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HEAVY METALS TOXICITY AND THEIR REMEDIATION THROUGH PHYTOTECHNOLOGY : A REVIEW

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Abstract

Heavy metals toxicity is considered to be an important contamination in the biosphere. Various strategies are applied to remove these kinds of contamination. Currently, phytoremediation is a cost-effective technology used to remove or extract inactive metal pollutants from contaminated water and soil. This technology is effective, eco-friendly and sustainable process. This review is to illustrate the various heavy metal generation sources, their toxicity and uptake mechanisms through phytoremediation technology. It also reviews the advantage of phytoremediation technology for the uptake of heavy metals from polluted sites.

Key words: Heavy Metals, Phytoremediation, Wastewater, Soil.

Introduction

Water quality is greatly affected by increasing rapid urbanization, industrialization, population explosion, fertilizers, pesticides and environmental pollution. Different types of industrial effluents mainly having heavy metal pollutants causes severe damages to flora and fauna, when directly discharged into nearby water bodies. Heavy metals contamination of water and soil is a global health concern. Heavy metal refers to any poisonous metal belong to the inorganic chemical constituents which are nondegradable in nature. Heavy metal toxicity means a surplus amount of concentration found naturally on earth. Property of heavy metals includes atomic weights between 63.5 and 200.6 and having specific gravity more than 5.0 g/cm^3, which are 5 times more than water density (Srivastava and Majumder, 2008).

Main elements come under the heavy metals are manganese (Mn), copper (Cu), cadmium (Cd), nickel (Ni), cobalt (Co), lead (Pb), iron (Fe), zinc (Zn), chromium (Cr), arsenic (As), silver (Ag) and the platinum. With the quick development of industries chiefly, fertilizer industries, paper industries, mining operations, tanneries, batteries, metal plating facilities etc, heavy metal effluents are continuously discharged into the health of the earth. Some heavy metal ions are known to cause toxic or carcinogenic effects. Toxic heavy metals in industries are generated by the treatment of industrial wastewaters; include nickel, mercury, cadmium, zinc, copper, lead and chromium. These sources are the major contributor to heavy metal pollution in wastewater and soil. Toxicological indications caused by these elements are dangerous and retired the growth of organisms. Implementation of stringent guidelines, in the present scenario is the main environmental issue, these days substantial metals are the ecological real contaminations and are getting to be one of the most genuine natural issues. So these harmful contaminations ought to be expelled from the wastewater to secure the general population and the earth. Development and increased pollution levels in recent times initiate the need for new technologies to determine the presence, migration of metals in soil and water (Shtangeeva *et al.*, 2004). Phytoremediation has turned into a cost-effective and affordable technological solution used to expel idle metals and heavy metal toxins from contaminated soil and wastewater.

Phytoremediation is a technology to reduce pollutants with the help of various plants from the contaminated soils, water or to convert them toxic free (Salt *et al.*, 1998). This technology is environmentally friendly and potentially cost-effective. Greek word Phyto means plant and remediation means restoration. In 1991, the term phytoremediation was used to describe the role of plants

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in the removal of heavy metals, their mobility and toxicity (USEPA, 2000). In this technology, contaminants are absorbed at various pH ranges in different parts of green plants and plants can tidy up numerous sorts of contamination including heavy metals, oil, explosives and pesticides. Phytoremediation has been rapidly used to clean up heavy metals contaminated water and soil systems because of its lower costs and fewer negative effects than chemical or physical engineering approaches (Reddy and DeBusk, 1987). Conventionally, phytoremediation of heavy metals contaminated water involves extraction, volatilization, stabilization and rihzofiltration (Mojiri, 2011). This review paper compiles the literature data on the phytoremediation process of heavy metals affected soil and wastewater to give a brief idea about the uptake mechanism by plants and to discuss the advantages and disadvantages.

Types, Sources and effects of heavy metals

Heavy metals are naturally compounded elements with a moderately high thickness and are harmful or noxious at low concentration. Biologically, these metals cannot be degraded but living organisms accumulated them in their body, which generated various types of diseases even in low concentrations (Pehlivan *et al.,* 2009). Heavy metals are the primary gathering of inorganic contaminations, huge landmass and water contaminated with them because of the utilization of pesticides, composts and outflow from industrial effluents or civil waste burns. Removal and biotransformation to non-toxic products of these metals are essential for a safe and clean environment (Gaur and Adholeya, 2004).

Lead

Lead is classified as heavy metal which present ubiquitously, it shows various properties like low melting point, good ductility, excellent malleability and softness. Due to its properties, lead is used in automobile batteries, paints and plastic industries (Schroeder, 2010). Because of this broad utilization, people have turned out to be a vulnerable target in its use. No amount of lead has been viewed as safe or useful to living creatures. Lead also influences the functioning of various organs like the sensory system, renal system, hematopoietic system, cardiovascular system and also shows some impacts on bone. The sensory system is the most affected compared with others for lead poisoning. High levels of lead may cause deadly outcomes like seizures, absence of coordination, daze and paralysis. It also influences the hematopoietic system which hinders the synthesis of hemoglobin and hence causes iron deficiency. Renal dysfunction has likewise been accounted for by virtue of lead-induced toxicity (Flora, 2012; Mahjoub and Moghaddam, 2011).

