



PHYTOREMEDIATION OF HEAVY METALS FROM SOIL AND WATER

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ABSTRACT

Environmental pollution affects the quality of pedosphere, hydrosphere, atmosphere, lithosphere and biosphere. Great efforts have been made in the last two decades to reduce pollution sources and to find out remedy for the polluted soil and water resources. There are mainly two methods of remediation, physico-chemical and phytoremediation. Phytoremediation is an emerging technology, which uses plants and their associated rhizospheric microorganisms to remove pollutants from contaminated sites.

This plant based technology has gained acceptance in the past ten years as a cheap, efficient and environment friendly technology than the physico-chemical methods especially for removing toxic metals. Plant based technologies for metal decontamination includes extraction, volatilization, stabilization, immobilisation and rhizofiltration. This

article has been attempted to provide a brief review on recent progresses in research and practical

applications of phytoremediation for soil and water resources.

KEYWORDS: phytoremediation, heavy metal, soil pollution, water pollution.

INTRODUCTION

Heavy metals are very significant environmental pollutants. Natural processes such as volcanic

eruption, continental dust anthropogenic activities like mining, combustion of fossil fuel, phosphate fertilizers, military activities, metal working industries etc. lead to emission of heavy metals and accumulation of these chemicals in ecosystem.

The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration. "Heavy metals" in a general, is a collective term, which applies to the group of metals and metalloids with atomic density greater than water (Hawkes 1997).

Heavy metals are natural components of the earth's crust, the most important natural source of heavy metals is geologic parent material or rock outcroppings (Table-1). In many ecosystems the concentration of several heavy metals has reached toxic levels due to consequence of anthropogenic activities. Fifty three elements fall into the category of heavy metals till date and defined as the group of elements whose densities are higher than 5 g cm^{-3} and recognized as ubiquitous environmental contaminants in industrialized. Heavy metals include lead (Pb), cadmium (Cd), nickel (Ni), cobalt (Co), iron (Fe), zinc (Zn), chromium (Cr), arsenic (As), silver (Ag), and the platinum group elements.

Table-1: Range of heavy metal concentrations (ppm) in igneous and sedimentary rocks (Cannon et al. 1978)

Metals	Basaltic igneous Shales and clays	Granite Black shales
Sand stone		
As	0.2-10	0.2-13.8
-	-	0.6-9.7
Cd	0.006-0.6	0.003-0.18
0.0-11	<0.3-8.4	-
Cr	40-600	2-90
30-590	26-1000	-
Co	24-90	1-15
5-25	7-100	-
Cu	30-160	4-30
18-120	20-200	-
Pb	2-18	6-30
16-50	7-150	<1-31
Mo	9-70	1-6
-	1-300	-

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Ni	45-410	2-20
20-250	10-500	-
Zn	48-240	5-160
18-180	34-1500	2-41

Heavy metals have largest availability in soil and aquatic ecosystem and to a relatively smaller proportion in atmosphere as particulate or vapors. Soil pollution caused by metals is different from air or water pollution, because heavy metals persist in soil much longer periods of time than in other compartments of the biosphere (Lasat, 2002). Over recent decades, the annual worldwide release of heavy metals reached 22,000 metric ton for cadmium, 939,000 mt for copper, 783,000 t for lead and 1,350,000 t for zinc (Singh *et al.*, 2003). The tolerance limits of some heavy metals are shown in Table-2.

Table-2 : Indian standards for heavy metals in soil, food and drinking water (Awashthi 2000).

	Heavy metal Water (mg/L)	Soil (mg/kg)	Food (mg/kg)
Mechanisms of carcinogenicity has been discussed for metals and classified arsenic	Cd	3-6	1.5
	0.1		
	Cr	-	20
	0.05		
	Cu	135-270	30
	0.05		
	Fe	-	-
	0.03		
	Ni	75-150	1.5
	-		
	Pb	250-500	2.5
	0.1		
	Zn	300-600	50
	5.0		
	As	-	1.1
	0.05		
	Mn	-	-
	0.1		

c, antimony, beryllium, cadmium, chromium, cobalt, lead, nickel and vanadium are some metals and metalloids that are carcinogenic to humans or considered to be carcinogenic to humans by international agency for research on cancer

(Beyersmann and Hartwig, 2008). Toxic heavy metals cause DNA damage and their carcinogenic effects in animal and humans are probably caused by their mutagenic ability (Knasmüller *et al.*, 1998; Baudouin *et al.*, 2002). Exposure to high levels of these metals has been linked to adverse effects on human health and wildlife.

