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Phytoremediation technology: A review

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Abstract

The pollution of the environment by heavy metals is becoming a serious problem. Environmental pollution directly or indirectly influences the condition of atmosphere, biosphere, hydrosphere, pedosphere and lithosphere. Heavy metals that are present in environment are outcome from industrial, thermal, and nuclear pollution. Non-biodegradable, heavy metals persist in the environment and can become part of the food chain through plants. Examples of some of the heavy metals are Arsenic (As), Lead (Pb), Mercury (Hg) etc. It is already possible to clean up the environment from these kinds of contaminants, but most of the methods are costly and difficult to achieve optimal results. At present to overcome these times problems a newly developed plant mediated technology has been used known as Phytoremediation. In this context, several phytoremediation methods are currently being used to remove heavy metal pollutants from contaminated soil and water, this technology is eco-friendly and cost effective. Over 400 plant species are capable of remediating contaminated soil and water. Some phytoremediating plants are *Brassica juncea*, *Brassica oleracea*, *Sedum alfredii*, *Thlaspi caerulescens*, *Ipomea*, *Arabidopsis thaliana*, and *Helianthus annuus* etc.

Keywords: heavy metals, environmental pollution, non-biodegradable, phytoremediation

Introduction

Industrialization and urbanization have greatly increased the amount of heavy metals in the environment over the past decades, causing significant concerns throughout the world. Generally, a heavy metal is any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. In addition to Cadmium (Cd), Mercury (Hg), Lead (Pb), Zinc (Zn), Copper (Cu), Nickel (Ni), and Arsenic (As) are also heavy metals/ metalloids. Heavy metals are non-degradable substances by any type of biological or physical mechanism and are stayed in the soil for a long time period and that cause a long-term threat for the public health and environment [1].

In biological processes, heavy metals are categorized as essential or non-essential. Physiological and biochemical processes during plant life cycle require heavy metals like Cu, Fe, Mn, Ni, and Zn. Plants do not need some elements such as Pb, Cd, As, and Hg. Plants may be severely affected by environmental pollution which will reduce agricultural productivity. It enters into the crops by the food chain; they can stores in the human cell and cause serious health threat [1].

Land and water are essential natural resources for agriculture and civilisation. Almost all human activities can also cause heavy metals to be released as side effects. In addition to the migration of contaminants into non-contaminated areas via dust, leachates, and sewage sludge, events resulting in ecological contamination are also present. Some pollutants like nitrogen oxides, ozone, and sulphur oxides affect plant pigments, growth, photosynthesis, and reproductive parts [2].

Phytoremediation is a method of using plants to extract, remove, or reduce soil-borne pollutants. Ionic compounds can be absorbed by plants through their roots even at low quantities in the soil. Using their root systems, plants establish rhizosphere ecosystems to accumulate heavy metals and modulate their bioavailability, thereby reclaiming polluted soil and stabilizing soil fertility. There are multiple advantages of using phytoremediation such as (i) It is easy to manage; cost effective or low maintenance cost (ii) Phytoremediation is an autotrophic mechanism which is drive by solar energy (iii) Various organic matters can also be released into the soil, thus it improves soil fertility [3].

Phytoremediation is a technology that uses plants to clean up polluted soils and waters, and is becoming more popular since last decade. Phytoremediation is a low cost system of remediation of soil and water, which allows some uprooted essence to be reclaimed for profitable use. Plant species that accumulate and absorb different heavy metals have been identified and tested. Now a day's phytoremediation has progressed and established in both the mechanical and practical aspects [4].

Sources of Heavy Metals at Environment

Several human activities contribute to heavy metal pollution of water, such as burning fossil fuels, releasing exhaust gases from vehicles, agricultural field, and mining, burning solid or liquid wastes. Natural sources of heavy metals include volcanoes, thermal springs, erosion, and infiltration. Heavy metals become a primary concern than other environmental pollutions because heavy metals cannot be destroyed by degradation. Heavy metals contaminated areas remediation process also done by phytoremediation. Several methods have being used for removing the pollutants from the contaminated environments. Acid leaching, soil washing, physical methods can treat soils that are contaminated with heavy metals or mechanical separation of the contaminant, electro-chemical treatment, electro-kinetics, chemical treatment, thermal or pyrometalurgical separation and biochemical processes [4]. Anthropogenic sources of several heavy metals in the environment presented in table 1.