The main aspect of lead poisoning is due to oxidative stress, which happens because of irregularity between pro-oxidant and anti-oxidant proportions. This imbalance brings about protein oxidation, lipid peroxidation and nucleic acid peroxidation which leads to cell death (Kumar *et al.,* 2012). The ionic mechanism is the other theory to explain the lead poisoning. In this lead imitates and replace particles like Na^{+}, Ca^{2+} and Mg^{2+} and stop numerous organic procedure like intracellular flagging, cell bond, protein collapsing, ionic transportation and so forth.

Lead is one of the widely present toxic elements in the soil and has adverse effects on the growth and development of plants. Mrozek and Funicelli, (1982) experimented and found *Spartiana alterniflora* seed germination was inhibited by various lead concentrations. The main causes of retired growth were due to various enzymes disturbed by lead. Kumar and Singh, (1993) studied the *Sesamum indicum* root growth inhibition at a higher concentration of lead. An increase in the level of lead in the soil causes abnormality in the morphology of plants. Paivoke, (1983) found the irregularity in thickness of pea root, cell wall of endodermis and lignifications of cortical parenchyma due to increased level of lead. Kaji *et al.,* (1995) also demonstrated the effect of lead on proliferation in vascular plants.

Cadmium

Cadmium is a dangerous heavy metal used in various industries like Ni–Cd batteries, electroplating industries because of its exclusive properties, like great ductility, high flexibility and softness, etc. (Llewellyn *et al*., 1994). It causes numerous unfriendly wellbeing impacts by damaging various organs of the body like kidney, liver, bone and heart tissues. The renal system is the most affected in the body due to cadmium toxicity. Kidney failure is the most widely recognized cadmium toxicity. Renal nutrient digestion is additionally influenced when cadmium accumulates in the kidney (Arroyo *et al*., 2012), which causes calcium irregularity and prompts osteoporosis and osteomalacia. The intracellular glutathione level decreases as the cadmium disables the cell reinforcement protection. It affects the action of different cell regulatory catalysts like superoxide dismutase and catalase (Filipic *et al.*, 2006). The combinatorial impact of these processes executes cells into a condition of oxidative pressure. The enhanced degree of ROS, negatively affects on DNA and restrains DNA repair causes mutation.

Various researchers also investigated the toxic effects of cadmium on plants, they reported different types of plant diseases, chlorosis, wilting, growth reduction, browning of the root tip and finally causes death in cadmium contaminated soil (Di Toppi and Gabbrielli, 1999).

Arsenic

Arsenic is considered as the most toxic heavy metal harming in adults and kids (Flora, 2012). It present in three allotropic structures: metallic grey, yellow and dark arsenic. Arsenic is widely used in making bug sprays, fungicides, weedicides and antifouling operators and in protecting woods. The areas having drinking water with a high concentration of arsenic reported with a large number of arsenicosis diseases. The harmful impacts of arsenicosis include pigmentation and keratosis on the skin. Arsenic toxicity also prompts numerous respiratory problems like decreased pneumonic capacity, lung malignancy, chronic cough, or chronic bronchitis. The diseases like black foot illness, liver fibrosis and gastroenteritis are caused by the consumption of arsenic-contaminated water (Mazumder and Dasgupta, 2011).

Arsenic also affects plant species by reducing their growth and development. Barrachina *et al.,* (1995) reported the reduction in fruit production, decreased leaf fresh weight in tomato in arsenic-contaminated soil. It was also investigated that arsenic causes stunted growth, chlorosis and wilting in *Brassica napus* (Cox *et al.,* 1996). Arsenic toxicity also reduces seed development, seedling height, reduces leaf area in *Oryza sativa* (Marin *et al*., 1993; Abedin *et al*., 2002).

Mercury

Mercury is present in three forms *viz*., inorganic, natural and vapor states. It has both industrial (batteries, non-renewable energy source emanation and paints and restorative items) as well as clinical applications (thermometers, sphygmomanometer and gauges) (Patrick, 2002). In nature, its introduction happens through the disintegration of mercury-containing minerals and as gases scattering from volcanic emissions that are wealthy in mercury. Mercury is a poisonous element that influences the sensory system (Tschirhart *et al.*, 2012). Brain and kidney are severely damaged by a higher concentration of mercury. When the fetus exposed to mercury its growth will be retired. Methylated mercury was formed from inorganic mercury in the water and accumulated in an aquatic organism like fish and successively biomagnified at various trophic levels in the food chain. It has various systems through which it can make biochemical damage to tissues and genes.

Mercury is not essential for plant growth. High level of this heavy metal causes the contamination of soil. Toxic effects of mercury in *Oryza sativa* causes reduce in plant height and panicle formation, reduction in yield of the crop (Kibra, 2008; Du *et al*., 2005). Shekar *et al*., (2011) observed the reduction of seed germination, reduction in length, flowering and fruit weight of the plant.

