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A Comprehensive Study on Native Plant Species for Phytoremediation of Heavy Metals Contamination in Soil

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Abstract

Phytoremediation refers to the use of plants to remove or stabilize environmental contaminants in an environment. It is regarded as a highly effective and inexpensive method in countering heavy metal pollution. This paper examines the feasibility of using native plants in phytoremediation through the demonstration of their sensitivity, survivability, and tolerance towards the local environmental condition and their capability to accumulate and tolerate contaminants such as lead, cadmium, and arsenic. Native species have various advantages that include lesser upkeep requirements, improved ecosystem incorporation, and least invasive danger. The mechanisms involved in phytoremediation range from phytoextraction, Phyto stabilization, and rhizofiltration to the specific roles played by native plants in remediation processes of soil and water. Case studies are presented to demonstrate the successful use of native species at various contaminated sites. Challenges related to scalability and ecological risks are addressed. Emerging trends, including biochar amendments, genetic modification, and expanded applications into urban areas, suggest promising future directions.

Keywords: Phytoremediation, Native plant species, Heavy metal contamination, Environmental remediation, Ecosystem stability.

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Introduction

Phytoremediation is a biotechnology that is regarded as more sustainable and cost-effective removal or stabilization of contaminants from the environment through the use of plants. This method makes use of the inherent ability of plants to uptake, store, or immobilize pollutants, especially heavy metals such as lead, cadmium, and arsenic, in soils and water. Heavy metal contamination is persistent and bio accumulative in nature, thus it creates important ecological and health risks, hence remediation. Emerging in this scenario as promising candidates for phytoremediation are native species. The ability of native species to thrive under local climates and to resist environmental stress, coupled with their tolerance, makes them ideal candidates for remediation. Most native species, if not all, are tolerant and can accumulate heavy metals economically with minimal management needs, that is both environmentally and economically beneficial. "Native plant species have garnered significant attention for their potential in phytoremediation of heavy metals contamination. Plants such as Indian mustard (Brassica juncea), Vetiver grass (Chrysopogon zizanioides), and Black nightshade (Solanum nigrum) have shown remarkable ability to hyperaccumulate heavy metals like lead, cadmium, and chromium. For instance, Indian mustard has been found to remove up to 45% of lead from contaminated soil, while Vetiver grass has been effective in reducing cadmium levels by 70%. Similarly, Black nightshade has demonstrated potential in absorbing chromium and copper. These native plant species offer a cost-effective, eco-friendly, and sustainable solution for remediation of heavy metal-contaminated sites, particularly in developing countries where resources are limited. Furthermore, their adaptation to local climate and soil conditions enhances their phytoremediation efficiency, making them ideal candidates for restoration of polluted ecosystems." This study provides an in-depth assessment of the potential of indigenous species for the phytoremediation of heavy metals. It delves into the principles that guide phytoremediation, the unique properties of native plants that allow their survival in toxic environments and the specific types of plants suitable for particular contaminants. Such a study also covers the overview of the advantages of native species in phytoremediation projects, usage in various settings, and examples of some successful outcomes. The present paper mainly addresses the challenges posed when implementing phytoremediation on a larger scale and discusses future research directions for optimizing the use of native species in environmental restoration.

Literature Review

Kumari, (2016) searched for eco-restoration-friendly plants in places polluted with fly ash (FA) close to the National Thermal Power Corporation (NTPC) at Kahalgaon, Bihar, India. A total of 30 plant species were surveyed for diversity and dominance, including 5 aquatic species, 25 terrestrial species, and 6 ferns. Eight land plants and five water plants were examined for the presence of Fe, Zn, Cu, Ni, Si, Al, Pb, Cr, and Cd following the screening of dominant species in a severely polluted environment. The accumulation of heavy metals by various plant species varies. Typha latifoliate is efficient at accumulating iron (927), copper (58), zinc (87), nickel (57), aluminum (67), cadmium (95), and lead (69), whereas Azolla pinnata is the aquatic plant with the highest capacity to hyper-accumulate Cr (93) in μg g−1. Of all terrestrial species, Croton bonplandium contains the greatest concentrations of iron (998), zinc (81), nickel (93), aluminum (121), and silicon (156). Naz, et al. (2022) investigated the levels of cadmium (Cd) in the soil and plants at Peshawar's Hayat Abad Industrial Estate. We evaluated the capacity of plants for phytoremediation by calculating the Bioconcentration Factor (BCF), the Translocation Factor (TF), and the Bioaccumulation Coefficient. All plants that were cultivated using BAC were native. From 50 different sites, we were able to determine soil cadmium values ranging from 11.54 mg/Kg to 89.80 mg/Kg. Depending on the source, the cadmium concentrations in the soil at the site might be anywhere from 12.47 mg/Kg (HIE-ST-14L Royal PVC Pipe) to 11.54 mg/Kg (HIE-ST-11 Aries Pharma). The majority of plant species showed promise in phyto-extraction and phytoremediation. Mousavi Kouhi, (2020) explored natural plant species that often flourish in the HM-contaminated salty-sodic soil near the Qaleh-Zari copper mine in eastern Iran, in order to identify prospective plant species for phytoremediation. We measured the buildup of heavy metals (HMs) (Cu, Zn, Cd, and Pb) in the soils surrounding the plants, as well as in their roots and shoots (leaf and stem), to determine whether phytoextraction or phytostabilization was the major phytoremediation strategy. Out of the seven native species that were able to withstand such severe conditions, five were Artemisia santolina Schrenk, four were Pulicaria gnaphalodes (Vent.) Boiss, two were Zygophyllum eurypterum Boiss. & Buhse, one was Peganum harmala L., the other was Pteropyrum olivieri Jaub. & Spach, and the last was Aerva javanica (Burm. f.) Juss. Ex Schult.

