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Phytoremediation: An ecofriendly tool for *In-Situ* remediation of contaminated soil

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Abstract
In the race of development, various indiscriminate anthropogenic activities result in the accumulation of heavy metals in the soil and get entered into our food chain. Heavy metals are well known for their toxicity and becomes major threat for human because of their deleterious health effects especially in children. Because of the persistency of heavy metals, researchers are getting interest in low cost, and environment friendly plant based remediation technology known as phytoremediation. In Phytoremediation, plants and associated soil microbes are used to eliminate the toxicant contaminants from the soil and is a successful substitute to engineering methods. Phytoremediation of metal contamination involved phytoextraction, phytostabilization, phytovolatilization and rhizofiltration etc. The drawback of this method is that it is observed more successful and fast in lesser contaminated areas in comparison to high contamination. The metal hyper-accumulators and some wild plants are found able to remove contaminants 10–500 times higher compared to cultivated ones.

Keywords: Phytoremediation, heavy metals, soil, pollution, plant, biochar

1. Introduction

Rapid industrial, urban, and intensive agricultural development are the most common reason of extensive organic and inorganic contamination and results into polluted unfertilized soil. The long-established way to remediate contaminated sites usually depend on the type of soil and consistently involves "*in situ*" techniques like land farming with occasional plowing or "*ex situ*" techniques such as windrows and biopile systems. *In-situ* techniques of soil remediation process comparatively relies on natural methods with least human effort while in *ex-situ*, engineering and human input is essentially required to improve natural attenuation. Phytoremediation (phyto=plant and remediation=recovery) can be defined as "green remediation," "botanical remediation" is a type of bioremediation process that use plants for the removal of contaminating substances from the soil. It does not need any special utensils all through application and endow with a reusable land. Various factors such as soil type, pH (5.8 to 6.5), nutrients availability, root depths and climatic conditions etc. affect the efficiency of exclusion of the contaminants by phytoremediation [1]. Biochar, a carbon-rich product, is professed to play noteworthy roles in biotransformation and bioremediation of contaminated soil by increasing bio accessibility and bioavailability of heavy metals. Biochar amended phytoremediation, is increasingly being picked out as a promising technology that can be used to remediate polluted soil. Many surveys have reported that biochar has been effectively applied to immobilize the metals in contaminated regions and influence the bioavailability and bio accessibility of metals. In this direction, concurrent phyto remedaiton along with getting valuable end products such as bioethanol, biodiesel, fiber, wood, charcoal, alkaloids, bioplastics etc. becoming an innovative strategy. There are multitudes of plant species that can be used for soil remediation studies depending upon the discipline of the researchers: the treatment evaluation can be based on simple soil analysis for TPH, TOC (bulk parameters), or more sophisticated involving measurement of soil respiration rates and detailed chemical analysis of residual hydrocarbons in addition to the traditional bulk parameters. Indeed, recent studies indicate that relying on bulk parameters for the evaluation of the treatment process may still lead to highly hazardous residual petroleum hydrocarbon components [2, 3].

2. Phytoremediation techniques

In general, phytoremediation includes phytoextraction, phytostabilization, phytodegradation, phytovolatilizationan, and rhizoremediation. Phytoremediation techniques are very effective in the remediation of the areas that are medium-contaminated and have slight risk.

