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# REVIEW ON PHYTOREMEDIATION OF THE ECOSYSTEM BY USING SUITABLE PHYTO ACCUMULATOR: A FINANCIALLY VIABLE STRATEGY

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**ABSTRACT**

Toxic heavy metals present in soil and water bodies are now seen as a major environmental issue that hurts both plants and animals. Phytoremediation is an effective, economical, and ecologically acceptable bioremediation method that may detoxify and accumulate hazardous heavy metals in the contaminated ecosystem of the plant. Due to a lack of waste treatment infrastructure, developing countries are especially susceptible to heavy metal contamination in their soil and water supplies. The majority of heavy metal expulsion methods are available but those methods are so expensive and out of reach for governments and small pollution treatment companies. Phyto technology is one of the most viable, sustainable, cost-effective, ecological, and economically friendly ways to treat contaminated soil and water as well as in residences and commercial buildings. The adoption of phytoremediation has thus been hampered by the fact that a sizable section of the population in developing nations has been unaware of recent developments and has expressed interest in more traditional remediation techniques. This review discusses the idea of phytoremediation by plants that show hyperaccumulator activities- they have a faster heavy metal accumulation and faster translocation of heavy metals from their roots to their shoots than non-hyperaccumulating plants in the ways that eliminate heavy metals.
***Keywords* :** Heavy metals, phytoremediation, detoxify, hazardous, bioremediation, hyperaccumulator

## Introduction

Since heavy metals are extremely poisonous even at very low concentrations and have high densities (densities > 4 g/cm$^3$) and atomic masses greater than 20, they are classified as metallic elements (Duruibe *et al.*, 2007). Examples of heavy metals include Fe, Co, Ni, Mn, Cu, Zn, Cr, Pb, and so on. Even though certain of these metals are necessary for biological processes including hormone production and normal enzyme, cell, and metabolic function, humans only require trace levels of these metals. There may be toxic effects on human health if heavy metals are incorporated into the human circulatory system [Mitra *et al.*, 2022]. Rocks that contain heavy metals, such as serpentine and black shale, are enriched in these metals (Yu *et al.*, 2011). When weathering occurs, all of the metals are released into the soil and water. Sewage, industrial, mining, and agricultural waste (fertilizers and pesticides) are the main sources of heavy metals (Kumar *et al.*, 2023). Iron, copper along with zinc are the heavy metals that are known to be necessary for the systems of plants and animals (Mitra *et al.*, 2022). However, when levels of these metals rise above tolerable levels, serious issues arise. Because of heavy metal contamination, soil all over the world has been experiencing serious issues. These heavy metals reduce soil productivity and alter the physiochemical characteristics of the soil. The health of every living organism is at serious risk due to the recent increase in heavy metal pollution in soil (Su *et al.*, 2014). Plants irrigated with water contaminated with heavy metals or growing in such areas absorb the metals. When animals and people eat these metal-contaminated plants, they enter the food chain and disrupt it (Jaishankar *et al*., 2014). Thus, the heavy metals uptake by plants increases the possibility of these toxic elements entering the food chain. Moreover, heavy metals hinder photosynthesis, which lowers plant energy production and stunts development. At the biochemical level, metals can further jeopardize plant health by causing ion imbalances, changing nutrient absorption, and inhibiting important enzymes. (Rahman *et al*., 2023) The plant's ability to reproduce and maintain its population health can be negatively impacted by genotoxic impacts including DNA damage and mutations (Tuteja *et al*., 2009). By changing the structure of plant communities, decreasing biodiversity, and contaminating the food chain as herbivores and higher creatures eat polluted plants, the buildup of heavy metals in aquatic plants can also have wider ecological effects.

These heavy metals can be immediately absorbed by plants and their leaves in both terrestrial and aquatic environments when they enter through rain, wind, soil erosion, etc. (He *et al*., 2023). As zinc, iron, manganese, and molybdenum uptake by plants has less of an effect on plant cells, it also has less of an effect on plant production. However, excessive cadmium (Cd) absorption damages plants oxidatively, inhibits electron transfer chain activity, and interferes with transcription and replication (Wang and Yudong, 2004). Also, some study reveals that copper at excessive level can badly affects the plant health. The primary source of Cu contamination in soil and water is ore mining from rocks. Since the threshold level of copper is 100 mg/kg, Cu primarily impacts humans, animals, and plants at concentrations greater than 100 mg/kg. A large number of plant species that can behave like Cu-tolerant plants are capable of either accumulating or excluding Cu toxicity, or both (Poggere *et al*., 2023). The environment contains a variety of heavy metals, but copper is the most dangerous of them all since it can firmly connect with the albumen and other tiny molecules in the human body. Copper damages nerves when it is present in the human body in a "free" state. Excess copper in the human body can lead to serious health issues such as nausea, and diarrhea, as well as tissue damage and other illnesses (Poggere *et al*., 2023; Teschke, 2024). Some other heavy metals such as Arsenic also reported as one of the most fatal heavy metals that are injurious to plant and animal health (Sinha *et al*., 2023; Zhakypbek *et al*., 2024). Arsenic (As) contamination poses a significant environmental, agricultural, and health challenge due to its highly toxic and carcinogenic nature. Even low levels of arsenic can have substantial impacts on plant growth, structure, and metabolism. The toxicity of arsenic to plants depends on its specific form, either arsenite (As (III)) or arsenate (As(V)), as well as the plant species and various soil factors that influence arsenic accumulation (Sinha *et al*., 2023)

Heavy metal buildup in soil and water can be quite problematic since it can readily bioaccumulate or biomagnify into both terrestrial and aquatic plants and animals. Nevertheless, some plants have evolved defenses against heavy metals, such as phytoremediation, in which the metals are absorbed and stored in vacuoles or changed into less harmful forms. However, these defense mechanisms may be overloaded by extended or high-level exposure, resulting in extensive ecological harm (Zhakypbek *et al*., 2024; Mocek-Płóciniak *et al*., 2023; Bosiacki *et al*., 2014; Muthusaravanan *et al*., 2020). Heavy metal removal from soil and water can be accomplished using a variety of methods. Among these methods are phytoremediation, bioremediation, and physiochemical methods. Physiochemical techniques, however, are not used very often due to their high cost and labor requirements, limited application, and numerous adverse consequences. In addition to being environmentally benign and cost-effective, bioremediation and phytoremediation have no negative side effects.

