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PHYTOREMEDIATION: A PROMISING TECHNOLOGY FOR REMOVAL OF HEAVY METALS FROM CONTAMINATED SOIL

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INTRODUCTION

Soil contamination is now a major threat to the world. Industrialization and urbanization are the main cause of soil contamination that happens by the accumulation of heavy metal. These heavy metals mostly originated from the oil or gas generated from many industries. It may be produced due to the use of phospahate fertilizers in agriculture sector, smelting and metal minin, sewage sludge, fossil fuel burning, pesticide application as explained by many researchers. Heavy metals can be classified to two categories essential and non-essential heavy metal based on their role in biological field. Cu, Fe, Mn, Ni, and Zn are some essential heavy metals which are required for physiological and biochemical processes that happening in plants (Cempel and Nikel, 2006). Non-essential heavy metals viz. Pb, Cd, Hg, and As are very toxic to plants which affects physiological and biochemical processes with decreasing the agricultural productivity (Clemens, 2006). After the development of research and technology on environmental remediation, some biologically-based approaches which is collectively known as bioremediation, now emerged as a special technique for eliminating or mitigating the impacts of environmental contaminants and to remove such contaminants from soil, a new novel technology has been developed for removal of contaminants from the soil called phytoremediation (Prasad, 2003; Salt et al. 1998). The term "phytoremediation" indicates that, the Greek prefix phyto means 'plant' and remedium which is means 'to correct or remove evil'. In a simple meaning it is the use of plant and bacteria and fungi to breakdown or to degrade toxic chemical compounds that have accumulated in the environment.

Phytoremediation is a simple, cost-effective and environment friendly method in which the plants are used to extract and remove the pollutants or lower their bioavailability in soil (Berti and Cunningham, 2000). Plants can absorb ionic compounds present in soil even if it presents with a low concentration through their root system. Plant's root creates a rhizosphere ecosystem inside soil to accumulate heavy metals with stabilizing the soil fertility (Ali et al., 2013; DalCorso et al., 2019). This technique is an autotrophic system as it uses the solar energy, economically feasible with a low maintenance. It can be applied over a large area of contamination and can easily be disposed. Numerous studies have been conducted to understand the molecular mechanisms behind heavy metal tolerance by the plants and to develop different techniques to improve phytoremediation efficiency.

SELECTION OF PLANT SPECIES

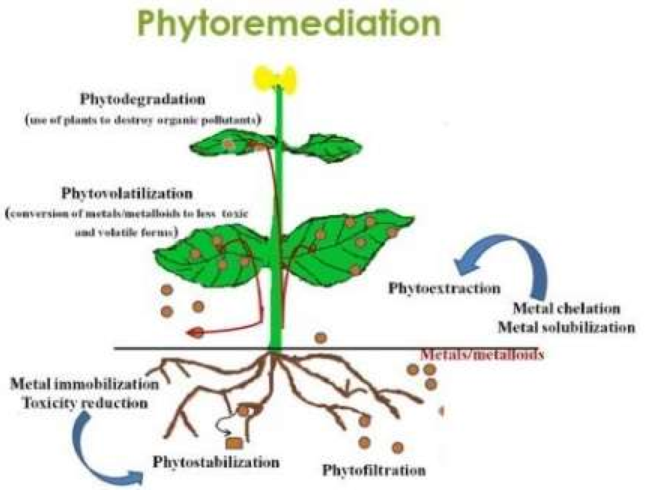
The efficiency and efficacy of phytoremediation technologies are mainly dependent on the physiological characteristics of the experimental plants and the kind of pollutants. However, the accumulation capability of heavy metals by plants varies remarkably between species and among cultivars within species because each species have different mechanisms of ion uptake based on their physiological, morphological, genetical and anatomical characteristics. So, it is most important to find a specific plant for a specific heavy metal for phytoremediation technologies. Many researchers have revealed a number of special plants which do not only grow easily in the soil containing heavy metals but can accumulate the heavy metals in their harvestable parts. These plants are known as hyperaccumulator having the ability to grow on metalliferous soils and to accumulate heavy metals in the harvesting organs without any harm by the phytotoxic effects. It has been observed by many researchers that some plants viz. *Thlaspi caerulescens*, *Arabis gemmifera*, *Arabidopsis halleri*, *Potentilla Griffithii* Hook, and *Sedum alfredii* are hyperaccumulators for Zn, while *Leersia hexandra* Swartz, *Nopalea cochenillifera* Salm. Dyck. and *Spartina argentinensis* are hyperaccumulators for Cr.