Table 1: Anthropogenic sources of several heavy metals in the environment [5]

Heavy Metals	Sources
As	Pesticides and wood preservatives
Cd	Paints and pigments, plastic materials, electroplating of cadmium containing plastics, chemical fertilizers
Cr	Tanneries, steel industries, fly ash
Cu	Pesticides, Fertilizers
Hg	Au-Ag mining disposals and coal burning, medical or surgical waste
Ni	Industrial wastes, cooking appliances, surgical or medical equipments, motor batteries
Pb	Atmospheric emissions from burning of petrol, battery production, pesticides

Effect of heavy metals on environment and human health

Heavy metals are elements that have metallic properties and have an atomic number greater than 20. Heavy metals contribute to environmental pollution in a serious way. Environmental conditions, pH, element type, organic substances in the media and fertilization, and plant species play an important role in the effects and bioavailability of heavy metals. Heavy metals have long been known to have severe health effects. The effects of heavy metals on public health can even lead to death. Heavy metals interfere with the effective functioning of crucial metabolic or cellular components, such as structural proteins, enzymes, and nucleic acids. Due to the inability of toxic heavy metals to biodegrade, they can accumulate in living organisms, causing several diseases and disorders in low concentrations [6]. This is evident from various reports citing harmful effects of heavy metals on human health (Table 2).

Table 2: Toxic effect of some heavy metals on human health [6]

Heavy Metals	PA Regulatory Limit (ppm)	Toxic Effects
Ag	0.10	Exposure may cause skin and other body tissues to turn gray or blue gray, breathing problems, lung and throat irritation and stomach pain
As	0.01	Affects essential cellular processes such as oxidative phosphorylation and ATP synthesis
Ba	2.00	Cause cardiac arrhythmias, respiratory failure, gastrointestinal dysfunction, muscle twitching and elevated blood pressure
Cd	5.00	Carcinogenic, mutagenic, endocrine disruptor, lung damage and fragile bones, affects calcium regulation in biological systems
Hg	2.00	Autoimmune diseases, depression, drowsiness, fatigue, hair loss, insomnia, loss of memory, disturbance of vision, tremors, temper outbursts, brain damage, and lung and kidney failure.
Ni	0.20	Allergic skin diseases such as itching, cancer of the lungs, nose, sinuses, throat through continuous inhalation, immunotoxic, neurotoxic, genotoxic, affects fertility, hair loss
Se	50.00	Dietary exposure of around 300 μg day-1 affects endocrine function, impairment of natural killer cells activity, hepatotoxicity and gastrointestinal disturbances
Cr	0.10	Hair loss

Phytoremediation technology

Phytoremediation technologies use living plants to clean contaminated soil, air, and water. As a new field of study, environmental biotechnology integrates living materials, mainly plants, and very small animals such as earthworms, microbes, to address problems of environmental management and development. Phytoremediation is a combination of two words: Greek word phyto meaning plant and Latin word remedial meaning to remove. By removing heavy metals from ores and processing them for various applications, humans have released them into the environment. Plants and soil microbes can be used to mitigate the toxic impacts of contaminants by phytoremediation [7]. Heavy metals, organic pollutants, and radionuclides can all be removed with it [8]. The technique is eco-friendly, cost-effective, efficient, and is In Situ applicable.