Since bioremediation uses microorganisms to clean up polluted sites, phytoremediation has been used more often than bioremediation over the past 20 years. However, bioremediation is a time-consuming process that is particularly challenging to manage when using microorganisms as they are highly sensitive to environmental factors (such as temperature, light, pH, and the toxicity of heavy metals). Compared to other methods, phytoremediation has numerous ecological and financial benefits. Phytoremediation is essentially the utilization of plants and related soil bacteria to lessen the levels of pollutants or their harmful effects on the environment (Kuppan *et al*., 2024; Adams *et al*., 2015). In addition to contaminants such as pesticides, polynuclear aromatic hydrocarbons, and polychlorinated biphenyls, it can be used to remove radionuclides and heavy metals. This cleanup method is new, economical, effective, eco-friendly, in situ applicable, and solar-powered. (Haiying *et al*., 2024)

The heavy metals are transformed into non-toxic forms after absorption, and they are either broken down or moved to various plant sections where they accumulate independently (L *et al*., 2022). Plants that can accumulates harmful heavy metals in their parts particularly in their roots and shoots are categorized as accumulators and hyperaccumulators (Quimado *et al*., 2015). Plant species of the Phyllanthaceae and Brassicaceae families are known to be hyperaccumulators.

Yaashikaa *et al.* (2022) Plant cells' plasma membranes contain transporters or carriers that move heavy metals from the soil to various plant components. The transporters in the root cell take up heavy metals from the soil (Shiyan *et al*., 2023).

The heavy metals combine with the chelators to form a complex that allows them to move into the plant's shoot. Hyperaccumulator plants have different heavy metal transporters or carriers than the vital nutrient carriers. The root or shoot system of hyperaccumulators accumulates a significant amount of heavy metals (Igolima *et al*., 2022). Phytoremediation capitalizes on the fact that a living plant can be thought of as a solar-powered pump that can draw specific materials from the surrounding environment and concentrate them. Phytoremediation targets several metals, including Pb, Cd, Cr, As, and different radionuclides. It is simple and safe to process the collected plant tissue which is rich in accumulated contaminants by drying, ashing, or composting. In comparison to many modern, more intrusive remediation technologies, the amount of toxic waste generated as a result is typically a fraction of that, and the related expenses are significantly lower. It is possible to recover some metals from the ash, which lowers the production of hazardous trash and increases recycling profits (AK *et al.*, 2023; Padmavathiamma *et al.*, 2007).

Many significant facets of this new plant-based technology have been summarized in extensive reviews written with an emphasis on the biological mechanisms and application methods, these studies offer broad advice and suggestions for using phytoremediation. (Kafle *et al.*, 2022) (Lavanya *et al.*, 2024; Ali *et al.*, 2013; Sharma *et al.*, 2023). The goal of the current review is to provide a more current and condensed version of the material already accessible about various phytoremediation subgroups. To provide the broad application of this green technology, recent literature is compiled to critically examine the causes, harmful consequences, and ecologically friendly phytoremediation technique of heavy metal-polluted soils.

Numerous methods have been put out to improve and speed up phytoremediation to get over these restrictions. These are Phytostabilization, phytostimulation, phytotransformation, hemofiltration, and phytoextraction are the several forms of phytoremediation (An *et al.*, 2020; Mitra *et al.*, 2022).

**Sources of Heavy Metals**

The toxicity of heavy metals continues to affect the ecosystem's soil component, which affects agricultural output. The toxicity and carcinogenicity of heavy metals and their known detrimental impacts on human health make them especially concerning (Lesley *et al.*, 2019; Angon *et al.*, 2024). The fact that many drinking water treatment methods, such as boiling, chlorination, and sun disinfection, are poor at eliminating heavy metals raises additional concerns about heavy metal pollution (Wan *et al.*, 2024). There are two distinct ways that heavy metals reach the soil: anthropogenic activities and natural processes (Garrett, 2000).

**Natural Sources**

It is believed that igneous and sedimentary rocks are the most common natural sources of heavy metals. The ratios of elements in one type of rock have been found to vary from those in another, suggesting that the proportions of components in one form of rock are different from those in another (Alengebawy *et al.*, 2021). Depending on the type of rock and the environment in which it is found, the amount of heavy metals can also change (Alengebawy *et al.*, 2021).

**Anthropogenic Sources**

Agrochemicals, mining, smelting, industrial and residential wastewater, and fuel production are some of the anthropogenic sources of heavy metals (Zhang *et al.*, 2019). Sources of heavy metals are shown in Fig 1.

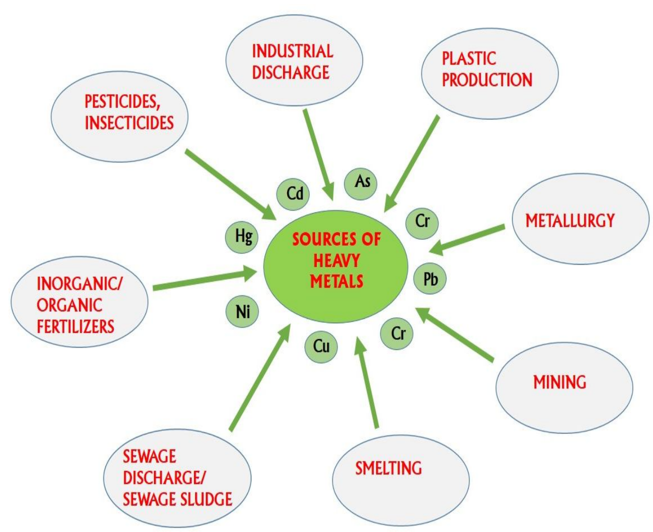


**Fig. 1 :** Sources of Heavy Metals

When building materials and energy are transported and produced, gases and dust are released into the atmosphere, releasing heavy metals. Heavy metals are found in the atmosphere as aerosols, which are subsequently deposited in soil by precipitation (Kim *et al.*, 2023). Lead, zinc, Hg, and Cr are among the various heavy metals found in biosolids, which are organic materials.

Extensive use of fertilizers, pesticides, biosolids, and herbicides in agriculture leads to greater accumulation of heavy metals in soil absorbed by plants (Liu *et al.*, 2023). Fertilizers such as potash and nitrogen fertilizers have a large amount of toxic heavy metals and due to their extensive use, the concentration of fatal heavy metals such as Cd, As, and Pb is increased (Briffa *et al.*, 2020).

