experiments utilizing species that can act as phytoremediators against sulfentrazone and fomesafen are required to validate these early investigations (Alves et al., 2019). Using a gas-chromatography mass spectrophotometer, edosulfan (ED) residues were detected in all soil samples, and radish plants split into shoot and root parts. The bioconcentration factor (BCF), which shows the proportion of ED concentrations in soils and radishes, was calculated using the data. During the study period, radishes had the highest ED-sulfate absorption and dispersion rates, followed by α- and β-ED. The BCF values to initial ED concentrations in soils were used to create regression equations by time; these values were larger for root parts (0.0077 to 0.2345) than for shoot parts (0.0002 to 0.0429). The maximum residue limit (0.1 mg/kg) of ED for radishes was compared with long-term BCFs estimated by the derived (Hwang et al., 2016). According to the study, most nitrates are deposited in storage tissue, or non-stiffened parenchyma, at higher than permitted. According to experimental data on the localization of nitrate in radish roots, the periderm (investing tissue) has the lowest concentration of nitrates, whereas the cambium accumulates less. Additionally, it was shown that the MaC of 0.05 mg/kg for pesticide content was not exceeded in any of the experimental samples.

Table 2. Phytoremediation of pesticides and heavy metals using the Radish

Contaminant	**Metal/Pesticide Source**	**Radish Uptake Efficiency (Parts of Plant)**	**Accumulation Order**	**Notable Findings**	**Reference**
Chromium (Cr)	Industrial effluents	Moderate (roots, shoots)	Roots > Shoots	Effective at lower concentrations, it shows potential in hyperaccumulation.	Marchiol et al., 2004
Cadmium (Cd)	Industrial, agricultural soil	High (leaves, roots)	Roots > Shoots	Shows high Cd accumulation in roots; higher concentration reduces plant growth.	Kashem et al., 2008
Arsenic (As)	Agricultural pesticides	High (roots)	Roots	Elevated levels found in roots with earthworm-enhanced bioavailability.	Study results
Lead (Pb)	Soil from contaminated sites	High (roots)	Roots	Effective in bioaccumulation with enhanced soil porosity from earthworm activity.	Garg & Kataria, 2009
Triazophos	Pesticide residues	Moderate (soil > radish > leaves)	Soil > Radish > Leaves	Radish demonstrated a notable capability for triazophos uptake, though with limited efficiency in leaves.	Study results
Chlorpyrifos	Pesticide residues	Moderate (soil > radish > leaves)	Soil > Radish > Leaves	Enhanced by earthworm activity, particularly with Eisenia fetida.	Study results
Endosulfan (ED)	Pesticide residues	Moderate (roots > shoots)	Roots > Shoots	It shows higher uptake in roots; regression analysis is used to project long-term accumulation.	Hwang et al., 2016

Conclusion and Future Aspects

Pesticides have been proven to have contaminated groundwater in several areas of Pakistan, such as Vehari, and this contamination is ongoing. Numerous indications point to the misuse and overuse of pesticides by farmers. Because of their non-degradability, hyper toxicity, and excessive release by industries, animal husbandry, agriculture, natural and artificial sources of heavy metals include mining, sewage discharge, industrial effluent, soil erosion, urban runoff, the earth's crust natural depletion insecticides and pesticides used on plants or crop heavy metals having a negative impact on the environment, humans, and other organisms. Our study's objectives were to evaluate the mobilization of pesticides and heavy metals by radish and to ascertain whether earthworms may aid in the remediation of pesticides and earthworms. According to our study, Cr was high in shoot, and Cd concentration was high in roots. Pesticide Triazophos increased in the following way: Soil>Radish>Leaves. So, radish has played a vital role in the phytoremediation of heavy metals and pesticides. *C chlorpyrifos* concentration in soil, radish, and leaves was increased in the following way: Soil>Radish>Leaves. Both species of earthworms have played a crucial role in growing capability for taking heavy metals and pesticides by radish. However, overall, species E2 (Esenia Fetida) did more efficient work than the E1 (*Pheretima Posthuma*) species of earthworms.

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COMPETING OF INTEREST

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