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Review Article

PHYTOREMEDIATION OF METAL CONTAMINATED SOILS - THE FUTURE OF ENVIRONMENT RESTORATION

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ABSTRACT
Phytoremediation is one of the most environment friendly approaches to treat metal contaminated soils which are prone to environmental problems and may pose threat to various living systems including humans and animals. Plants are being widely used to treat contaminated soils around the world. This review provides a detailed information on how phytoremediation is done and the type of plants used for this purpose. Since heavy metals are not biodegradable, they are taken up by plants and then these metals are extracted from the plant's biomass.

***Keywords**: Phytoremediation, Heavy metals, Hyperaccumulators, Phytoextraction, Phytostabilization, Rhizofltration*

INTRODUCTION
Phytoremediation is the use of plants to remediate polluted soil. Pollutants are adsorbed and accumulated in plant tissues thereby reducing their bioavailability in soil (Asati *et al*., 2016). Phytoremediation helps us to treat pollution in an environment friendly way. Phytoremediation is a great way to expand Phyto companies and to reduce animal danger. Land owners can make use of this technology to remediate their polluted land in an environmentally safe way (Bajpai and Pandey, 2019). Microorganisms can be inoculated into plants for better uptake of pollutants like metals. Serpentine bacteria have proven to increase metal uptake and translocation in *Brassica juncea* and *Ricinus communis* (Ma *et al.*, 2015). Metals like magnesium, copper, iron, manganese are generally adsorbed by plants at particular levels. Increase and decreased uptake may lead to plant toxicity. Magnesium is used by plants to split water molecules. Deficiency of magnesium will lead to chlorosis and leads to oxidative stress in plants (Alia *et al*., 2015). So, to use a plant for phytoremediation, the plant must have high tolerance towards the pollutant which is targeted. Plants which belong to the category called hyperaccumulators can be used for this purpose (Souri *et al*., 2017). The advantages of using phytoremediation (Yan *et al*., 2020) over other methods include:

i. Economic feasibility
ii. Environment friendly approach
iii. Large scale applicability
iv. Easy disposal
v. Prevention of soil erosion which may lead to leaching of metals to other places
vi. Less waste generation
vii. Can be done in-situ
viii. Minimum environmental damage
ix. Aesthetically pleasing
x. Reduced movement of contaminants
xi. Sunlight and water are the major sources which are abundantly available
xii. Cost effective technology
xiii. Less environmental impact
xiv. Increases the quality of the soil

xv. Plants will also increase air quality
xvi. Easy use on large sites
xvii. Multiple crops can be grown in one season

The main objective of this review is to highlight how plants are used to remediate heavy metal contaminated soil.

PHYTOREMEDIATION OF HEAVY METALS

Phytoremediation is a plant-based approach to remove pollutants or lower their level in soil by plant adsorption. For example, arsenic contamination can be removed using ferns (Cai *et al.,* 2019). Plants can be used to clean metals, oil toxins and even explosives from contaminated soil. Plants of radish, lettuce and spinach can also be used to treat metal contaminated soil (Hamadouche, 2012) (Gunduz *et al.,* 2012). Agricultural soil which is contaminated with heavy metals would lead to danger of both animals and humans. Traditional physical and chemical process might be too expensive involving heavy labor and hence phytoremediation would help to solve the problem. There are different types of phytoremediation methods to treat heavy metal contaminated soils (Muthusaravanan *et al.,* 2020) and they are classified as the following:

Phytoextraction- This is the most common method in which adsorption and translocation of contaminants from root to shoot of the plant occurs after which the plant is incinerated to harvest metal from the ash. Chelating agents are useful to transport heavy metals from root to shoots of plants (Asgari *et al.,* 2019).

Phytostabilisation- This method involves the use of plants to immobilize contaminants by adsorption and accumulation in their tissues. This helps to prevent the migration of contaminants either by erosion or deflation. Phytostabilisation occurs as a result of precipitation, sorption or complexation (Shackira and Puthur, 2019).