**Impact of Heavy Metal on Terrestrial and Aquatic Ecosystems**

Both metalloids and heavy metals can contaminate agricultural soil. Extremely high soil concentrations of heavy metals may negatively impact crop productivity and health (Rashid *et al.*, 2023).

Heavy metals not degreed because they are non-biodegradable Certain plants are hyperaccumulators, meaning that they can retain heavy metals and pollutants in their soil or root system for a very long time, making it impossible for them to move across the entire land or water. If the plants are unable to absorb or expel the heavy meals, they can change them from more toxic to less toxic (AK *et al.*, 2023; Chandra *et al.*, 2018). The following elements are frequently found in contaminated agricultural soils and hurt plants: Ni, Cd, Hg, Cu, Cr, As, Pb, and Zn. Among the other contaminants and heavy metals, some of which can be more detrimental to soil and plant life are Cr, Cd, Hg, As, and Pb; this means that these metals cause all levels of pollution in soil, water, and plants (Okereafor *et al.*, 2020). According to the Environmental Protection Agency (EPA), the most prevalent and detrimental metals to our ecosystem are mercury, lead, chromium, and arsenic (Balali *et al.*, 2021).

Since each heavy metal can contaminate soil differently, there are different standards for heavy metal contamination. The most common contaminated heavy metals have contamination standards of Cr-1.10%, Cd-1.50%, As-1.60%, Pb-2.70%, and Hg-7.00%, respectively (Angon *et al.*, 2024). There are more than 5 million locations worldwide where the concentration of heavy metals in the soil exceeds the allowable limit, while in those cases, they are regarded as safe (Adhikari *et al.*, 2024). Normally, when the concentration of heavy metals exceeds its acceptable limit, we can say that the entire ecosystem is unsafe.

Human activities that are primarily responsible for the production of heavy metals in soil are the use of large amounts of fertilizers for agricultural purposes, the manufacturing of chemicals, and the mining of minerals (Adnan *et al.*, 2022). Several studies have already been conducted on the main sources of anthropogenic and natural sources of heavy metals and several studies are comparing all the studies, that are already conducted, the main purpose of this comparison is to compare the anthropogenic activities and natural activities that activity is cause serious problems in the soil, after comparisons several studies have indicated that anthropogenic sources of heavy metals in the environment have causes most deleterious effects in soil. The influence of environmental heavy metals is lower than that of anthropogenic sources. Heavy metals are believed to be a major contributor to the next level of soil contamination because they alter the biological and structural characteristics of the soil, including the microbes that are in charge of the soil's enzymatic activity (Nyiramigisha *et al.*, 2021). The structural characteristics of soil include its porosity, organic matter content, texture, biological activity, and aggregate property, all of which are impacted by heavy metals. It is also essential to maintain the soil's porosity, penetration power, and water intake propensity to preserve the soil's fertility and structural integrity.

Since they can destabilize aggregates, the main heavy metals that can restrict soil are Cd, Pb, and Cu (Alloway and Brian, 2013). Additionally, heavy metal contamination can decrease soil porosity, which might impact adequate soil aeration. The following heavy metals (HMs) can clog soil pores: Cr, Cd, and Pb. These metals clog soil pores tightly, which means that clogging soil pores reduces the amount of water and nutrients that can reach through them and balance soil moisture and productivity. Ultimately, this reduces soil fertility and increases soil erosion (Alloway and Brian, 2013). Recent study state that all of the metals under study (such as Cr, Zn, Mn, Pb, Fe, Cu, Mn, Cd, Ni, and Co) have an impact on the ecosystem when they surpass their threshold values, but that the concentrations of Cd, Zn, and Pb that rise above their allowable limits have the potential to impact the entire ecosystem in comparison to other metals (Nazir, Ruqia *et al.*, 2015).

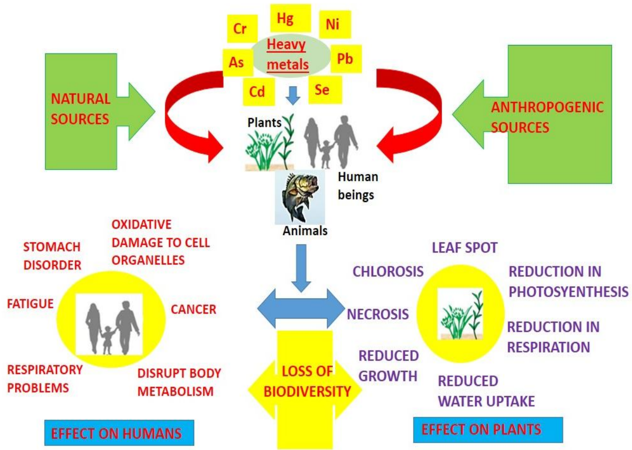


**Fig. 2 :** Effect of Heavy Metal on Plants and Humans

## Effects of Heavy Metals on Animals

The progressive increase of heavy metals in the atmosphere has drawn attention worldwide due to their toxic effects and biomagnification properties, which pollute even in deficient quantities. In multilayered soil and environmental pollution, heavy metals are regarded as one of the most important hazardous substances (Briffa *et al.*, 2020). Increases in the presence of these heavy metals in the environment raise the possibility that living organisms both terrestrial and aquatic, will consume these harmful substances. They can build up in various body organs, such as the kidney, liver, and bone, and they can cause serious harm to aquatic animals, particularly fish, in the form of gills, fins, scales, and other organs. Furthermore, when these metals build up, they negatively impact several internal systems, including the circulatory, immunological, skeletal, endocrine, and neurological systems (Ali *et al.*, 2024; Abd-Elghany, 2020).

Little is known about the kinds of cellular and molecular alterations that take place in human cells and how heavy metals lead to DNA mutations. Numerous animal studies have been carried out, but the information is insufficient to understand how the combined effects of Cd and diazinon can cause a significant loss of spermatogenic element, addition to disarray, seminiferous epithelium, and decreased germ cell maturation in rats (Năstăsescu *et al.*, 2020).