Zinc

Various industries like electroplating, production of batteries, galvanization and metallurgical industries discharge zinc contaminated wastewater (Radhika *et al.*, 2006). Zn can play a major role in plant development since plants development hinders, when Zn is in lesser concentration in the environment. Zn can help in the stabilization of the plant by changing its internal structure. Fundamentally, zinc in metallic structure is not available to plants and does not cause any harm to the environment. Zinc reaction with oxygen and acids forms a dangerous compound which are toxic to the living world (Fosmire, 1990).

Zn help in the production of chlorophyll in the plants. Deficiency of Zn causes chlorosis in the tissues and turns them yellow. High level of Zn in the plant results in the improper functioning of the plant species, reduction in the growth and causes senescence. Zn toxicity causes plant growth inhibition (Choi *et al*., 1996).

Copper

Copper is contributed to heavy metals contamination or pollution. Copper is available in unbounded form in nature for example, chalcopyrite (Chang, 2005). Copper is an intermediate element in the periodic table along with the other 25 elements which are found inside the earth covering (Davies and Bennett, 1983). The human-generated sources of the copper are generally found in landfills, mine, ignition of petroleum derivatives and local wastewaters. The other source of Cu discharge includes volcanic eruptions, residue and timberland fire. The copper toxicity can be dangerous to different living life forms. Copper can irritate sensory organs, headache, dizziness, nausea and diarrhea due to long time exposure. Other toxic effects of copper include renal and liver damage and even death when exceeding in high concentration. The amount of copper accumulation inside the human body is gradually increased with the declination of zinc and sulfates (Lee, 2003). Cu is a basic element for living beings as it acts as a cancer prevention agent, through its participation in the electron transport chain (ETC). Copper is beneficial for human health in a limited amount as a micronutrient.

Copper is an essential heavy metal needed for the growth and development of plants but also causes toxicity when present beyond level. In normal concentration, it helps in CO_2 assimilation and ATP synthesis (Kumar, 2015). A high amount of Cu in the soil causes a cytotoxic role, increases stress, damages the plant tissue, affects growth and leaf chlorosis (Katare *et al*., 2015; Lewis *et al*., 2001).

Nickel

Nickel acts as a significant environmental contaminant. It has the capability of cancer-causing, poisonous and clastogenic effects. The diverse dissolvability of Ni has distinctive cancer creating possibilities. The insoluble form of Nickel is Ni_2S_2 or NiO which is a strong cancer stimulating compound, while the nickel in the solvent is weak cancer-causing chemicals (Dunnick *et al.,* 1995). Nickel Carbonyl $Ni(CO)_4$, is normally present in the air, intermediate product that enters the body through the respiratory system. Nickel can create mortality when inhaled through air in the form of dangerous unstable fluid. It is responsible for certain diseases, for example, pneumonia, aspiratory edema and respiratory failure. Crosby, (1998) stated that a few people have higher affectability towards the exposure of nickel-containing compounds even in negligible amounts.

Nickel is an essential nutrient in plants. A high level of Ni in the soil causes different toxicity functions like chlorosis and necrosis including rice (Zornoza *et al*., 1999; Rahman *et al*., 2005; Das *et al*., 1997). Lin and Kao (2005) examined the inhibition of root growth in *Oryza sativa* due to Ni toxicity. Pandolfini *et al*., (1992); Barsukova and Gamzikova, (1999) reported the reduction in plant nutrient acquisition in the case of the wheat plant due to this heavy metal.

Chromium

Chromium (Cr) is a grey color hard metal, most ordinarily present in the Cr^{3+} state on earth (Islam *et al.,* 2015). Chromium (VI) is additionally found in little amounts. Chromite ($FeOCr_2O_3$) is the main mineral containing a lot of chromium. This metal has not been found in the pure structure; it mostly contains about 55% chromic oxide. Chromium (VI) in soil and water can be quickly decreased to chromium (III) by organic matter. As chromium is practically pervasive in nature, chromium noticeable all around may start from wind disintegration of rocks, shales, earth and numerous different sorts of soil. Chrome ulcers, destructive responses on the nasal septum, unfavourably susceptible eczematous dermatitis and intense irritative dermatitis have been recorded among subjects exposed to chromium (VI). In the kidneys, high dosages of chromates (10-20 mg/kg) caused the dysfunctioning (Kaufaman *et al.,* 1970; Langard *et al.,* 1986; Langard and Vigander, 1983). The abundance danger of creating malignant growth in the gastrointestinal tract is additionally happening because of the introduction of chromium.

Chromium is one of the toxic heavy metal that can cause severe damage to both plants and animals. Important growth parameters like enzymatic activities, photosynthesis electron transportation were reduced by chromium toxicity (Clijsters and Assche, 1985).