2.1 Phytoextraction

In phytoextraction, contaminants are extracted from soils into harvestable plant biomass by the use of the plants or algae. Root biomass contains the contaminants after plants absorb them or move them into the stems or leaves. A plant which grows in contaminated ecosystem should be chosen, because it will be harvested later so it should not be seasonal. They are burned in incinerator or exposed to another method with composition after they are harvested[4]. When a living plant harvested it stops to absorb contaminants and a lower level of the contaminant will remain in the soil, so the harvest cycle must usually be repeated through several crops to achieve a significant decontamination and metals accumulated in harvestable parts of the plant can be simply restored from the ash that is produced after drying, ashing, and composting these harvestable parts [5]. Phytoextraction is also known as phytomining or biomining. This technique can also be applied in mineral industry to commercially produce metals by cropping[6]. Natural and Assisted hyper-accumulation are usually two forms of phytoextraction. Hyperaccumulating plant such as *N. caerulescens* strongly reduces Cadmium content in agricultural soils [7]. Also, Hyperaccumulators like *Thlaspi caerulescens* (Brassicaceae family), *Pteris vittata*, *Noccaea caerulescens* And *Arabidopsis halleri* accumulate heavy metals effectively [8-12]. Hyperaccumulating plants notably higher rate of heavy metal uptake [13]. Yanai *et al.*, defined that phytoextration is a phytoremediation technique that uses plants to remove heavy metals, such as Cd, from water, soil, and sediments [14]. Soil properties remain unaffected using this technique. In this approach, Phytoextraction is classified into: chelate-assisted phytoextraction [15] (induced phytoextraction) and long-term phytoextraction (continuous phytoextraction) [16], out of which chelate-assisted phytoextraction is more acceptable and presently being implemented commercially. The success of the phytoextraction depends upon ability of plants to transport and uptake heavy metals from the soil into their above-ground shoots and the harvestable parts of their underground roots [17]. Surahmaida *et al.* studied the potential of *J. curcas L.* for decontamination of Cd- and Pb-contaminated soil and the garden soil was artificially contaminated by $Pb(NO_3)_2$ and $Cd(NO_3)_2$ [18]. The removal of Cd, Pb, As and Hg from slime tailings at Forest Research Institute, Malaysia also studied using different timber plants [19]. The results of this study indicates that *A. mangium* was suitable for removal of As where as *H. odorata* and *I. palembanica had* the potential for Cd removal in a short period of time compared with others.

2.2 Phytodegradation

Phytodegradation is the use of plants and microorganisms to metabolize and degrade the organic contaminants present in soil, clay, sediment and underground waters as a physiological process, and do not depend on microorganisms is the most advantageous aspect of this method and on the other hand, the exposure of the toxics and end use products and the difficulty of their detection are drawbacks of this method [20]. The hazardous substances such as herbicides, munitions wastes and chlorinated solvents (trichloroethane (TCE)) are known to be degraded by the plant enzymes [21]. Removal of soil contaminates with organic compounds are done using plants roots in couple with the microorganisms [17]. It is also known as phytotransformation. Metabolization of contaminants can be done by some plants by producing enzymes [22]. This involves organic compounds, including herbicides, insecticides, chlorinated solvents, and inorganic contaminants. Also, plants like *cannas* is able to detoxify organic pollutants- pesticides, explosives, solvents, industrial chemicals, and other xenobiotic substances by metabolising them [23].

2.3 Phytostabilization

Phytostabilization is a plant-based remediation technique that focuses on reducing the risk of metal pollutants by stabilizing them through formation of a vegetative cap at the plant rhizosphere, where binding and sorption processes immobilize metals so as to make them unavailable for livestock, wildlife and human exposure [24-26]. Phytostabilization involves stabilization of metal contaminants rather than to remove metal contaminants from a site this reduces the risk to human health and the environment. Being cheap, less environmentally evasive and easy to implement, phytostabilization is more advantageous than other soil-remediation practices [27]. With increase in the organic matter content, cation exchange capacity (CEC), nutrient level, and biological actions the chemical and biological characteristics of polluted soils are modified [28]. Phytostabilization is a favourable technique to remediate Cd, Cu, As, Zn and Cr. The effect of three organic residues, sewage sludge, municipal solid waste compost, and garden waste compost, on the phytostabilization of an extremely acidic metal-contaminated soil has been investigated using perennial ryegrass (*Lolium perenne L.*) [29]. Wang *et al.*, performed experiment on the development and Cu absorption of corn plant (*Zea mays* L.) where *Acaulospora mellea*, an arbuscular mycorrhizal fungus, inoculated or non-inoculated corn plant by using different doses of Cu-applied pots in laboratory conditions [30]. It is also observed that fungus modifies the concentration and the structures of the organic acids in the soil such as malic acid, citric acid and oxalate acid.