Those who had pancreatic cancer and had been exposed to pesticides had greater levels of Cd and Mn, even though each patient had a different career, according to a recent study (Khoshakhlagh *et al.*, 2024). The toxicity of Cr is dependent on the state of chromium; if chromium is in an oxidized state, it has a greater impact on human health than in other states because Cr (III) is a vital component and plays a significant role in human metabolism, while Cr in an oxidized state (VI) is highly carcinogenic and affects other major body organs as well (Monga *et al.*, 2022). Higher concentrations of lead can harm both internal and external organs in humans, animals, and plants. These organs include skin cancer, dermal lesions, angiosarcoma, and neurological disorders. If lead crosses the placenta, it can harm the developing fetus in the womb (Massányi *et al.*, 2022). A buildup of heavy metals in the human body can result in unforeseen alterations and serious issues, such as black foot, Minamata, and itai itai illnesses; various heavy metals can have an impact on different body organs. Zinc depletes HDL, gastrointestinal issues (headache, nausea, and dizziness), and liver issues. Long-term inhalation of Cu results in lung inflammation and kidney failure, and it also causes liver poisoning. Environmental Protection Agency (EPA) claims that nickel is a major cause of cancer and that it causes infertility in humans (Balali *et al.*, 2021). When humans consume these metals daily, they increase their risk of developing cancer and their Hazard Quotient (HQ).

The main way humans get heavy metals orally is through edible crops and vegetables cultivated in soil that has been enhanced with heavy metals. In Karachi, Pakistan, there is a study that shows a direct correlation between rising Pb content and rising cancer risk. In addition, Pb can induce neurological issues, prevent the proper synthesis of hemoglobin, and cause problems with the kidneys, joints, and ovaries. Children were more susceptible to the effects of greater levels of heavy metals (6.5 times) than adults (Sharfuddin *et al.*, 2008).

## Effect of Heavy Metals on Plants

Since the rhizosphere and root exudates of plants growing on heavy metal-enriched land readily interact with the metals and minerals found in contaminated soil, the rhizospheres of these plants will exhibit the earliest noticeable effects. (Alengebawy *et al.*, 2021). Multiple mechanisms have been identified as the primary contributors to the rise in metal ion concentrations in the rhizosphere of plants. Many minerals that are vital to plants' structural, functional, and anatomical functions are deficient as a result of cadmium poisoning (Nazar *et al.*, 2012). Various physiological and metabolic defaults can result from elevated trace element concentrations (Baj *et al.*, 2023) Increased intracellular reactive oxygen species (ROS) levels lead to oxidative stress, which damages biological components (e.g., proteins, nucleic acids, lipids, and enzymes). A flaw in any of these biochemical components ultimately results in several cellular issues, including DNA damage, cell damage, and the suppression of enzyme activity, which can ultimately cause the plant to die (Chatterjee *et al.*, 2017).

Because it is crucial to the Krebs cycle and the TCA cycle for ATP generation, growth, and development, copper is a necessary element for plant nutrition. However, if copper levels rise over their permissible limits, it may become poisonous to plants. A surplus of copper in plant roots inhibits the growth of the entire plant (Lidon *et al.*, 1993; Cruz *et al.*, 2022). Plants exposed to copper poisoning also experience excessive oxidative stress and the production of ROS (Thounaojam *et al.*, 2012). Plants that are poisoned by copper exhibit certain obvious symptoms, such as dwarfism and a loss of leaf pigmentation, which eventually results in plant death (Chen *et al.*, 2022). Numerous processes that are crucial to the production of macromolecules and micromolecules in plants are impacted by biotic and abiotic stressors (Ramakrishna *et al.*, 2011; Chauhan *et al.*, 2023). Anytime a high amount of copper deposition results in a decrease in plant life, biomass, and overall mass output (Rehman *et al.*, 2019; Saleem *et al.*, 2020). Symptoms vary from plant species to plant species. For example, beans (*Phaseolus vulgaris*) are more susceptible to copper toxicity than other plants of the same species (Ke *et al.*, 2007). Cu poisoning also exhibits a variety of symptoms. In *Triticum* sp., or wheat. The standard for soil containing cadmium (Cd) is 100 mg/kg. Chlorosis, growth retardation, root tip browning, and ultimately plant mortality is among the detrimental consequences that plants cultivated in soil that is highly contaminated with cadmium (Abedi *et al.*, 2020). Excess cadmium builds up in soil and has an indirect interaction with both Cd and Fe (II). An increase in Cd inhibits the root Fe (III) reductase, which aids in the synthesis of Fe (II), which significantly impacts photosynthesis. The loading and unloading of various micro and macronutrients, minerals, and water into plants has been demonstrated to be hampered by cadmium (Ran *et al.*, 2024). Cd also helps with nitrate absorption and transport by inhibiting nitrate reductase, which is found in plant shoots (Zhang *et al.*, 2022).

Zn concentrations are micronutrients, meaning that although zinc is already present in soil, it is needed externally to nourish plants. However, with time, zinc levels can surpass these levels, pollute soil, and potentially result in phytotoxicity. In polluted soils, the permissible limit of zinc is between 150 and 300 mg/kg (Allowany and Brian, 2013). Because it alters the internal structure of plants, zinc buildup in soil at greater levels limits several physiological and structural processes of plants (Alloway and Brian, 2013).

Additionally, deficits of several key components that are necessary for plants to grow normally might result from excessive zinc buildup. Deficits of all the essential nutrients have been attributed to the obstruction of the flow of these macronutrients and micronutrients from the soil to the roots and from the roots to the shoots. Zn concentrations in roots and shoots are higher than those in micro and macronutrients, which is implied by this barrier to nutrient transfer (Balafrej *et al.*, 2020).

Toxic metal contamination of the environment has drastically increased since the beginning of industrialization (Adnan *et al.*, 2022). The estimated global anthropogenic outflow of Cr in freshwater bodies is 3550 mt (Rogora *et al.*, 2017). Excessive levels of Cr have been shown to limit plant development, chlorosis, photosynthetic inhibition, nutrient deficiencies, aberrant cell division, water loss, and many other symptoms in plants (Shanker *et al.*, 2005). The growth of roots stems, and leaves and changes in the germination process are among the toxic effects of Cr on plant growth and development. As a result, exposure to elevated Cr levels impacted plant yield and total dry matter output (Sadeeq *et al.*, 2023).

The natural forms of cobalt, cobaltite [CoAsS], erythrite [$Co_3(AsO_4)_2$], and smaltite [$CoAs_2$], are found in the crust of the earth. Cobalt is produced by anthropogenic causes such as burning fossil fuels, wearing alloys containing cobalt, and spreading manure and sewage sludge, all of which raise the element's concentration in soil (Bakkaus *et al.*, 2005). Plants can absorb a tiny quantity of Co from the soil. Depending on the species, plants have varying rates of cobalt uptake and distribution, which are regulated by various processes (Khalid *et al.*, 2023).