Phytoremediation Technology

The phytoremediation process introduced in 1991 which means "to heal again with plants" or "to cure evil with plants". The definition of phytoremediation can be given as "the use of specialized plant for the cleaning of water or soil". In other words, this process can convert contaminated wastewater or groundwater into a usable form for the environment. The Greek word "phyton means plant" and the Latin word "remediare which means remedy" are combining and form the word phytoremediation. In the process of phytoremediation, the plants are utilized for the removal, transfer, stabilization or destruction of contaminants from soil and ground water (Alkorta *et al*., 2001). Plants having more metal-removal capacity through accumulation are known as hyperaccumulators. These plants are used to remediate contaminants by the uptake or transpiration of contaminated water (Cho-Ruk *et al.*, 2006; Smolyakov, 2012). Nutrients are absorbed by plant roots, water vapour release through leaves and formed a mechanism to detoxify the organic as well as inorganic pollutants (heavy metals) (Dhir and Srivastava, 2011). Plants consume large amounts of toxic elements and nutrients out of which only small amounts of toxic elements are harmful or they affect the plants only at higher concentrations. When the level of contamination increased in plants, they will be injured or die. The phytoremediation technology is best suited for the plants where the contaminants are spread within their root zone (Augustynowicz *et al.*, 2010). Various processes for treating the water are introduced, for example, biological, physical and chemical, but they are very costly and only applicable for the small amount of wastewater (Rezania *et al.*, 2015). Hence, an alternative process for wastewater treatment is introduced *i.e.*, phytoremediation, which uses various plants for the treatment of wastewater and removes the toxic pollutants from wastewater. This treatment process is relatively cheap and considered the most suitable option for various countries. Many conventional technologies such as reduction and chemical oxidation, Reverse osmosis, electrochemical treatment, ion exchange and coagulation-flocculation etc. are used to remove heavy metal contaminants (Volesky 2001; Rai, 2009). Various researchers defined the phytoremediation technology in their own words, which are given in Table 1.

Heavy Metals Uptake by Plant through Phytoremediation

Several researchers demonstrated the removal

Table 1: Definitions of phytoremediation.

S. No.	Researchers	Definition of phytoremediation technology
1.	Prasad *et al.*, (2003)	The utilisation of plants, trees and grasses, to remove out contaminants from water, s oil and air.
2.	Rodriguez *et al.*, (2005)	The use of plants to remove harmful chemicals from contaminated soil, sediment, sludge, underground water, surface water and wastewater.
3.	Moreno *et al.*, (2008)	The utilisation of plants to refine degraded and contaminated environments.
4.	Ginneken *et al.*, (2007)	Phytoremediation infers the utilisation of plants and blend with their related microorganisms to expel, degrade, or balance out contaminations in water, air and soil.
5.	Gaur *et al.*, (2013)	Phytoremediation technology utilise chosen plants to degrade, absorb, metabolize and also detoxify heavy metals, pesticides and unrefined petroleum from soil and water to enhance its quality.
6.	Sood *et al.*, (2011)	Phytoremediation technology uses naturally or genetically engineered plants to mitigating pollutant concentrations in contaminated soils and water.
7.	Cunningham and Ow, (1996)	The utilisation of green plants and their related agronomic techniques, soil modification and microorganisms to expel harmless contaminants.

mechanism of heavy metals through plants. Sinha *et al.*, (2007) defined that plants act both as “accumulators” and “excluders”. Accumulators are those plants that are capable to accumulate heavy metals in their tissues after absorption through roots. The excluder stops the metals uptake into their biomass. In normal condition plants required a small amount of element and don’t accumulate the heavy metal beyond the metabolic limits (USDE, 1994). While hyperaccumulator plants uptake metals at a level of thousands ppm. The plants having a shoot-to-root metal concentration ratio greater than one are considered to be hyperaccumulators and if this ratio is less than one then plants are known as non-hyperaccumulators. Contaminated environment suitability for growth, large biomass production, low cost of maintenance of few plants fulfill the requirements as hyperaccumulators (Salido *et al*., 2003).

Hyperaccumulator plant species have the capability of uptaking heavy metals like Cd, Zn, Co, Mn, Ni and Pb up to 100 or 1000 times more than non-accumulator (excluder) plants. Different types of living organisms also helps in mobilization of metal ions and increasing the bio-available fraction. The concentration of organic contaminant removal is more than that of inorganic compounds (Erdei *et al*., 2005). The soil properties, availability of metals and type of metals are some of the factors on which the procedure and capacity of phytoremediation depend (Cunningham and Ow, 1996). Remediation of contaminated sites by plants is occurring by several removal mechanisms. The root system absorbs the metals from the water and soil, they develop preventing mechanisms against the toxicity. The root system helps in the accumulation and absorption of nutrients and water, which are essential for plant growth (Raskin and Ensley, 2000).