Plants are extremely capable of absorbing pollutants from the environment and detoxifying them. Chaney (1983) suggested the idea of phytoremediation. It has good public acceptance and is aesthetically pleasing [8, 9]. From an economic point of view, the purpose of phytoremediation of polluted land can be various folds:

Phytostabilization

Phytostabilization is the use of metal tolerance system that drops their bioavailability and it migrates into the ecosystem and enters into the food chain. This technique is used to reduce the mobility and bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into the food chain. Plant roots play a crucial role in immobilizing heavy metals, stabilizing soil profile and structure, and preventing soil erosion. Phytostabilization stops the accumulation of heavy metals in ecosystem and minimizes filtration into the underground water. Phytostabilization is not an endless effect as heavy metals stays in the soil. To ameliorate phytostabilization effectively organic and inorganic emendations can be mixed to the polluted soil. These soil emendations can converts metals speciation and decrease heavy metals solubility and bioavailability through changing pH values as well as redox status of that site soil [8].

Phytoextraction

As present scenario, phytoextraction is one of the most vital phytoremediation mechanisms for reclamation of heavy metals and metalloids from the contaminated soil sites. Phytoextraction process is used to extract metals with market value, such as Pb, Zn, Ni, Au etc. It has been reported that Broccoli, *Helianthus annuus*, *Zea mays*, and *Cannabis sativa* are hyperaccumulators for phytoextraction. Phytoextraction gradually improves soil quality for subsequent cultivation of high-value crops. Phytoextraction is an endless effect for junking of heavy metals from weakened soil [9].

The effectiveness of phytoextraction depend on several factors like selection and performance of the plant species, heavy metal bioavailability, soil and rhizosphere properties. Proper plant species selection is essential to effective phytoextraction. For phytoextraction, the selection of plant should possess the following characteristics: (i) Biomass production is high with fast growth, (ii) A high tolerance for heavy metal toxic effects, (iii) highly resistant to pathogens and pests are repulsive to avoid heavy metals to enter into food chain [10].

The procedure of phytoextraction includes (i) rallying of heavy metals in rhizosphere, (ii) uptake of heavy metals by roots, (iii) translocation of metal ions from roots to upstanding corridor of plant system, (iv) insulation and compartmentation of heavy metal ions [8, 10].

Among these characteristics, heavy metal-accumulating abilities and atmospheric biomasses are the vital matters which standardized phytoextraction of a plant species. That is why two different methods are adopted for plant selection such as the use of hyperaccumulator shops, which can store heavy metal in atmospheric corridor to a smaller extent and the use of shops with high atmospheric ecosystem product that may have lower metal-storing abilities. Though the overall storage of heavy metals is same as that of hyperaccumulators [11]. Hyperaccumulators plant species can be able to store very high quantities of heavy metals like as Arsenic, Cadmium, Mercury, Manganese, and Nickel. Over 300 hyper accumulator plants have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae, and Euphobiaceae [8, 12].

Phytofiltration

Phytofiltration is the use plant roots, shoots, or seedlings to remove heavy metals from face waters or wastewaters. Root factor called rhizofiltration and shoot factor called caulofiltration. During rhizofiltration, heavy metal (Zn, Se, Pb) absorbed by the roots or adsorbed onto the root surface [8].

Rhizodegradation is the breakdown of organic pollutants by soil microbes [13]. Around the root is a rhizosphere that extends about 1 mm and is maintained by the plant. The plants which are used for rhizofiltration are hydroponically grows in clean water to produce a huge root system; the clean water is substituted with unclear water to adjust. The plants used for rhizofiltration need to be dense root system, high biomass generation capacity, and can be able to tolerant to heavy metals. Both terrestrial and aquatic plants are using rhizofiltration processes [8].

Plant exudates rich in carbohydrates, amino acids, and flavonoids stimulate microbial activity in the rhizosphere about 10-100 times higher than in the soil. Methyl-Mercury (Hg) that taken up by root or leaves absorption is transformed to ionic Hg. Then change into a relatively less toxic elemental status [8].

Phytovolatilization

In terms of phytoremediation, phytovolatilization is the most controversial. Phytovolatilization is the process of plants absorbing pollutants from soil, converting them to volatile forms, and releasing them into the atmosphere. This method can be used for organic pollutants and some heavy metals like Se, Cd, and Hg. Among Brassicaceae family members, *Brassica juncea* and *Brassica juglanda* are excellent Se volatilizes [14, 15]. The benefits of phytovolatilization compared with other phytoremediation matters is that heavy metals (metalloid) pollutants are removed from the point and dispersed, without any requirement for harvesting and disposal [8, 15].