In terms of cobalt accumulation, a recent study found phytotoxicity in barley (*Hordeum vulgare* L.), oilseed rape (*Brassica napus* L.), and tomato (*Lycopersicon esculentum* L.) (Li *et al.*, 2009). What is known about the phytotoxic effect of excess Co is rather little. Setting environmental quality standards and requirements, however, helps to control the environmental risks of Co.

Lead, a heavy metal, has the potential to be a dangerous pollutant because of its high toxicity (Balali *et al.*, 2021). Lead-based paints, children's toys, paints, lead pipes, jewelry, e-waste, and lead bullets are the sources of lead pollution in soil. Pb has a significant negative impact on soil and water bodies as well. It disrupts the microbial population, lowers soil nutrients, decreases soil productivity, and promotes soil erosion, among other changes that may or may not be reversible (Kumar *et al.*, 2021).

One crucial aspect that should be prioritized is the reduction of lead from soil and water bodies, which can be achieved using a variety of phytoremediation techniques (Lan *et al.*, 2020). The amount of lead absorbed and retained in the soil at a given time was also examined by (Vega *et al.*, 2006) who also looked into the types of changes that occur in the soil and their characteristics due to high lead accumulation. The final findings demonstrated that lead had varying effects on several soil characteristics. The key soil parameters that are affected by lead pollution include pH, acidity, alkalinity, and cation exchange capacity.

The plants were grown in soil with a higher level of Pb accumulation and a higher pH. The findings showed that Pb accumulation in the soil hurts the soil and results in defects in the plant's ability to absorb nutrients from the soil. Many plant species exhibit aberrant morphology when exposed to higher levels of lead contamination in the soil. Decreased water potential, decreased respiration, altered metabolism, and morphological changes such as lignification of the cortical parenchyma and thinning of the endodermis cell walls are among the physiological changes that lead to pollution causes in plants (Rahman *et al.*, 2024).

## Heavy Metals in Food Chain

The aquatic environment has also been found to contain heavy metals. The main ways that these metals enter water bodies are man-made (such as fertilizers, industrial wastes, and household wastes), natural (such as soil erosion and rock abrasion), and atmospheric (such as urban runoff). They are also highly soluble in aquatic environments and are either directly or indirectly consumed by living things (Panchamoorthy *et al.*, 2024). In contaminated aquatic environments, they have been building up in the various body organs of various fish species. This process, known as biomagnification, occurs when the accumulated heavy metals are transferred from low trophic levels to higher trophic levels by fish consumption by other organisms (Jamil *et al.*, 2023). Metals come from a variety of sources, and heavy metals build up in waterbodies, where they eventually find their way to the soil through contaminated wastewater. Aquaculture populations that live in such contaminated aquatic environments are also impacted by these metals (Hama Aziz and Kareem, 2023). When agricultural land is irrigated with wastewater that has previously been contaminated with heavy metals, increased concentrations of heavy metals are found in the edible sections of the crops that are growing in the soils (Khan *et al.*, 2023).

Higher levels of metal contamination in soil can increase the risk of several issues through direct inhalation or contact with the contaminated soil. This affects the normal lifestyle of the soil, plants, humans, or soil-plant-animal-human because of the slow increase of heavy metals in the ecosystem, such as groundwater, soil, and from soil to edible food (primarily crops), which results in a decrease in the quantity and quality of food due to phytotoxicity (AK *et al.*, 2023). All-important nutritional components, such as amino acids, enzymes, minerals, and vitamins, are found in crops, which are vital sources of the human diet (Alagawany *et al.*, 2020). The edible sections of plants that are cultivated in heavy metal-polluted areas acquire these metals, which humans then inhale and accumulate in various bodily parts (Alengebawy *et al.*, 2021).

After entering the food chain, heavy metals have the potential to enter the human body and cause several illnesses. Inhaling contaminated dust and aerosols and consuming contaminated food and water can expose one to metals (Briffa *et al.*, 2020). Produced on soil contaminated with metals or irrigated with water contaminated with metals, edible crops can demonstrate that the food accumulates metals in significant quantities that affect food purity and quality (Yvette *et al.*, 2024).

## Impact of Heavy Metals on Microorganism

Microbes contain essential compounds like C, N, S, P, and many more that can play a major role in human gut health, soil fertility, and soil refreshment through bioremediation, microorganisms play a key role in several fields independently, including agriculture, industries, biotechnology, and the human gut. In the industrial sector, microorganisms are crucial in the production of large quantities of human-use products, such as food and medicine (Rebello *et al.*, 2021).

The removal of heavy metals from soil may be possible with certain microbes. The remediation of heavy metals and other contaminants has been aided by several microbes, including bacteria, fungi, and algae. According to (Zolgharnein *et al.*, 2017) *Pseudomonas aeruginosa* is a viable and potent option for the removal of metal pollutants. Bacteria mostly clean up heavy metals by using surface phenomena and diffusion processes (Zolgharnein *et al.*, 2017).

Rhizosphere bacteria are soil-dwelling microorganisms that help plants fix nitrogen from the atmosphere. This helps plants grow, feed crops, and become less susceptible to disease because the bacteria help plants produce phytohormones, and activate certain enzymes, and some actinomycetes produce antibiotics that help control plant pathogens. Other compounds, like iron chelators (deferoxamine, deferiprone, and deferasirox), aid plants in avoiding iron chlorosis.

To fix nitrogen in the atmosphere and support plant growth, some microorganisms and microbial fertilizers can assist plants externally. Phosphate solubilizing, *Bacillus cereus*, and arbuscular mycorrhizal fungi are examples of microbial fertilizers that promote plant growth by increasing the availability of essential elements found in soil. Microbial fertilizers also aid in increasing the availability of trace elements such as iron and zinc (Oleńska *et al.*, 2020).

It is an active process (direct or indirect) for metals to bioaccumulate through microorganisms. *Pseudomonas putida* causes cadmium to accumulate both intracellularly and periplasmically, indicating that metal binding receptors for metal resistance are present inside microbial cells. In *E. coli*, metals concentrate in the cytoplasm and periplasm as a result of metallothionine expression (Sauge-Merle *et al.*, 2012).

*Bacillus* has a roughly 57% potential to accumulate lead. There are essentially two types of bacteria in the environment: those that are sensitive to heavy metals and those that are resistant to them. The population and diversity of metal-sensitive bacteria decline as the concentration of heavy metals rises over time, while the population and diversity of metal-resistant bacteria rise due to their ease of survival in environments enriched with metals (Wróbel *et al.*, 2023).