The exposure of plants to toxic levels of heavy metals triggers a wide range of physiological and metabolic alterations (Dubey, 2011; Villiers *et al.*, 2011). However, as different heavy metals have different sites of action within the plant, the overall visual toxic response differs between heavy metals. The most widespread evidence of heavy metal toxicity is a reduction in plant growth (Sharma and Dubey, 2007) including leaf chlorosis, necrosis, turgor loss, a decrease in the rate of seed germination, and a crippled photosynthetic apparatus, often correlated with progressing senescence processes or with plant death (Dalcerso *et al.*, 2010; Carrier *et al.*, 2003). The removal and recovery of heavy metals from contaminated media are of great importance in terms of protection of the environment as well as abatement of heavy metal toxicity (Kim *et al.*, 2004).

There are some physico-chemical methods for removal of heavy metal from environment but they are very costly techniques. Phytoremediation has emerged out as a new low-tech cost effective technology that uses plants and their associated microbial flora for environmental cleanup (Raskin *et al.*, 1994; Salt *et al.*, 1995 a; Salt *et al.*, 1998). Along with angiosperms many pteridophytes are involved in phytoremediation.

Technologies for removal of contaminants from polluted soil and water:

The cleaning of contaminated soils from heavy metals is the most difficult task, particularly on a large scale. The soil is composed of organic and inorganic solid constituents, water and mixture of different gases present in various proportions. Therefore, soils vary enormously in physical, chemical and biological properties. Different approaches have been used or developed to mitigate/reclaim the heavy metal polluted soils and waters including the land

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fill/dumping sites. These may be broadly classified into physicochemical and biological approaches.

Biological approaches for removal of contaminants from polluted soil and water :

Biological approaches of remediation include:

Physicochemical approaches for removal of contaminants from polluted soil and water:

Some physicochemical approaches are as follows:

- **Excavation** - Commonly used *ex-situ* remediation method that involves the physical removal and disposal of contaminated soil in designated landfill. Even though it produces rapid remediation results, excavation is often expensive because of the operation, transport, and special landfill requirements.
- **Capping** - *In-situ* method. A hard cover is placed on the surface of the contaminated soil. Capping is also a rather simple method that reduces the contaminant exposure. However, it does not remove contaminants from the soil.
- **Solidification and stabilization** - Solidification/Stabilization (S/S) is one of the top five source control treatment technologies used at Superfund remedial sites, having been used at more than 160 sites. "Solidification" refers to a process in which materials are added to the waste to produce an immobile mass. This may or may not involve a chemical bonding between the toxic contaminant and the additive. "Stabilization" refers to converting a waste to a more chemically stable form.
- **Soil washing** - Soil washing is an *ex situ* treatment technology for the remediation of contaminated soil. It has been applied to a variety of inorganically, organically, and even radioactively contaminated soils. Soil washing technology involves mixing the solvent (water) and contaminated soil in an extractor vessel.

- Use of microorganisms to detoxify the metals by valence transformation, extracellular chemical precipitation, or volatilization [some microorganism can enzymatically reduce a variety of metals in metabolic processes that are not related to metal assimilation], and
- Use of special type of plants to decontaminate soil or water by inactivating metals in the rhizosphere or translocating them in the aerial parts. This approach is called phytoremediation, which is considered as a new and highly promising technology for the reclamation of polluted sites and cheaper than physicochemical approaches (Garbisu and Alkorta, 2001; McGrath *et al.*, 2001; Raskin *et al.*, 1997).