Principles of Phytoremediation

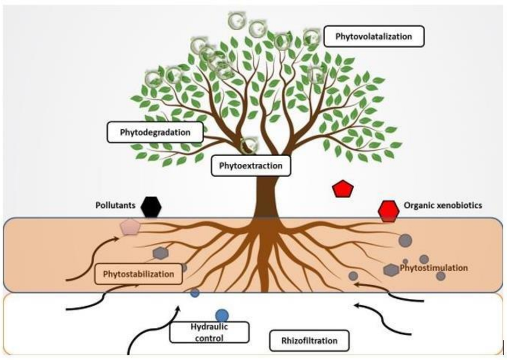

Figure 1: Mechanism of Phytoremediation

Core Concepts of Phytoremediation: There are several mechanisms employed by phytoremediation to remove environmental pollutants: Phytoextraction: Heavy metals taken up from the soil via the root system and sequestered in aboveground parts to decrease soil pollution. Phyto stabilization: The plant retains contaminants within the soil through immobilization to prevent transport and lessen bioavailability. Phytovolatilization: Certain plants metabolize taken-up contaminants to volatile compounds that can be transferred to the atmosphere. Rhizofiltration: Roots remove heavy metals and other inorganic contaminants from water and make them unavailable to the general environment.

Role of Native Plants in the Principles of Phytoremediation: Native plants are valuable in phytoremediation because they are tolerant to local conditions, meaning they are adaptable to regional climate, soil, and ecological stressors. Also, native plants are natively integrated in the ecosystem, which plays a crucial role in the stabilization of contaminated sites via Phyto stabilization. They efficiently accumulate metals, as in hyperaccumulators. They stabilize them and do not allow the spread of contaminants within water bodies and soil ecosystems. Normally, they require less maintenance compared to non-native species and are therefore quite practical for large-scale or long-term phytoremediation projects.

Native Plant Species: Definition and Properties

Definition of Native Plants in Context of Phytoremediation: Native plants are flora species naturally adapted to a certain environmental condition, climate, and soil of a given region. Within the context of phytoremediation, they have ecological benefits since they fit well into their local environments and more often than not, they seem to have better hardness and survival rates than non-natives.

Relevant Properties to Phytoremediation: Native plants are good for phytoremediation because they possess some of the following characteristics:

A root structure- Deep or extensive root systems make it possible for plants to absorb toxins while providing anchorage within contaminated soil and therefore stabilizing it.

Biomass- Biomass-rich plants absorb more pollutants. Plants that tolerate heavy metals can survive in polluted environments. Native plants can store heavy metals in their tissues to lower soil and water concentrations.

Figure 2: Some of the Native Plant Species

Types of Native Plants for Phytoremediation: Each native plant species has characteristics that make it more suited to remediation of certain contaminants:

Hyperaccumulators: Plants natively growing in the regions can accumulate extraordinarily high amounts of heavy metals, for example, cadmium, lead, and arsenic; in such cases, they prove to be excellent candidates for phytoextraction.

Stabilizers: Some native grasses and shrubs can stabilize contaminated soils from erosion and leaching.

Aquatic and Riparian Species: They filter out polluted water and retain soil along rivers and other water bodies.

Applications of Native Plants in Phytoremediation

Heavy Metal Contaminant Removal: Native plants for effective removal or stabilization of heavy metals such as lead, cadmium, and arsenic in soils and water will be used. They reduce metal concentrations and improve the quality of soil through mechanisms like phytoextraction and rhizofiltration.