Although metal-resistant bacteria undergo several systemic modifications, heavy metals have a continuous impact on bacterial biomass, system, and activity.

The bacterial community's ability to survive can also be impacted by the kind of environment in which they dwell, the contaminants present in that environment, and the bacteria's sensitivity and resistance (Goswami *et al.*, 2023).

### Classes of Phytoremediation Technology

There are five subclasses of phytoremediation technology: phyto-stimulation, phyto-transformation, phyto-filtration, phytoextraction, and phyto-stabilization (Ramanjaneyulu *et al.*, 2017).

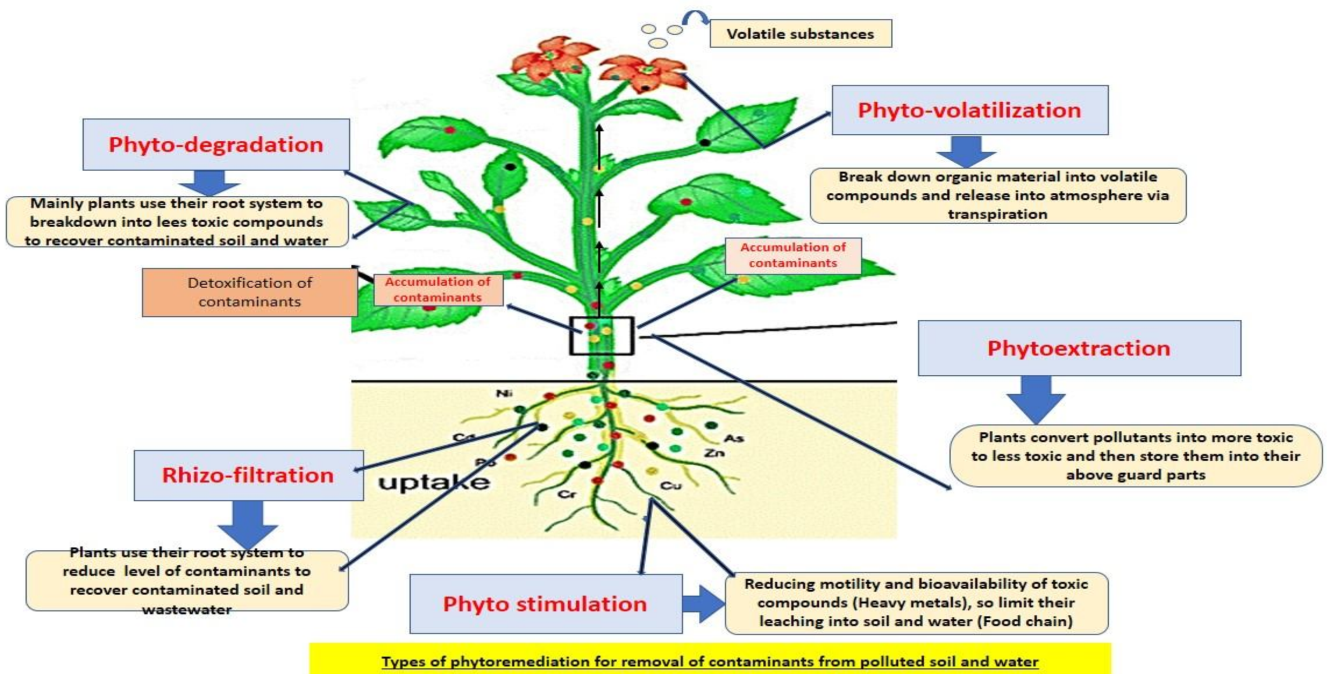


**Fig. 3:** Types of Phytoremediation Technology

**Phytostimulation**

By reducing the mobility and bioavailability of heavy metals, this approach seeks to limit their absorption into groundwater and leaching into the food chain, respectively (Erakhrumen, 2007; Khalid *et al.*, 2017). Plants are less important in phytostabilization than soil additives. Additionally, known as photodegradation, phytostimulation is the breakdown of organic pollutants in the rhizosphere with increased microbial activity (Mukhopadhyay and Maiti, 2010). The soil volume around a root, or rhizosphere, is impacted by root activity (Pilon-Smits, 2005). There are several approaches to increase microbial activity in the rhizosphere: (Yadav *et al.*, 2010) Native microorganisms are enriched by root exudates that contain amino acids and carbohydrates; ii) roots guarantee the rhizosphere's oxygen supply for aerobic transformations; iii) root biomass increases the amount of organic carbon available; iv) Mycorrhizae fungi break down substances that bacteria are unable to break down; and v) plants offer habitat for an increased microbial population.

**Phyto transformation**

The breakdown of organic substances by plant metabolic processes or plant-produced enzymes is referred to as phytotransformation, or phytodegradation, and it occurs independently of the microbial community (Vishnoi and Srivastava, 2008).

**Phytovolatization**

Only the breakdown of organic materials benefits from the use of phytodegradation. "Phytovolatilization" is the process by which volatile compounds are released into the atmosphere via transpiration from plants. By this process, contaminants are taken up by plants from the soil, transformed into volatile molecules, and subsequently released into the atmosphere. Only organic compounds and heavy metals like Se and Hg can be treated with this technique (Padmavathiamma and Li, 2007).

**Phytofilteration**

According to Mukhopadhyay and Maiti (2010), phytofiltration is the process of recovering surface and groundwater as well as wastewater with low levels of contaminants by using plant roots (Mukhopadhyay and Maiti, 2010). Polluted water is used to acclimate plants before they are transferred to the contaminated site for restoration. Mesjasz-Przybylowicz *et al*. (2004) distinguish between three types of phytofiltration: rhizofiltration, which uses plant roots, blastofiltration, which uses seedlings, and caulofiltration, which uses plant shoots (Mesjasz-Przybylowicz, 2004).

**Phytoextraction**

Fast-growing plants are used in phytoextraction to extract heavy metals from the soil and water (Yanai *et al.*, 2006; Pajevic *et al.*, 2016). According to Ghosh and Singh (2005), there are two methods for phytoextraction: chemically induced phytoextraction and continuous or natural phytoextraction (Ghosh and Singh, 2005), A method known as continuous phytoextraction involves removing heavy metals via a network of roots before directing them to the upper plant tissues above ground. Plant biomass that has been harvested can be burned or used to produce biogas (Jadia and Fulekar, 2008).