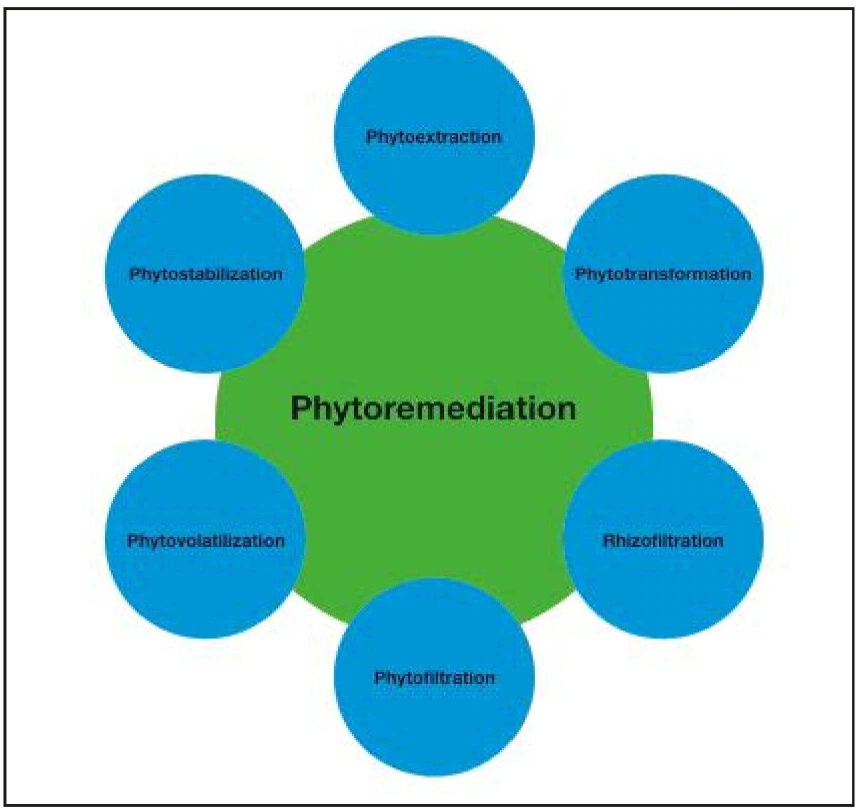

Fig. 1: Phytoremediationmechanisms.

Mechanism of Phytoremediation

Phytoremediation is a wide concept and generally happens through various mechanisms or processes (Fig. 1).

Phytoremediation is defined as

important and cost-effective technology using selected plants to remove or stabilize heavy metals and hazardous contaminants from water, soil and air. For the removal of heavy metals, it involves six mechanisms depicts in fig. 1, which can be involved are Rhizofiltration, Phytostabilization, Phytoextraction, Phytovolatilization and Phytotransformation.

Phytoextraction

Phytoextraction is also known as phytoaccumulation. It is the process in which metal contaminants are accumulated and stabilized upper portion of plants, during this process, root uptake the metals and transfer to the upper portion. Metals affected soil is mostly treated by phytoextraction (USEPA, 2000). This technique helps to eradicate heavy metals contamination from the soil by using plants that assimilates, accumulate poisonous heavy metals in various parts of plants. A hyperaccumulator plant species have more tendency of metal accumulation as compared to non-accumulating plant (UNEP). It has been demonstrated a huge number of plants (about 400) that uptake and absorbs uncommonly a lot of metals. The hyperaccumulation is the main mechanism behind the phytoextraction. Plants like *Pteris vittata, Eicchronia crassipes, Lemna gibba, Hydrilla verticillata,* etc. can accumulate toxic metal at relatively higher concentrations. The process of hyperaccumulation occurs on metalliferous soils and those plants grow on this type of soil are called metallophytes (Rascio *et al*., 2011). The plants which are used in the process of phytoaccumulation have the capacity of growing into the contaminated soil, so that they can remove out toxic metals from the soil and pass them into the shoot part (Lasat, 2000). Hyperaccumulation is generally categorized in two forms: Natural hyperaccumulation and chemically induced hyperaccumulation. The process of natural hyperaccumulation involves the use of those plants which absorb the toxic heavy metals in the roots and pass them to shoots, where these toxic heavy metals store in a non-harmful form. Another process is chemically induced hyperaccumulation which involves the use of specific types of chemical inducers (chemical agents) like EDTA, NTA etc, for the absorption and translocation of toxic metals from the soil into the shoot system of the plant. This process is used in absorption and translocation of toxic heavy metals, which are immobilized in soil and are not absorbed properly (Tangahu *et al.*, 2011). Chemically induced hyperaccumulation is a better process compared to natural hyperaccumulation (Kaur *et al.*, 2013). The four major steps which are involved in metal hyperaccumulation are (1) Solubility of metals nearby roots (2) Metals uptake by roots (3) Translocation of metal in shoot parts (4) Metal ion distribution and detoxification.