Mycoremediation

Paul Stamets gave the term Mycoremediation. Mycoremediation involves the use of fungi to clean up a site. Fungi have been shown to be a cost-effective, ecologically friendly system of barring a wide range of poisons from defiled settings or wastewater. The fungi produce enzymes and acids that breakdown natural polymers like keratin, chitin, lignin, pectin, cellulose, and hemicelluloses. In land, fresh water, and marine ecosystems, these pollutants include heavy essence, organic adulterants, cloth colourings, leather tanning chemicals and wastewater, petroleum energies, polycyclic sweet hydrocarbons, medicinal and particular care products, fungicides, and dressings. Derivations of the remediation process, similar as enzymes, comestible or medicinal mushrooms can be precious coffers in and of themselves, making the remediation process indeed more profitable. Some fungus can help with the biodegradation of adulterants in high cold or radioactive situations, where typical remittal procedures are moreover too precious or insolvable to use due to the severe conditions [16].

Mycofiltration

Mushroom-forming fungi are primarily terrestrial, aerobic organisms whose vegetative growth takes the form of an intricate and dynamic three- dimensional web of tube-suchlike cells called mycelium. The filtration part of mycelia, or mycofiltration, has been generally contemplated as a fashion to sanitize storm water. In the remediation of adulterants xenobiotics, fungal mycelium is reported to use styles similar as biosorption, bioaccumulation, and biodegradation. Several fungus species have been examined and set up to have outstanding capability to absorb and remove essence and other pollutants from waste and/ or runoff water. Fungal species, whether alive or as dried biomass, have a high biosorption capacity for essence like Cu, Zn, Fe, and Mn, as well as the capability to change resistant medicinal composites and break down germicides [11, 15, 17].

Translocation of Heavy Metals Through Plants

Metal uptake is highly a complex process. There are several steps of uptake and accumulation of heavy metal in plants. These steps are absorption of metals from soil or water, radial movement of water from root surface to the tracheary element, ascent of sap, phloem loading and unloading. Maximum Heavy metals are exits as insoluble form of soil, which is not directly available to plants. By releasing some kind of root exudates, plants can increase their bioavailability, as a result change rhizophore pH, and increase heavy metal solubility [17].

After entering into root cells, heavy essence ions can form complexes with colourful chelators, similar as organic acids. These formed complexes including carbonate, sulfate, and phosphate precipitate, are also paralyzed in the extracellular space (apoplastic cellular walls) or intracellular spaces (symplastic chambers, similar as vacuoles). The essence ions sequestered inside the vacuoles may transport into the stele and enter into the xylem sluice via the root symplasm [16] and latterly are translocated to the shoots through xylem vessels. Through apoplast or symplast, they are transported and distributed in leaves, where the ions are sequestered in extracellular chambers (cell walls) or factory vacuole, thereby precluding accumulation of free essence ions in cytosol [17].

Transporter of Heavy Metal Ion

Plants absorb metals in the form of ions and complex agents. Absorption of ions by plants requires transport of the ions across plasma membrane of an epidermal cell. Absorption of ions at the cellular level depends on the selective permeability of plasma membrane. Absorption of ions is mediated by both active and passive transport. Passive transport occurs without direct expenditure of energy by the cell. Transport proteins may be facilitating diffusion by serving as carrier proteins or forming selective channels. Metal transporters are classified into several families such as mediate active transport [16, 17].

Zip

ZIP gene family is a novel metal transporter family, which stands for ZRT-IRT like Proteins. It was first discover in the year 1900. It is first identified in plants that are capable of transporting a variety of cations, including cadmium, zinc, iron, and manganese. The ZIP transporters family are related with heavy metals storage procedures which include uptake and transport of various cations (Fe, Mn, and Zn) from root to shoot. ZIP proteins such as ZRT-IRT. In plants, zinc-regulated, iron-regulated transporter-like proteins (ZIP) and iron-regulated transporters (IRTs) participate in Zn uptake, intracellular trafficking, and detoxification [16].