Rapid growth, high biomass, an extensive root system, and the ability to absorb and store large amounts of heavy metals are all requirements for plants used in phytoextraction (Romkens *et al*., 2002; Sytar *et al.*, 2016). In continuous phytoextraction, hyperaccumulators from nature are employed. Metalliferous locations employ hyperaccumulator plants (Usman *et al.*, 2018).

For a plant species to be suitable for phytoextraction, it must meet the following criteria: High biomass production, metal tolerance to poisons, and effective HM accumulation in harvestable sections are the first three factors (Vangronsveld *et al.*, 2009).

The fundamental idea behind the phytoextraction method of polluted region rehabilitation is to grow appropriate plant species in situ, extract the biomass containing heavy metals, and then treat it to reduce its volume and weight (by either thermal breakdown, composting, compacting, or drying).

One benefit of natural hyperaccumulators is that they have higher rates of bioaccumulation. Autochthonous species often avoid the introduction of potentially invasive and non-native species; however, this approach has certain disadvantages as well, such as high metal specificity, which usually refers to only one hyperaccumulation heavy metal element low-biomass, often slowly growing species with specific ecological needs and requirements related to climate, soil properties, water regime, etc. (Salt *et al.*, 1997).

**Metallophytes' Application in Phytoextraction**

"Metallophytes" are plants that may thrive in soil contaminated with heavy metals (Sheoran *et al.*, 2011). Metallophytes are divided into three classes: excluders, indicators, and hyperaccumulators. The majority of them belong to the Brassicaceae plant family (McGrath *et al.*, 2002; Bothe, 2011). Metal excluders take up heavy metals from the environment and store them in roots, but they prevent them from moving to plant tissues above ground (Malik and Biswas, 2012). Metal indicators collect in their top portions after absorbing pollutants from contaminated soil (Sheoran *et al.*, 2011) A metal hyperaccumulator should accumulate at least 100 mg/kg of As and Cd, 1000 mg/kg of Co, Cu, Cr, Ni, and Pb, and 1000 mg/kg of Mn and Ni (Watanabe, 1997; Reeves and Baker, 2000).

## Hyperaccumulator

It's critical to implement a sustainable plan to lessen heavy metal pollution in the environment. Phytoremediation has emerged as one of the most effective solutions for the problem of metal contamination (Nedjimi, 2021). A heavy metal hyperaccumulator is a plant that can absorb and accumulate heavy metals at levels much higher than those of other plants in its aboveground parts, such as its leaves (Parmar *et al.*, 2015). Hyperaccumulators are capable of absorbing heavy metals at concentrations 10–500 times higher than those of other plants without showing any symptoms of phytotoxicity. Metal-tolerance Plants can resist heavy metals by either avoiding uptake or neutralizing them through certain plant activities. Metal-transporting and metal-binding proteins Plants can use proteins including P-type adenosine triphosphatase, metallothionein's, and phytochelatins to move heavy metal ions across the cell membrane (Mahar *et al.*, 2016). Based on the strategy of survival, Baker (1991) identified two primary tactics used by plants that naturally thrive in metalliferous environments. Maximum exclusion of HM ions from the plant is the survival strategy used by excluders, which make up the bulk of plant species that can survive in soils with high concentrations of hazardous trace elements (Baker *et al.*, 1991). Plants that can accumulate heavy metals (HM) in their aboveground portions without exhibiting symptoms of phytotoxicity are known as hyperaccumulators (Baker *et al.*, 1991; Rascio and Navari-Izzo, 2011). Originally used to describe the New Caledonian Ni accumulating tree *Sebartia acuminata* (Sapotaceae), the term "hyperaccumulator" was discovered to have a nickel content of 26% of dry weight in the latex. (Jaffré *et al.*, 1976). There are approximately 450 identified HM-hyperaccumulating species, spread over 45 angiosperm groups, as of 2015 (Rascio and Navari-Izzo, 2011; Krzciuk and Gałuszka, 2015). The number of known hyperaccumulators has been rising significantly. Asteraceae, Euphorbiaceae, Rubiaceae, Fabaceae, Scrophulariacea, Myrtaceae, Proteaceae, Caryophylaceae, and Tiliaceae are also abundant in hyperaccumulators; the Brassicaceae family accounts for about 25% of all hyperaccumulators found to date (Reeves, 2000; Rascio and Navari-Izzo, 2011). A significant proportion of hyperaccumulator species appears to exist in several plant genera; for instance, research that looked closely at the genus Alyssum revealed that 48 out of 170 species hyperaccumulate Ni. (Brooks *et al.*, 1979; Brooks and Radford, 1978).

Several published studies have shown that hyperaccumulators have an exceptional ability to take up heavy metals (HMs) from the soil and store them in aerial plant organs. This feature seems potential for application in phytoextraction.

For instance, phytoextraction using *N. carulescens* would be entirely possible for low Cd soil levels, according to Robinson *et al*,1998); plants would achieve bioaccumulation coefficients of about 60 and 10 for 1 mg•kg$^{-1}$ Cd in soil, respectively, and only one harvest would be needed to reduce a soil Cd content of 10 mg•kg$^{-1}$ in half (Robinson *et al.*, 1997)

Using N. caerulescens grown at a Cd soil value of 5 mg•kg$^{-1}$, Nishiyama *et al*. (2005) discovered that the Cd concentration could be lowered to 50% in as little as two to six harvests, depending on whether the soil was Andosol or Fluvisol. Additionally, Jacobs *et al*. (2017) showed that the removal of Cd and Zn from the soil was within a range that is already practically relevant for phytoextraction via field trials on urban HM-contaminated soil using *N. caerulescens* (Cd and Zn absorption values of 200 g. ha$^{-1}$ and 47 kg. ha$^{-1}$, respectively) (Nishiyama *et al.*, 2005).

In their 1997 field investigation, Robinson *et al*. used the autochthonic Ni hyperaccumulator *Alyssum bertolonii* on ultramafic soils in Italy. It may be possible to economically mine Ni by producing up to 72 kg Ni. ha$^{-1}$ without having to resow for a subsequent harvest. Likewise, in a single crop, field tests with *A. murale* recovered up to 112 kg Ni. ha$^{-1}$ (Robinson *et al.*, 1997; Bani *et al.*, 2015).