Phytovolatilization

In this process, contaminants are uptake by roots, translocate in upper plant parts and release through the leaves in the volatile form into the atmosphere (USEPA, 2000). Plants can volatilize both organic (trichloroethene) and inorganic (selenium and arsenic) pollutants (Singh, 2010). The first heavy metal which has been used in this process was Mercury. This process involves the diffusion of volatile pollutants through open stomata of the leaves in a less toxic form. The plants having a high level of transpiration pull are used in this process (Singh, 2010). This method involves the removal of the pollutants in a gaseous form and the particular pollutant remove in safer forms. Sakakibara *et al.,* (2010) studied the efficiency of volatilizing As (90%) from arsenic polluted soil by using *Pteris vittata*. Carvalho and Martin, (2001) reported the process of phytovolatisation of selenium by using four aquatic plants (*Typha domingensis, Lemna obscura, Hydrilla verticillata Royle* and *Crinum americanum*). It was found that inorganic selenium was converted into the organic one by plants which is less toxic and then transpired.

Phytostabilization

Phytostabilization is a process which involves the stabilization or fixation of heavy metals so that proper absorption and precipitation takes place mainly through soil, sediment and sludge (USEPA, 2000). This is also referred to as in-place inactivation. In this process, the contaminants are absorbed and accumulated by roots, or precipitate within the root zone of plants (rhizosphere). The phenomenon of phytostabilization are as follows (Shilev *et al.,* 2009; Costa and Kristbergsson, 2009):

a. Phytostabilization in the root zone: In this process, roots get transude in the rhizosphere and heavy metals get fixed in the root zone itself.

b. Phytostabilization of the root membrane: This step involves the stabilization of the root membrane by fixing the heavy metals to the root’s surface.

c. Phytostabilization in the root cells: The step further involves the stabilization of root cells and the translocation of heavy metals.

This technique is very useful at the sites, where there is high contamination of heavy metals in soil and the growth of vegetation is limited or less. Different types of metal-tolerant species are used in these contaminated sites to restore vegetation. This process is very effective for the removal of Pb, As, Cd, Cr, Cu and Zn. For effective phytostabilization, the plants should have a proper root and shoot systems. Transpiration rate is increased by a well-developed shoot system and helps in preventing the precipitation of heavy metals in groundwater. Cambrolle *et al.,* (2011) examined two *Spartina* species and studied the process of phytostabilization and bioaccumulation of heavy metals Cu, Cr and Ni in two marshes with various concentrations. Soudek *et al.,* (2012) studied the immobilization of heavy metals (Zn and Cd) by *Sorghum* species in soil.

Phytostabilization involves the use of plant species to immobilize the contaminated soil and water through accumulation and adsorption by plant roots, accumulation on plant tissues or precipitation within the root and preventing their migration in soil or water (Erakhrumen and Agbontalor, 2007). The main objectives to use plants for remediation of soil, sediments and sludge to reduce down water percolation that contains the contaminants (EPA, 2000; Mueller *et al.,* 1999) which depends on roots ability to limit contaminant bioavailability and mobility in the soil and water. The soil is stabilizing by the well-developed root system and prevents soil erosion (Berti and Cunnigham, 2000).

Phytofiltration/Rhizofiltration

Precipitation and absorption by plants from soil and water are the main mechanism in rhizofiltration. In this process, the contaminants restricted to only to the root system. Various heavy metals are retained by the root system in rhizofiltration (USEPA, 2000). In rhizofiltration, plant roots grow very rapidly and require minimal time for decontamination (Sarkar *et al.*, 2011). Yadav *et al.,* (2011) investigated the removal of lead using rhizofiltration technique from wastewater using *Carex pendula*. In another study, Vesely *et al.,* (2011) studied the removal of lead and cadmium by using different plants and found that *Pistia stratiotes* has the better efficiency of accumulating heavy metals in the roots. Various Indian continental growing plants like Sunflower, Indian mustard, tobacco, spinach and corn have been shown the rhizofiltration potential for heavy metals removal from contaminated soil. The most important step in this process is to grow the plant in a greenhouse; to provide them a constant pH; special harvesting and plant disposal is done with a good understanding of chemical separation.

Phytotransformation

Phytotransformation also known as Phytodegradation, is a process in which the restriction of contamination uptake is done with the help of plants. It helps to remove organic contaminants such as chlorinated solvents, herbicides etc. (EPA, 2000) and also involves the degradation of complex organic molecules into simple molecules.

Various studies on phytoremediation by using macrophytic plants depicted in table 2. Kaur *et al.,* (2013) studied that pH plays an important role in accumulation capacity of *Lemna minor* in 28 days of exposure and the removal rate of Pb and Ni were 99.90% and 99.30%, respectively, while Mishra *et al.,* (2013) investigated about the accumulation of heavy metals Cu and Hg by using *Lemna minor* from effluent water and observed that 71.4% Cu and 66.5% Hg removal from the untreated paper mill effluent water. The studies carried out by Al-Khafaji *et al.,* (2018), the potential of *Lemna minor* in the removal of heavy metal like Ni and Pb from industrial wastewater. Their experiment result showed that the average removal efficiency of Ni and Pb was 74.48% and 79.1% respectively.

Mishra and Tripathi, (2008) examined the removal of heavy metals, Cu and Fe by using *E. crassipes* and *Pistia stratiotes L.* The results obtained from their study indicated that Cu removal percentage was 96% at 1mg/l and for Fe was 95% at 2 mg/l for *Pistia stratoites* and Cd removal percentage was 85%, Cr was 89% and Zn was 95% at 2mg/l each for *E. crassipes.* Rai, (2019) experimented and used different macrophytic plants for the removal of heavy metals and found that *E. crassipes* was the most efficient macrophyte for the removal of heavy metals.