Rhizofiltration-In this method, plant roots take up the metal and they are grown until they become strong and then transported into contaminated soil. Plants are then removed after the roots become saturated with contaminated metals. It also helps to avoid heavy metals from spreading deeper. Plants used for rhizofiltration should have the below mentioned characteristics (Yan *et al*., 2020).

i. Strong and dense roots
ii. High biomass yielding capacity
iii. Higher tolerance for heavy metals

Phytovolatilization- In this type, the mechanism is that the plant roots take up heavy metals like mercury along with water and convert them into volatile organic compounds before releasing into the atmosphere in a less toxic form. This method is not efficient as the contaminant is released into the atmosphere. Genetically modified plants are mostly used for phytovolatilization (Nigussie and Awgchew, 2022).

SELECTION OF PLANTS FOR PHYTOREMEDIATION

In order to select a plant for phytoremediation, one must understand the type of contaminant which has to be treated. Characteristics of the soil and contaminants should be studied thoroughly before choosing a plant for phytoremediation. In case of metals, the element character should be studied carefully because of its unique soil and chemical properties of the plant. Factors like bioaccumulation factor, metal accumulation index, comprehensive bioconcentration index and translocation potential can be tested for a plant to determine its hyperaccumulation capacity (Parihar *et al.,* 2020). After all the characteristics are studied, the plant would be selected based on the following factors (Akram *et al.*, 2015).

i. Contaminant type
ii. Regulatory concerns
iii. Bioavailablity of the pollutant
iv. Site growing conditions
v. Site specific condition

FACTORS AFFECTING HEAVY METAL UPTAKE BY PLANTS

There are several factors which can influence the uptake of heavy metals by plants. Understanding these factors efficiently and making use of them will help the researchers to understand and determine a proper design to cultivate plants for phytomining or phytoremediation. (Jung, 2008). Some of the factors are:

I. Plant Species

The uptake of a chemical compound depends on the species to which a plant belongs. Many plants belonging to Brassicaceae and Amaranthaceae have proven to be hyperaccumulators. (Nouri *et al*., 2009). The success of phytoextraction technique depends on proper choice of a plant which could take up the desired metal.

II. Medium Properties

Several properties of the medium in which the plant is grown can influence the metal uptake by the plant. Some of the properties are pH, organic matter content, soil texture, addition of chelators, fertilizers, metal concentration (Jung, 2008).

III. Root Structure

Root parts of the plant will influence the rate of metal uptake. Metals could be adsorbed, stored, transported or metabolized in the root portions of the plant. Increased root diameter and reduced size will help in proper remediation of dried soils (Merkl *et al*., 2005).

IV. Bioavailablity

A plant's ability to uptake a metal depends on the bioavailability of that metal in water phase. Metal should react with water and other contents for easy uptake by the plants (Tangahu *et al*., 2011).

V. Chelating Agents

Chelating agents can be added to increase the bioavailability of the heavy metals. Addition of chelating agents might carry the risk of increased leaching. Exposure of chelating agents to the plant for a period of two weeks improved metal translocation and phytoextraction potential. These chelating agents can form complexes with metal ions and thereby increasing their availability in soil (Dipu *et al.,* 2012). Some examples of chelating agents are given below:

1. EDTA

Ethylenediaminetetraacetic acid (EDTA) is the most widely used and most efficient synthetic chelating agent. It has proven to increase the concentration of various heavy metals in plant biomass (Hasan *et al.,* 2019). Slow degradation and long persistence may lead to leaching and EDTA might not be useful in treating on-site because EDTA is non-biodegradable. EDTA also has a risk of contaminating ground water (Shahid *et al*., 2014).

2. Citric Acid

Citric acid is a natural chelating agent which is non-toxic. Using citric acid is environment friendly because it can be easily degraded in the environment. Citric acid is easily available and cost effective. Citric acid can help the plant to release exudates thereby increasing the root growth of the plant (Saffari and Saffari, 2020).

3. EDDS

Ethylenediamine-N, N'-disuccinic acid is also a biodegradable chelating agent. EDDS is not as efficient as EDTA in increasing metal uptake by plants. But EDDS can be used instead of EDTA because it's easily degraded and is comparatively expensive when compared to other chelating agents (Chen *et al.*, 2020).

HYPERACCUMULATORS

The first hyperaccumulating plant was reported by Jaffre *et al.,* 1976. *Sebertia accuminata* was found to accumulate about 20-25 percent nickel in its latex. The most common hyperaccumulator plant families (Muszynska and Fajerska, 2015) are:

i. Brassicaceae
ii. Caryophylaceae

iii. Fabaceae
iv. Euphorbiaceae
v. Violaceae
vi. Asteraceae
vii. Laminaceae
viii. Poaceae
ix. Cyperaceae

Some examples of plant hyperaccumulators are given in table 1

Table 1- Examples of hyperaccumulating plants.