Thlaspi sp. are best known to hyperaccumulate more than one metal, for example., *T. caerulescens* can grow in presence of Cd, Ni, Pb and Zn, *T. goesingense* in Ni and Zn, *T. ochroleucum* in Ni and Zn, and *T. rotundifolium* for Ni, Pb and Zn *T. caerulescens* has the ability to uptake higher amount of Cd.

Moreover, there is no suitable utilization for these hyperaccumulators, which enrich a large number of heavy metals and easily release them to surrounding environment again. It may be concluded that the plants having large biomass, stress resistance, and non-food ways of utilization could be promising candidates of hyperaccumulator (grass) (Lewandowski et al. 2003). Landberg and Greger, 1999 have been identified that the plants having large biomass are best for remediation of soil or the plant with low biomass but high hyperaccumulating characteristics viz. *Arabidopsis* and *Thalspi* sp. The plant species that have been identified for remediation of soil include either high biomass plants such as willow or those that have low biomass but high hyperaccumulating characteristics such as *Thlaspi* and *Arabidopsis* species.

PHYTOREMEDIATION TECHNOLOGIES

There are a number of phytoremediation strategies that are applicable for the remediation of heavy metal-contaminated soils, that includes (i) phytostabilization- where plants are used to reduce the bioavailability of heavy metal in soil, (ii) phytoextraction- where the plants can extract the heavy metals from soil, (iii) phytovolatilization- where plants uptake heavy metal from soil, make them volatile and release them to atmosphere and (iv) phytofiltration- involves where the plants absorb or adsorb heavy metal ions from groundwater and aqueous waste hydroponical (v) phytodegradation- where the contaminants are taken up by plants further breakdown through metabolic processes within the plant. Another phytoremediation strategy known as phytodegradation which is used for breakdown of organic pollutants.



PHYTOSTABILIZATION

Phytostabilization uses certain metal-tolerant plant species to immobilize heavy metals present in soil by lowering their bioavailability thereby preventing their migration into the ecosystem. Precipitation of heavy metals occur in the rhizosphere whereas absorption, and sequestration happens within root tissues, or adsorption onto root cell walls. It also prevents the dispersion of heavy metal-containing soil particles by wind. The selection of appropriate plant species is crucial for phytostabilization. Ofcourse, plants should be tolerant to the heavy metal conditions especially the plants having dense root system are better perform for phytostabilization. Here plant roots play a pivotal role to immobilize heavy metals, stabilize soil structure, and prevent soil erosion.

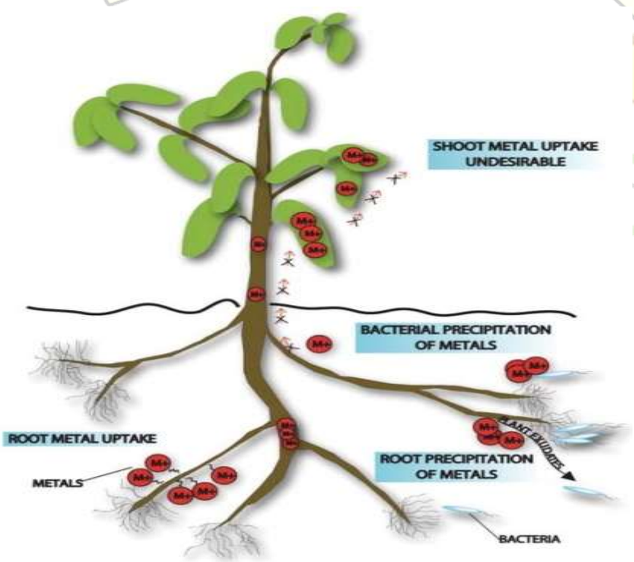


Fig. 1 Schematic diagram of Phytostabilization

To improve the effect of phytostabilization efficiency, organic or inorganic samples can be added to the contaminated soil. These soil amendments can change the metal speciation, reduce availability and solubility of heavy metals by changing the pH value and redox status of the soil. To facilitate the immobilization of heavy metal, the physiochemical properties of the metal-soil complex to be altered by introducing a multipurpose anion, such as phosphate, that enhances metal adsorption via. anion-induced negative charge and metal precipitation. It also benefits plant colonization and improve water-holding capacity.

Microorganisms such as bacteria and mycorrhiza that are living in the rhizosphere assist phytostabilization by adsorbing metals onto their cell walls, producing chelators and promoting precipitation processes (Göhre and Paszkowski, 2006; Ma et al., 2011). These microorganisms also serve as a barrier where it prevents the translocation of heavy metal ions from roots to shoots.