2.4 Phytovolatilization

This involves the release of contaminants either directly, or in a metabolically modified form, into the atmosphere. The transformation of the excessive toxic compounds (mercury contained compounds) into less toxic forms is the most important aspect of this method. The release of these hazardous and toxic materials into the atmosphere is the major disadvantage [31]. As vascular system helps in carrying water from the roots to the leaves; therefore, the contaminants are released to the air through evaporation or volatilization eg; Poplar tree [4]. According to Ghosh and Singh some plants such as *Brassica juncea* and *Arabidopsis thaliana* can release heavy metals to the atmosphere with phytovolatilization by absorbing and transforming them into gas form [32]. Some tress because of their capacity to take contaminants with phytoremediation such as *Populus* and *Salix* are often used in phytovolatilization [33]. The phytovolatilization has been used primarily for the removal of mercury, where Hg^{2+} is transformed into less toxic Hg^0. Inserting bacterial Hg ion reductase genes into plants leads to remediation of mercur such as *Arabidopsis thaliana L.* and *Nicotiana tabacum L.* so as to achieve phytovolatilization of mercury to a greater extent [34-36].

2.5 Rhizodegradation

In Rhizodegradation, the microorganism activities lead to the decomposition of the organic contaminants in soil surrounding the roots of the plants. Plant's roots releases amino acids, sugar, organic acid, sterol, fat acids, growing factors, nucleotide, flavanone and enzymes and the microbial activities affected in the surrounding area of the roots. The dissolution of the contaminants in their natural environment is the most important benefit of rhizodegradation method for eg; Pesticides (herbicide, insecticide), benzene, toluene, ethylbenzene, xylene (BTEX), total petroleum hydrocarbon (TPH), polycyclic aromatic hydrocarbons (PAH), surface active substances, chlorinated solvents (TCE, TCA), pentachlorophenol (PCP), polychlorinated biphenyls(PCB) are the contaminants that can be dissolved with rhizodegradation [31, 37]. *Mentha spicata* L., *Morus rubra* L., *Medicago sativa* L. and *Typha latifolia* L. are used in rhizodegradation method [31, 1, 33, 38]. Lugtenberg *et al*. reported that some bacteria have emerged with the strategies to out-compete other microorganisms by releasing toxins, using extremely efficient nutrient utilization systems or by physical exclusion[39]. Xiang *et al*. performed pot experiment to study the decrease in the plant uptake and enhancement in the rhizodegradation of 2,2',4,4'-Tetrabromodiphenyl ether(BDE-47) in soil where carrot (*Daucus carota* L.) was used as a model plant [40].

2.6 Rhizofiltration

Contaminants hold on tightly to the roots or absorbed by the roots in accordance with biotic and abiotic processes in the rhizofiltration method. The plants may be planted directly in the contaminated area or the contaminated water can be collected from a waste site and taken to where plants are being hydroponically cultivated. As a result, the roots draw up both the water and its associated contaminants. It is important is to maintain the immobilization of the contaminants in or on the plants and then using different methods the contaminants can be taken from the plants. This method is successfully used for underground waters, surface waters and waste waters to remove the radioactive substances or metals [1]. The terrestrial and aquatic plants can be used in this method. Apart from the natural environment this method is also used in basins, tanks, and ponds [41]. The advantages of this method for use in in situ as well as ex situ applications, various studies performed on plants such as sunflower, Indian mustard, tobacco, rye, spinach and corn have shown its application in the removal of lead from effluent, with sunflower having the greatest ability [42, 43]. Chaudhry *et al*. reported rhizofiltration can be used for lead (Pb), cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn) and chromium (Cr), which are primarily retained within the roots [44]. Berkheya *coddii* growing in pots on soil accumulates signfivcant amount of Cd, Ni, Zn or Pb metals [45].

2.7 Rhizoremediation

Soil contaminants in rhizosphere are degraded through plants and degradation further can be enhanced with the use of microbes such technique is known as rhizoremediation [46]. The plant growth promoting rhizobacteria (PGPR) is the reason for the enhanced degradation of contaminants which enhances the complexation and bioavailability of metals [47, 48]. The association of the plant roots with several microbes that are found in the rhizosphere have been identified [49, 50]. By reducing the toxicity of metals PGPR can improve the growth of plants on contaminated sites [51]. The growth of the microbes are assisted by the substrates (root turnover and root exudates) produced by the plants which acts as the degrading agents. Mackova M *et al.* reported that complete degradation pathways are introduced in plants which leads to enhanced degradation of highly recalcitrant compounds such as explosives, PCBs and PAHs [52]. *Pseudomonas metafolia* is a microbe that reduces toxic Cr, Hg, Pb, and Cd into nontoxic forms [53]. Rhizobacteria facilitates the accumulation of nickel in *Alyssum murale* [54]. Also, rhizobacteria increases the uptake of Cadmium in *Brassica napus* [55]. The accumulation of metals increases due to the release of siderophores by bacteria [54]. In an experiment with *Thlaspi caerulescens* it was observed that the addition of bacteria increased the uptake of zinc [56, 57]. The accumulation of As increased by the mycorrhizal interaction with the roots of *P. vittata* [58] and *Enterobacter asburaie* bacteria remediate Cadmium by interacting with *Vigna radiata* seedlings [59]. Similarly, Plant *Oryza sativa* L. remediate Arsenic by interacting with microbe *Brevundimonas diminuta* Bacteria [60].