Narain *et al.,* (2011) investigated about the removal efficiency of chromium and cadmium heavy metals by free-floating water hyacinth was 80.26% for chromium and 71.28% for cadmium from the municipal wastewater and average removal rates of chromium and cadmium were 0.10µg/day and 0.12µg/day. While Bakers *et al.,* (2000) demonstrated *Thlapsi caerulescens* to accumulate Cd in leaf dry matter and found that the accumulation level was upto 1000ug/g. Mojiri *et al.,* (2013) investigated the removal of Pb, Ni and Cd from urban waste leachate by using *Typha domingenesis* and the amount of removal for Pb, Ni and Cd were 0.9725, 0.4681 and 0.3692 mg/kg, respectively. Their findings clearly showed that *Typha domingenesis* is best hyperaccumulator for these heavy metals. Kim *et al.,* (2003) investigated heavy metal accumulation in *polygonum thunbergii*. The results of their study revealed the mean content of heavy metal in the whole plants increased in the order of Cd (8.5ug/g) < Pb (183.3ug/g) < Cu (548.1ug/g).

Srivastava *et al.,* (2011) used *Hydrilla verticillata* plant for arsenic removal from contaminated water. They investigated the arsenic level increase in *Hydrilla verticillata* plants with an increase in the duration of exposure. The level of arsenic in dry biomass at 45 days

Table 2: Hyperaccumulation plants species used for heavy metals removal.

Sr. No.	Species	Metals	Removal conc.	Removal %	Metal Accumulation	Medium	References
1	*Eichhornia crassipes*	Cr Cd	- -	80.26% 71.28%	- -	Waste water	Narain *et al.*, (2011)
2	*E. crassipes*	Cd Cr Zn	2 mg/l 2mg/l 2mg/l	85% 89% 95%	- - -	Metal solution	Mishra and Tripathi, (2008)
3	*E. crassipes*	Zn		79%	-	Wastewater	Rai, (2019)
4	*Eleocharis acicularis*	Fe Pb Zn	- - -	- - -	59500 mg/kg 1120 mg/kg 964 mg/kg	Mining site	Ha *et al.*, (2009)
5	*Pistia stratoites*	Cu Fe	1 mg/l 2 mg/l	96% 95%	- -	Metal solution	Mishra and Tripathi, (2008)
6	*Acorus calamus*	V Cr Cd	- - -	52.40% 46.80% 90.00%	- - -	Synthetic aqueous	Lin *et al.*, (2018)
7	*Lemna minor*	Hg Cu	- -	66.50% 71%	- -	Paper mill Effluent	Mishra *et al.*, (2013)
8	*Lemna minor*	Pb Ni	- -	99.99% 99.30%	- -	Wastewater	Kaur *et al.*, (2012)
9	*Lemmna minor*	Ni Pb	- -	74.48% 79.10%	- -	Industrial wastewater	Al-Khafaji *et al.*, (2018)
10	*Lemna gibba*	Cr Cu	- -	- -	6 ppm 4.67ppm	Wastewater	Obek, (2009)
11	*Lemna gibba*	Mn Ni	15.150 mg/g -	- -	- -	Polluted environment	Doganlar *et al.*, (2012)
12	*Lemna trisulca*	Zn	-	97%	-	Wastewater	Jafari and Akhavan, (2011)
13	*Typha angustifolia*	Na Cr Cu Zn	- - - -	62% 42% 38% 36%	6698 mg/l 20210 mg/l 7022 mg/l 16325 mg/l	Tannery sludge	Bareen and Khilji, (2008)
14	*Typha domingensis*	Pb Ni Cd	0.9725 mg/kg 0.4681 mg/kg 0.3692 mg/kg	- - -	- - -	Urban waste leachate	Mojiri *et al.*, (2013)
15	*Typha angustata*	Cu Zn Pb	164.8 mg/kg 151.6 mg/kg 59.7 mg/kg	- - -	- - -	Wetland	*Ramachadra et al.*, (2018)
16	*Polygonum thunbergii*	Zn Cu Pb	- - -	- - -	1506.7 ug/g 548.1 ug/g 183.3ug/g	Soil	Kim *et al.*, (2003)
17	*Thlaspi caerulescens*	Cd	1000 ug/g	-	-	Wastewater	Baker *et al.*, (2000)
18	*Hydrilla verticillata*	As	-	72%	-	Wastewater	Srivastava *et al.*, (2011)
19	*Phyla nodiflora*	Pb Cu Zn	- - -	- - -	1183 mg/kg 460 mg/kg 598 mg/kg	Soil	Yoon *et al.*, (2006)
20	*Cyperus rotundus*	Sn	-	86%	-	Ex- tin mine	Ashraf *et al.*, (2013)
21	*Nelumbo nucifera*	As	-	56%	-		Ashraf *et al.*, (2013)