PHYTOEXTRACTION

Phytoextraction refers to uptake contaminants from soil or water, translocate and accumulate those contaminants in their aboveground biomass (Salt et al., 1995). Phytoextraction is the most important phytoremediation technique for removal of heavy metals and metalloids from the polluted soil (Ali et al., 2013).

Phytoextraction is also called phytoaccumulation.

The process of phytoextraction of heavy metals undergoes 4 steps as explained by Ali et al. (2013) that involves: (i) mobilization of heavy metals in rhizosphere, (ii) accumulation of heavy metals by plant roots, (iii) translocation of those heavy metal ions from roots to above part of plant, (iv) sequestration and distribution of heavy metal ions in plant tissues. There are successful factors on which the efficacy of phytoextraction relies viz. plant selection, plant performance, heavy metal bioavailability, properties of soil and rhizosphere. Also, the plants should have high tolerance capacity to uptake the heavy metals, must a fast growing with high biomass.

Plant's genetic ability and some agronomic practices including (1) soil management practices to improve the effectiveness of phytoextraction, and (2) crop management practices to develop a commercial cropping system are the successful factors for phytoextraction of heavy metals.

PHYTOVOLATILIZATION

Phytovolatilization is a process, in which uptake of contaminants from soil occur by the root and release them into the atmosphere as volatile form through transpiration. The process happens as growing plants absorb water and organic contaminants from underground. As water move from the roots to the leaves along the vascular system of the plant, it is changed and modified along the way. So, some of the