ATPase

ATPase is a group of enzyme that stand for adenosine triphosphatases and it is catalyzing the decomposition of ATP into ADP**.** The P1B-type ATPases of heavy metals transporting ATPases transporter family are related with the transport of heavy metals like Zn, Cd, Co, Pb and play a crucial role in metal homeostasis. The heavy metals ATPase are eight transmembrane domains with a large cytoplasm loop between TM6-TM-7. A subfamily of p-type ATPase P1B involved in transport of $Zn^{2+}/Co^{2}/Cd^{2+}/Pb^{2+}$ cation [16-19].

MTP

MTP stands for mitochondrial trifunctional protein. It is attached to the inner mitochondrial membrane and which are catalyzes three out of the four steps. It is a heterodimeric protein that consisting of a unique 97-kDa subunit and a 58-kDa ubiquitous multifunctional protein. MTP is resistant and are associated with macrophage proteins and involved in heavy metal transport ions [18]. In *Thlaspi goesingense* MTP members are involved in Ni vacuolar accumulation [19].

ABC transporters

ABC transporter is present all plants, fungi, yeast and animals. The ATP-binding cassette (ABC) superfamily is a very large and diverse family of membrane protein transporter. Most of the ATP transporters are wide range of substrates including ions, sugar, lipids etc. It involves in the uptake of Cd in the form of a heavy metal chelate [19].

Affecting factor in the heavy metal uptake mechanisms

Several factors can affect heavy metal uptake mechanism. Some factors are

Varieties of Plant Species

In order to select plants with superior remediation properties, plant species or varieties are screened. Mustard, alpine pennycress, hemp, and pigweed, have demonstrated their capability to hyperaccumulate poisons at poisonous waste spots. Compound uptake is affected by plant species characteristics. Phytoextraction relies on identifying best fit plants which can hyperaccumulate heavy metals and generates huge quantities of biomass using crop production and management processes. Plant species can absorb and hyperaccumulate pollutants in root and shoot from the growth substrate by phytoextraction method [20].

The Root Zone

The root zone is the most important factor of heavy metal uptake mechanism. It can absorb adulterant and accumulate or metabolize this inside the plant cell. In drought stress increase in root diameter and reduced root extension so heavy metal less uptake in dried soil [20].

Age Effect

Age effect is the most important factor for biophysiological function of a plant. Young roots of a plant have larger capacity to absorb ions than those of a mature plant. It is vital to apply healthy young plants for more effectiveness for heavy metals removal [21, 22].

Vegetative Uptake

Vegetative Uptake is highly affected by the environmental factors such as temperature and heat. Temperature effect root growth and development. Basically plants metal uptake depends on the bioavailability the heavy metal in the water phase that in turn highly depends on the retention time of the metal and the interaction with other mineral elements and/ or substances present in the water. When metal are binding to the soil, the pH, redox potential, and organic matter content will all are affected and the tendency of the metal to exist in ionic and plant-available form. Bioavailability's of heavy metals increases by the addition of biodegradable physicochemical conditions like chelating matters and micronutrients [22, 23].

Medium Properties

Heavy metal uptake mechanism depends on Medium Properties like pH adjustment; addition of chelators, fertilizers. Lead absorption by plants is influenced by factors such as pH, organic matter, and phosphorus. The lead uptake is reduce by the pH of the soil is maintained with lime up to a level of 6.5 to 7.0. In addition to pH adjustment, chelators are added; fertilizers are applied to enhance remediation. Amount of lead absorbed by plant depend on pH, organic matter [21, 24].

Advancement of Phytoremediation Technology

In general, phytoremediation can be defined as a technology that uses selected plants to clean up contaminated environments and improve their quality. Essence, fungicides, detergents, snares, and crude oil painting and its derivations have all been reduced through phytoremediation operations around the world. Phytoremediation is a factory grounded system of rooting and removing essential adulterants from the terrain or lowering their bioavailability in soil. Phytoremediation technology can absorb both organic and inorganic contaminants. Inorganic mechanisms include phytostabilization, rhizofiltration, phytoaccumulation, and phytovolatilization [4].