In soil or water, harmless chemicals can be removed, retained, or supplied by rapidly developing plants (Mahar *et al.*, 2016). It is an environmentally friendly, cost-effective, and aesthetically pleasing method of detoxifying pollutants (Zhang *et al.*, 2010). Plant species that can absorb and store large concentrations of metal pollutants in their shoot sections can make phytoremediation effective.

**Table 1 :** List of some hyperaccumulator

| Latin Name of metal Hyperaccumulator plants | Family Name | Accumulate in part of plant | Heavy metals | References |
|---|---|---|---|---|
| *Bornmuellera emarginata*<br>*Odontarrhena chalcidica*<br>*Noccaea goesingensis*<br>*Alyssum murale* | Brassicaceae<br>Brassicaceae<br>Brassicaceae<br>Brassicaceae | Shoots and roots<br>Roots<br>Young leaves<br>Shoot | Nickel | (Serigne *et al.*, 2024)<br>(Wang *et al.*, 2024)<br>(Wenzel *et al.*, 2003)<br>(Li *et al.*, 2003) |
| *Calendula officinalis L*<br>*Thlaspi caerulescens*<br>*Solanum nigrum*<br>*Tagetes patula L.* | Asteraceae<br>Brassicaceae<br>Solanaceae<br>Asteraceae | Roots<br>Mesophyll protoplast<br>Leaves<br>Roots | Cadmium | (Liu *et al.*, 2023)<br>(Chaney *et al.*, 2005)<br>(Wang *et al.*, 2007)<br>(Sun *et al.*, 2018) |
| *Pteris vittata* | Pteridaceae | Fronds | Arsenic | (He *et al.*, 2016) |
| *Pteridium aquilinum*<br>*Ipomea aquatica*<br>*Pongamia pinnata (L.) Pierre* | Dennstaedtiaceae<br>Convonvulaceae<br>Fabaceae | Gametophyte and sporophyte<br>Roots and Shoots<br>Stems and leaves | Chromium | (Silva *et al.*, 2023)<br>(Ton *et al.*, 2015)<br>(Das *et al.*, 2021) |
| *Mentha arvensis*<br>*Erato polymnioide*<br>*Miconia sp.* | Lamiaceae<br>Asteraceae<br>Asteraceae | Shoot and root<br>Roots<br>Aerial organs | Mercury (Hg) | (Manikandan *et al.*, 2015)<br>(Chamba *et al.*, 2017)<br>(Chamba *et al.*, 2022) |
| *Chlorophytum orchidastrum*<br>*Agrostis tenuis* | Asparagaceae<br>Gramineae | Roots<br>Aerial parts | Lead (Pb) | (Manginsay *et al.*, 2017)<br>(Anguilino *et al.*, 2022) |
| *Brassica juncea*<br>*Thlaspi caerulescens*<br>*Cratoxylum sumatranum* | Brassicaceae<br>Brassicaceae<br>Hypericaceae | Leaf and stem<br>Mesophyll protoplast<br>Leaf, stem and roots | Zinc (Zn) | (Lohmann *et al.*, 2023)<br>(Bert *et al.*, 2000)<br>(Castanares *et al.*, 2020) |

### Obstacles to the Effectiveness of Phytoextraction

The solubility of metal pollutants in soil solution is directly related to the accessibility of heavy metals to specific plant roots, which is necessary for the effectiveness of phytoextraction (Felix, 1997; Antoniadis *et al.*, 2017). Increased cation exchange capacity, organic matter content, and metal retention and dissolution in soil solution are all influenced by high soil pH (Tang *et al.*, 2015) Depending on how plants absorb them, heavy metals in soil can be divided into accessible, exchangeable, and unavailable fractions (Zhou and Song, 2004). Applying plant species with high biomass output, faster growth rates, and a strong propensity to accumulate toxic heavy metals in their aboveground portions is necessary for efficient phytoextraction (Clemens *et al.*, 2002).

### Pros, Cons, and Upcoming Developments in Phytoremediation

One technique that shows promise for wiping up heavy metal-polluted ground is phytoremediation. The extended duration of phytoremediation, limited bioavailability of heavy metals, and sluggish growth rate of metal-accumulating plant varieties are some drawbacks of this technology (Naees *et al.*, 2011). The least expensive method of treating soil affected by heavy metals is phytoremediation (Rakhshaee *et al.*, 2009). Following phytoextraction, the collected plant biomass can be utilized to produce bioenergy (Van Nevel *et al.*, 2007). There aren't many field studies on the still-emerging topic of phytoremediation, which is only studied at the pot level. Under field and greenhouse conditions, results may change (Ji *et al.*, 2011). Numerous elements, including the uneven distribution of contaminants, soil pH, pathogens, nutrients, moisture, or temperature, influence the phytoremediation process at the field level.

The success of this technology requires the identification of plant species with high biomass output and the ability to accumulate heavy metals (Rodriguez *et al.*, 2005).

## Conclusion

One of the biggest risks to soil and human health, according to this review, is heavy metal contamination. There are several ways that these metals might enter the environment. Using traditional repair methods is expensive and bad for the environment. Heavy metal-polluted soils must therefore be remedied using inexpensive, environmentally benign solutions. The most efficient plant-based method for eliminating contaminants from contaminated areas without endangering the structure of the soil is phytoremediation of metals.

The field of phytoremediation is still in its early stages, and many technological problems still need to be resolved. Although the results are positive, they also highlight the need for further action. Concurrent developments in agricultural and environmental engineering should have a major impact on the efficiency of plant cultivation and the disposal of metal-enriched biomass.

There are several applications for the multidisciplinary technology known as phytoremediation. According to current findings, several plants may be useful in the elimination of dangerous metals. To achieve meaningful long-term improvements in phytoremediation, scientists must identify genes from various plant, bacterial, and animal sources that can improve the plant's capacity to absorb metals. Phytoremediation is a remediation technique that uses green plants to remove pollutants from the environment. Another eco-friendly technique for treating areas impacted by heavy metals is phytoremediation. Previous research indicates that some plants have a high capacity for bioaccumulating heavy metals, making them suitable for use in the phytoremediation process.

## Data Availability

Data will be made available on request.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Credit of Authors

**Sakshi Verma –** Writing original draft, Data curation, Drafting the article, conception or design the work, Data collection.

**Akanksha Dubey–**Review and editing, Conceptualization, Graphical and diagram analysis.

**Pramila Pandey-** Critical revision of the article, Review and Editing.

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