was 8546 ug (72% of total As supplied). Ashraf *et al.*, (2013) evaluated the phytoremediation process occurring at Ex- tin mining catchment. Different types of aquatic macrophytic plant species were analysed to assess the phytoextraction potential for remediation of Sn and As. Results showed that phytoextraction rates of *Cyperus rotundus L.* (86%) for Sn and *Nelumbo nucifera* (56%) for As were recorded. Doganlar *et al.*, (2012) investigated the metal uptake in *Lemna gibba* exposed to Mn and Ni. The result of their study showed that Mn was accumulated upto 15.150 mg/g after 72 h at 16 mg/l Mn exposure and Ni accumulated upto 1.874 mg/g at the same conditions.

Yoon *et al*., (2006) studied the removal of Pb, Cu and Zn in *Phyla nodiflora* on a contaminated Florida site and found that *Phyla nodiflora* was most efficient in accumulating Cu and Zn in its shoots and Pb in its roots with an accumulation level of 460 mg/kg, 598 mg/kg and 1183mg/kg, respectively. Bareen and Khilji, (2008) studied the bioaccumulation of Na, Cr, Zn and Cu from tannery sludge by *Typha angustifolia L*. Results of their study clearly showed the maximum reduction of 62% for Na, 42% for Cr, 38% for Cu and 36% for Zn in 30% sludge and maximum metal uptake observed was 6698 mg/kg for Na, 20210 mg/kg for Cr, 16325 mg/kg for Zn and 7022 mg/kg for Cu in roots, respectively. Ha *et al*., (2009) examined *Eleocharis acicularis* for the removal of heavy metals like Fe, Pb and Zn. The results revealed that the concentration of Fe, Pb and Zn accumulation within the plants were 59500, 1120 and 964 mg/kg, respectively. Obek, (2009) studied the removal of heavy metals from municipal wastewater *by Lemna gibba*. His experiment result showed that *Lemna gibba* removed high levels of Cr (6 ppm) and Cu (4.67 ppm).

Jafari and Akhavan, (2011) examined the accumulation of Zn from polluted water by using *L. trisulca*. They observed that the metal bioaccumulation process was affected by various values of pH and concentration of Zn solution. During their experiment they treated the plants with 15 mg/l of Zn, which accumulated 18366.4±2614 mg/kg DW and the highest bioaccumulation potential was 97%. The metal was accumulated in the highest amount in dry biomass with increasing Zn levels. Ramachandra *et al*., (2018) analysed different macrophytic plants and their heavy metal accumulation potential from Bellandur Lake, Banglore, India. Study revealed that metal accumulation concentration by macrophytic plants ranked in the order: Cu (164.8 mg/kg) >Zn(151.6 mg/kg) > Pb(59.7 mg/kg). Lin *et al*., (2018) investigated three macrophytes, *Acorus calamus L*., *Phragmites communis Trin*. and *Alternanthera philoxeroides* (Mart.) Griseb and their heavy metal removal efficiency from synthetic aqueous solution. The result of their study showed that *Acorus calamus* has the highest efficiency of removal V^{5+}, Cr^{6+} and Cd^{2+} was 52.4, 46.8 and 90.0%, respectively.

Advantage of Phytoremediation

Phytoremediation procedure use plant to remove toxicants, it is cost-effective and less problematic than the remediation process (Erdei *et al.,* 2005). The major advantages of this technology are its adequacy in the decrease of contamination, cost-effective and relevant in the wide scope of contamination including inorganic and organic contamination and toxic metals (Liu *et al.,* 2000; Mwegoha, 2008).

Rhizofiltration/ Phytofiltration is also a cost-effective method for the removal of contaminated water by accumulation into plant biomass (Lone *et al.,* 2008). In this process, both terrestrial and aquatic plants are involved in the removal of contaminants. The contaminants do not have to be translocated to the shoot system.

Phytoextraction is an inexpensive technique. This process helps in the permanent removal of contaminants from the soil and can be recycled from contaminant biomass also. This process is very effective in the reduction of soil erosion and decrease the amount of water available in the system.

Phytovolatilization helps in the transformation of contaminants into less toxic forms. Contaminants can be easily and effectively degraded in the atmosphere.

Phytostabilization is a cost-effective process and is less disruptive than other soil remedial techniques.

Conclusion

The phytoremediation process is an ecologically sustainable and low-cost method in the removal of heavy metals from contaminated sites through heavy metal uptake by plants. Through all the phytoremediation methods, rhizofiltration is the most common method used for the treatment of contaminated water. This technology helps in the complete cleaning of the contaminated site and it is superior to other conventional technologies. But to achieve good performance in this technology several factors must be considered. The selection of plant species is the most important criteria in this technology. Few plants can accumulate thousand ppm concentrations of heavy metals, these are called hyperaccumulator plants and can be used in the phytoremediation process. However, plants growing on heavy metal polluted soil and water show a reduction in growth due to changes in their biochemical and physiological activities.

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