Soil and Water Remediation: Native plants are used in projects of soil and water remediation, especially in wetlands and riparian zones. Their good adaptability makes them establish and thrive in contaminated sites, absorb metals from soil and water, and gradually permit the restoration of natural habitats.

Reclamation of Contaminated Land: Restoration of the ecological balance helps stabilize soils and reduces the concentration of metal, allowing native plants to reclaim contaminated lands. Such reclaimed sites can be opened up for agriculture or other recreational uses or other activities on safe and sustainable grounds.

Advantages of Using Native Plants for Phytoremediation

Figure 3: Phytoremediation using Native Plant

Adaptability to Local Environment: Since native plants are adjusted to their climates and ecosystems, they are less demanding. Thus, with native plants, there is more resilience in phytoremediation projects even when the conditions are harsh, contaminated.

Higher Sustainability: Phytoremediation utilizes local species of flora to preserve biodiversity, support indigenous plant and animal life, and stabilize the ecosystem. Since it is assimilated with the natural ecosystem, such efforts can be more sustainable without causing a jolt.

Cost-Effective: A native plant uses fewer inputs, such as fertilizers and pesticides, because of its adaptation to the local climate and soil.

Lower Invasive Risk: Native species pose lower risks of invasiveness and environmental disruption as compared to non-native plants. They balance the ecological environment; thus, they do not spread and compete with natural plants.[7]

Types of Native Plants Suitable For Phytoremediation of Heavy Metals

Hyperaccumulators: Unusual heavy metals are absorbed by these native plants. Because Brassica junco, an Indian mustard, absorbs a lot of lead and cadmium, it can be used to phytoextract contaminated soil.

Native plants with stabilizing potential: These plants have the ability to absorb and stabilize heavy metal pollution, but they are not hyperaccumulators. These plants aid in soil stabilization by reducing metal leaching and soil erosion.

Riparian and Wetland Plants: The best specimens for water-based phytoremediation are Typha's species. The common reed, Phragmites, can be used in riparian and wetland environments because it absorbs heavy metals from water.[14]

Case Studies

Native Plants for Lead Remediation: Such lead-free spaces have been achieved through numerous successful projects that use the removal of lead from the contaminated area using specific native plants. For example, it has been shown scientifically that the presence of hyperaccumulating plants reduces levels of lead in a polluted soil over time.

Cadmium and Arsenic Phytoremediation Using Native Species: It has been demonstrated in various studies that native hyperaccumulator species can be used for the phytoremediation of cadmium and arsenic. These species are applied in sites contaminated by industrial or mining activities to decrease heavy metals concentrations to safer levels.

Water-based Phytoremediation through wetland plants: Wetland plants are constructed as artificial wetlands using local water-borne flora species in the water body being polluted with heavy metals, thereby improving water quality by cleansing the heavy metal residues present in it, resulting in aquatic ecosystem health.

Challenges and Limitations

Table 1: Challenges and Limitations of Phytoremediation

Challenge/ Limitation	**Description**
Scalability and Site-Specific Effectiveness	Not easily scalable because the same levels of growth may not occur everywhere for plants, nor would be the same soil and degree of contamination.
Plant Toxicity and Growth Effects	Heavy metals present in large concentrations may have deleterious effects on plant growth and can also pose a threat of toxicity in indigenous species, reducing their effectiveness in the long run.
Environmental and Ecological Hazards	They can alter an ecosystem and impact its micro-flora and fauna and increase the danger of metal getting in the food chain.

Future Perspectives

Emerging Trends in Phytoremediation: Current advancements focus on boosting the ability of plants with genetic modification, biochar amendments, and plant-microbe interactions. These recent developments improve the uptake capability, stability, and contaminant tolerance of plants.

Native Plant Species in Urban and Industrial Sites of Waste: Native species are also being considered in the application of urban and industrial waste sites, which could include abandoned industrial locations or urban areas contaminated by heavy metals.

Research Directions and Opportunities: Future research will be able to generate new hyperaccumulator species; it will focus on carrying out field trials to examine effectiveness and examine the ecological effects of phytoremediation in terms of soil health and biodiversity. 9

Conclusion

Native plants play a very important role in sustainable phytoremediation of heavy metal contamination. They have excellent ecological and practical benefits, mainly through adaptation to local environments and the presence of high metal uptake and stabilization capabilities, which makes them useful for soil and water remediation in contaminated areas. Native species support biodiversity, improve ecosystem stability, and provide a cost-effective alternative for environmental clean-up. Advances in phytoremediation techniques could lead to new applications, including biochar amendments to increase native metal uptake or genetic modification for improved uptake. With these promises, native plants are still very promising and will see broader applications in the future both in environmental restoration and in sustainable land management, increasing their importance for ecological conservation and pollution reduction.

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