2.8 Phytohydraulic control

This method involves removal of ground water contaminants by using deep-rooted plants where roots come in contact with water [61-63]. The expansion of the roots without any artificial system makes its impact over the wide area. However, its main disadvantage is the dependence of the water absorption on the season and climate. Pivetz reported that, a 5-year-old *Populus* tree can absorb 100–200 liters of water in a day [20]. The dissolution of organic and inorganic water-soluble contaminants can be done by the phytohydraulic control method [31]. This technique has been employed to recover ground water column of methyl-tert-butyl-ether [64]. *Prosopis* and *Eucalyptus* are phreatophytes trees useful in bioremediation [65].

3. Phytoremediation with Biochar

Immobolization of the metals in the contaminated soil can be done effectively using biochar and it also has an influence on the bioavailiability and bioaccessibility of metals. Biochar is prepared from the pyrolysis of the different kinds of the biomass such as oak wood [66-68], corn stover [66-68], pine needles [69], sludge70, manure71, bamboos [72] usually at low temperature. The carbon sequestration in soils increases because biochar containing more aromatic black carbons lasts longer in the soil than any other form of organic carbon [73, 74]. Biochar derived from the plants contains relatively lower nutrients than the manure derived biochar. Several studies on the biochar amended phytoremediation have been used in actual practices. *Brassica napus L.* reported to extract Cd in the presence of biochar [75]. Lepp NW *et al.* showed that *Miscanthus* can be used in combination with the biochar for phtostabilisation [76]. Thus, biochar improve the characteristics of the polluted soil such as water-holding capacity and nutrients [77] and increases the soil microbial activity [78]. As a result, the ecological risk of heavy metals in soil decreases with immobilization of the heavy metals in the polluted soil.

The increases of the dissolved organic matter and the increases of the soil pH by the presence of the biochar derived from the hardwood or *Eucalyptus saligna* increases the mobility of the Arsenic in soil pore water [79]. Biochar interacts with soil components for a prolonged period of time and as a result, their occurs alteration of biochar, a process known as aging. During the aging process, a large variety of functional groups such as carboxylic, phenolic, and hydroxyl could be formed, and immobilization of heavy metals was not affected by biochar aging in soils with aged biochar[80]. The large-scale and long-term field trials will be necessary to determine the feasibility and stability of biochar amended phytoremediation.

4. Conclusion

Phytoremediation takes advantage of natural plant processes and requires less equipment and labor than other methods since plants do most of the work. Also, the site can be cleaned up without digging up and hauling soil or pumping groundwater, which saves energy. Trees and smaller plants used in phytoremediation help control soil erosion, make a site more attractive, reduce noise, and improve surrounding air quality. However, Phytoremediation is limited to the surface area and depth occupied by the plant roots. Also, slow growth and low biomass require a long-term commitment. The survival of the plants also gets affected by the toxicity of the contaminated land and the general condition of the soil. Accumulation of contaminants, especially metals, into the plants which then pass into the food chain, from primary level consumers upwards, or requires the safe disposal of the affected plant material. In addition, it is important to select appropriate biochar so as to develop effective strategy to immobilize anionic metals in situ. Furthermore, more thorough studies are needed to evaluate the efficiency of biochar amended bioremediation of highly contaminated alkaline soils. Future research should be performed with focuses on: illustrate the correlations among pyrolysis feedstocks, physic-chemical properties of biochar, and soil bioremediation; evaluate the biochar stability and its influence on fate and transport of metals in mining tailings and soils on a large timescale; and understand the mechanisms of biochar-assisted bioremediation, especially involved in the interactions among biochar, soil particle, and soil microbial/plant roots, which is the key point for the development of cost-effective remediation strategies.

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