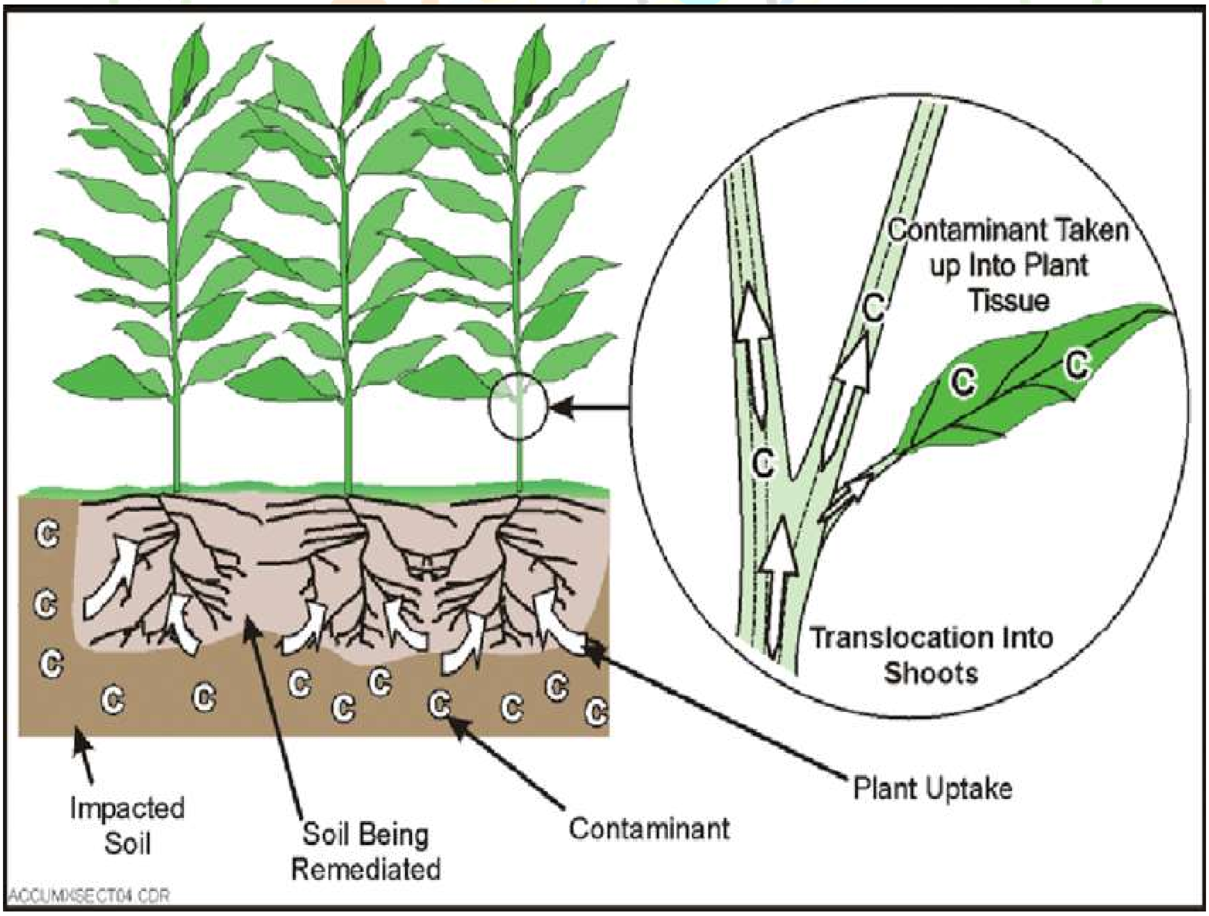


Fig. 2 Schematic diagram of Phytoextraction

contaminants proceed through the plants to the leaves and evaporate or volatilize into the atmosphere. Firstly, the process of phytovolatilization used to remove mercury. In which the mercuric ion is converted into less toxic elemental mercury then contaminants taken up by the roots pass through the plants to the leaves. After that they are volatilized through stomata, where gas exchange occurs. Mercury exists mainly as a divalent cation (Hg^{2+}) in the environment because of its high reactivity; bacteria can catalyze the reduction of the mercuric ion to elemental Hg and increase the volatilization capabilities of selected plants. This is a successful strategy for detoxification of metal ion contaminants e.g, Hg and Se by the chemical conversion of toxic elements into less toxic and volatile compounds from soil and plant foliage and then release it to atmosphere; as Mercury and selenium are high volatile in nature (Cristaldi et al. 2017; Wang et al. 2012). For example, the volatilization of Se involves the formation of organic selenoaminoacids selenocysteine and selenomethionine from inorganic Se. The latter is converted to volatile form by biomethylation process to form dimethylselenide, which can be lost to the atmosphere. *Brassica juncea* was identified as a successful plant for removing Se from soils (Banuelos & Meek, 1990;) via Se volatilization. *Astragalus racemosus* follow phytovolatilization process by converting the selenium into dimethyl diselenide. *Arabidopsis thaliana* can convert Hg^{2+} into Hg, which increases the volatility of mercury. However, the light intensity and temperature help the leaf tissues on releasing the mercury to the atmosphere (Wang et al. 2012).

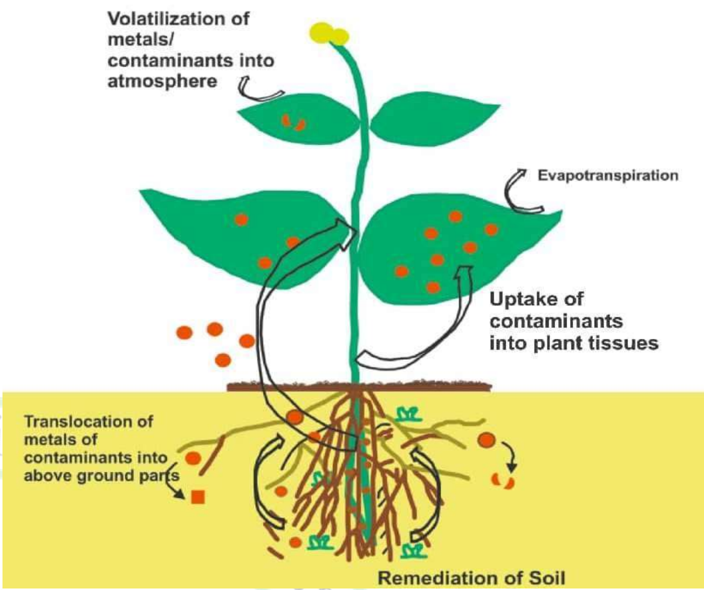


Fig 3. Schematic representation of Phytovolatilization

RHIZOFILTRATION

The process in which plants roots are used to adsorb and precipitate the organic and inorganic contaminants to remove them from the contaminated water or aqueouswaste streams is known as rhizofiltration. It is also called as phytofiltration. If the seedlings are used in place of roots, it is to be called blastofiltration. Plant roots or seedlings grown in aerated water absorb, precipitate and concentrate toxic heavy metals from polluted mass (Dushenkov and Kapulnik 2000). Bioabsorption involved some mechanisms that include chemisorption, complexation, ion exchange, micro precipitation, hydroxide condensation onto the biosurface, and surface adsorption. Essential factors such as hypoxia tolerant, metal tolerant, and large absorption surface area of plant are suitable to perform rhizofiltration (Cristaldi et al. 2017; Zhang et al. 2009). Aquatic plants are more desirable than terrestrial plants to perform in situ or ex situ rhizofiltration as the former have much larger fibrous root systems covered with root hairs with extremely large surface areas.