PLANT	METAL	REFERENCE
Alyssum murale	Ni	Lucisine *et al.*, 2014
Arabidopsis halleri	Zn	Schvartzman *et al.*, 2018
Pteris vittata	As	Wan *et al.*, 2015
Astragalus racemosus	Se	Lindblom *et al.*, 2013
Alyssum bertolonii	Ni	Mengoni *et al.*, 2012
Biscutella laevigata	Tl	Karman *et al.*, 2015
Solanum nigrum	Cd	Khalid *et al.*, 2019
Isatis pinnatiloba	Ni	Altinozlu *et al.*, 2012
Sedum alfredii	Pb	Lu *et al.*, 2013
Corrigiola telephiifolia	As	Garcia-Salgado *et al.*, 2012
Polypogon fugax	Cu	Ghaderian and Ravandi, 2012
Brassica nigra	Pb	Koptsik, 2014
Silene vulgaris	Hg	Perez-Sanz *et al.*, 2012

IMPORTANCE OF HYPERACCUMULATING PLANTS

Metal toxicity can be a major cause of several diseases for animals and humans. For example, short term lead poisoning can lead to effects like constipation, abdomen pain, tiredness, headache, weakness, tingling of hands and feet, short term memory loss. Lead poisoning can also cause anemia and dementia. Over exposure of metals can cause reproductive, respiratory and neurological problems. It might also cause cancer (Singh and Kalamdhad, 2011). Since heavy metals are not biodegradable, once it enters the soil it will remain contaminated unless treated. Phytoremediation is an important process to treat this contaminated soil. Phytoremediation using hyperaccumulator plants is an environment friendly way to treat contaminated soil and water. Metals are extracted from these plants later and used (Leitenmaier and Kupper, 2013).

Agromining or phytomining uses hyperaccumulator plants to take up metals in harvestable biomass of plants. Harvesting, drying and incineration of this biomass will yield high grade bio-ore. General mining procedure can cause acid mine drainage, soil erosion chemical pollution, contamination of ground water, loss of bio diversity. Agromining or phytomining helps to overcome these difficulties. Mining process can be less harmful by using phytomining process (Kidd *et al.*, 2018).

MECHANISM OF HYPERACCUMULATION

A plant is regarded as a hyperaccumulator (Muszynska and Fajerska, 2015) based on three main characteristics. They are:

i. Capacity to extract the heavy metal from soil into the plant by their roots.
ii. Ability to tolerate and extract high level of elements is a key character of hyperaccumulating plant. It is mainly achieved due to vacuolar compartmentalization and chelation.
iii. Enhanced ability to translocate the metals from their root to shoot.

iv. The concentration of metals in roots will be higher when compared to shoots in normal plants. In hyperaccumulators, the shoot metal concentration can be more than root metal concentration.
v. Larger capacity of storage of heavy metals in their shoots and root.
vi. Hyperaccumulator plants can store high concentrations of metals in their tissues which can be extracted from their biomass (Ancona *et al.,* 2020).

BIOTECHNOLOGY TECHNIQUES TO IMPROVE PHYTOREMEDIATION

The ability of hyperaccumulation in plants can be increased using biotechnology techniques. Genetic engineering technologies can help to design a plant which will have higher hyperaccumulation capacities. For example, *Agrobacterium*-mediated transformation helps to introduce genes which encode for phytochelatin synthase or metallothioneins which will give transgenic plants with enhanced metal uptake, translocation and binding efficiency. Somatic embryogenesis-based regeneration systems can be used to propagate the transgenic plants for commercial applications (Muthusaravanan *et al.*, 2020).

CONCLUSION

Plants used for phytoremediation of metals generally has the capacity of phytoextraction, phytostabilization and rhizofiltration. Plants like grasses to trees can be used for phytoremediation purpose. Phytoremediation of metal contaminated soils are done widely because heavy metals are closely related to plant growth. Valuable metals can be extracted and used by this phytoremediation process. Phytoremediation is the least destructive method for remediation of heavy metal contaminated soils.

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