Various Plant Species Used for Phytoremediation

30 plant species, with moderate levels of Cd, Cu and Zn, were tested in hydroponics for 4 weeks to identify heavy metal-accumulating populations [24]. According to the results, *Brassica juncea*, *Brassica napus* and *Brassica rapa* exhibited moderately enhanced Zn and Cd accumulation. In 1997 Ebbs *et al*. found Zn was removed most effectively from soils contaminated with Zn by this method. 400-plant species have been identified as metal hyperaccumulators, representing less than 0.2% of all species of angiosperms. *Thlaspi* and *Arabidopsis* species shows high hyperaccumulating characteristics. There was a higher expression of the *Thlaspi* Zn transporter ZTP1 in calamine plants than in serpentine or normal soil, and calamine plants were the most Zn-tolerant plants [25, 26].

Thlaspi is known to be Zn hyperaccumulators and Cd or Ni hyperaccumulators. *Arabidopsis helleri* tolerate and accumulate of Zn and Cd but they perform differently toward Ni. Whereas protoplasts of *Thlaspi caerulescens* were shown to be much more resistant to Ni. It is indicates that a specific Ni-tolerance mechanism occurs in *T. caerulescens* at the cellular level. Robinson *et al*. (1998) found that *T. caerulescens* as hyperaccumulator for Zn and Cd has been shown to remove up to 60 kg Zn per hectare and 8.4 kg Cd per hectare. It can accumulate as high as 2600×10^{-6} Zn without showing any injury (Brown *et al*., 1995) [26, 27].

Advantages and Disadvantages of Phytoremediation

Heavy metal-contaminated soils can be remedied with phytoremediationit also suffers from advantages and disadvantages.

Advantages

- It improves soil health, yields and phytochemicals in plants [8]
- Plants that phytoremediate toxic elements can be harvested, thus removing them from the polluted area [8, 9]
- It is used in environments contaminated by inorganic and organic materials [22]
- Due to the use of naturally occurring organisms and preservation of a more natural environment, it is potentially the least harmful method [22, 28]
- A phytoremediation approach can be a low-cost, inexpensive solution for resolving environmental problems at contaminated sites [4, 29]
- It can be easily monitored [29]

Disadvantages

- Heavy metals are not removed from the area by phytoremediation, they are simply relocated from that place [8].
- Low biomass and slow growth require long-term commitment [4]
- Temperature and other climatic conditions affect the efficiency of the methods [28, 30].
- Long time required for clean up [8]
- Mismanagement and lack of proper controls can result in food chain contamination through the phytoremediation process [6, 31]
- Plants cannot extract heavy metals from soil organic matter when the metal is bound to the organic matter [4, 32]

Conclusions

The impurity of heavy essence to the terrain, i.e., soil, water, factory, and air are of great concern due to its implicit impact on mortal and beast health. A phytoremediation is amenable to a variety of organic and inorganic composites may be applied either In Situ or Ex Situ. Phytoremediation, on the other hand, is a better approach. Phytoremediation is a remediation technology to clean up the pollutants from terrain by using green shops. But several factors must be considered in order to negotiate a high performance of remediation result; some factors are varieties of Plant Species. The root zone and vegetative uptake, climate, root depth. The green synthesized nanobiotechnnological approaches also help in the remediating heavy metals from contaminated site [33-42]. The process of heavy metal hyperaccumulators is the most simplified way for phytoremediation, and huge of hyperaccumulator have been related so far. So better understanding of the process of heavy metals uptake, translocation, detoxification, identification, characterization and signalling pathway will be of vital and prominent significance for the design of ideal plants for remediation through inheritable technology. In Phytovolatilization metal contaminants in groundwater, soils, sediments, and sludges medium. One of the advantages of phytoremidation is the greater cation of a recyclable metal-rich plant residue. Phytoremediation and phytomining of heavy metals will benefit from phytoextraction of heavy metals.

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Conflict of Interest

The author declares no conflict of interest.

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