Thus,

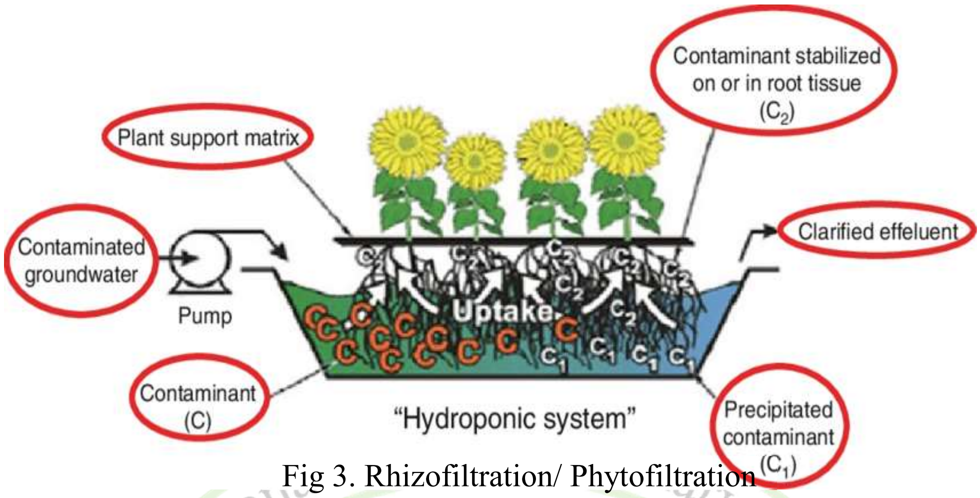


Fig 3. Rhizofiltration/ Phytofiltration

Phaseolus vulgaris and *Helianthus annuus* are two successful plants which can remove uranium from contaminated groundwater. *Helianthus annus L.* (Sunflower) and *Brassica juncea* Czern. (Indian mustard) are the two most favourable candidates for removing metals from contaminated water. Indian mustard is good at accumulating Cd, Cr, Cu, Ni, Pb, and Zn (Dushenkov et al. 1995) whereas sunflower absorb Pb (Dushenkov et al. 1995), U (Dushenkov et al. 1997a) from waste water. *Carex pendula* is a wet land plant which can accumulates large amounts of lead, particularly in root biomass, and can be considered for the removal of lead contaminated wastewaters in combination with proper biomass disposal alternatives (Yadav et al.,2011).

RHIZODEGRADATION/ PHYTODEGRADATION:

This is a method where the degradation of organic contaminants in the soil occurs by the microorganism present in the rhizosphere. Microorganisms viz. fungi, bacteria, and yeasts are carried out the process of rhizodegradation (Ely and Smets 2017). Plant exudates contain amino acids, carbohydrates, some enzymes and flavonoids. The nutrient enriched exudates provide nitrogen and carbon sources to the microorganisms present in the root surface. metabolic activities of the microorganisms enhanced by 10–100 times higher (Ali et al. 2013; Cristaldi et al. 2017). Due to this nutrient rich environment the process of extraction and removal of contaminants increased to an extent level. Also, the enzymes released by the plants help in growth of the soil microbes and degradation of the organic contaminants in the soil. This process shows a symbiotic relationship that has evolved between plants and microbes where plants provide sufficient nutrients that is necessary for the microbes to grow, while microbes provide a healthier soil environment.

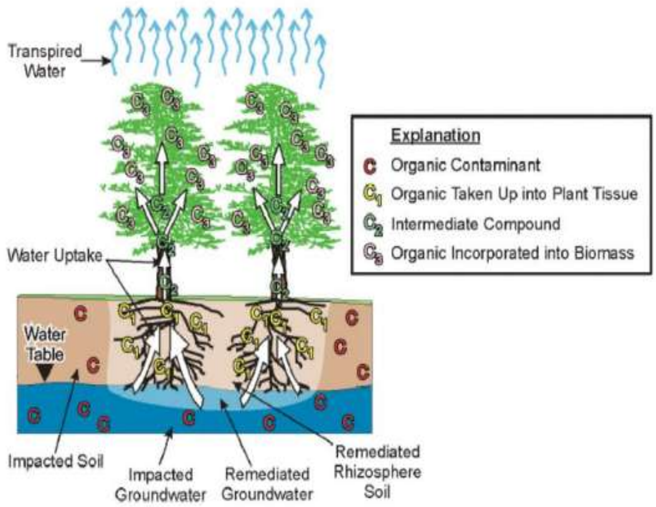


Fig 5. Phytodegradation

Phytoremediation can be considered as a green technology to analyse the heavy metal contaminated areas. As the physical and chemical remediation methods are expensive, create irreversible changes in soil properties and negative impact on human health, phytoremediation gives a better choice of technology to remediate the heavy metal–contaminated soil because it is cost effective and it can be applied to wider range of polluted sites without any side effects.

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