Phytoremediation

The generic term "phytoremediation" consists of the Greek prefix *phyto* (plant), attached to the Latin root *remediation* (to correct or remove an evil). Phytoremediation is defined as an emerging technology using plants to clean up the contaminated environment from hazardous contaminant to improve the environment quality. Phytoremediation is a very cost effective and eco friendly approach for remediation of contaminated soil and water using plants comprised of two components, one by the root colonizing microbes and the other by plants themselves, which accumulates the toxic compounds to further non toxic metabolites.

Phytoremediation technologies:

A range of processes of phytoremediation mediated by plants are useful in treating environmental problems (fig-1):

Phytoextraction - Metal phytoextraction relies on metal-accumulating plants to transport and concentrate polluting metals from soil into the harvestable aboveground shoots (Salt *et al.*, 1998;

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Vassil et al., 1998). The plant material can subsequently be used for nonfood purposes (e.g. wood, cardboard) or ashed, followed by disposal in a landfill or, in the case of valuable metals, the accumulated element can be recycled. The latter is termed phytomining (Chaney et al., 2000). Popular species for phytoextraction are Indian mustard and sunflower because of their fast growth, high biomass, and high tolerance and accumulation of metals and other inorganics (Blaylock and Huang, 2000; Salt et al., 1995b).

Although it has been known since the late 1800s, that a special category of plants, the so called hyperaccumulators can accumulate extraordinary levels of metals, the idea of using these plants for phytoextraction only appeared in the literature in the last 20 years. At present, at least 45 plant families are known to contain metal-accumulating species (Reeves and Baker, 2000). Such plants can accumulate As, Cu, Co, Cd, Mn, Ni, Se, Pb or Zn upto levels that are 100 to 1,000 times of those normally accumulated by plants grown under the same conditions (Baker et al., 2000; Ma et al., 2001; Brooks, 1998). Despite these properties hyperaccumulators are of limited use for large scale applications because they are often slow growing and attain low biomass.

Pteris vittata, an As (arsenic) hyperaccumulating fern may also show promise for phytoextraction of As (Ma et al., 2001).

Phytostabilization - The term denotes the use of plants to stabilize pollutants in soil (Berti and Cunningham, 2000). Phytostabilization of metals may employ plants to reduce leaching, runoff, and erosion via stabilization of soil by plant roots or root exudates may cause metals to precipitate, converting them to less bioavailable form (Berti and Cunningham, 2000; Burken et al., 2000; Kramer and Chardonnens, 2001). It is used to provide a cover of vegetation for a moderately to heavily contaminated site, thus preventing wind and water erosion (Kramer, 2005). Plants suitable for phytoestabilization develop extensive root system, provide good soil cover, possess tolerance to the contaminant metals, and ideally immobilize the contaminant in the rhizosphere. Arsenic-tolerant plants that may be potentially used for phytostabilisation purposes have been known for a long time.

- **Phytovolatilization** - Phytovolatilization is the release of pollutants from the plant to the atmosphere as a gas. Although it works well for organics, this can be used for a few inorganics that can exist in volatile form i.e. Se, Hg and As (Hansen et al., 1998; Rugh et al., 1996). Among the aquatic species, rice, rabbit foot grass, *Azolla* and pickle weed are the best Se volatilizers (Hansen et al., 1998; Lin et al., 2000; Pilon-Smits et al., 1999; Zayad et al., 2000). Volatilization of Se involves assimilation of inorganic Se into the organic selenoaminoacids selenocysteine (SeCys) and selenomethionine (SeMet). The latter can be methylated to form dimethylselenide (DMSe), which is volatile (Terry et al., 2000). Volatilization of As and Hg has been demonstrated for microorganisms, but these elements do not appear to be volatilized to significant levels by nontransgenic plants (Rugh et al., 1996). Because volatilization completely removes the phytoimmobilisation pollutant from the site as a gas, without need for plant harvesting and disposal, this is an attractive technology. A risk assessment study for volatile Se and Hg reported that the pollutant was dispersed and diluted to such an extent that it did not pose a threat (Lin et al., 2000; Meagher et al., 2000). Although phytovolatilization is a passive process, it may be maximized by using plant species with high transpiration rates.
- **Phytoimmobilisation**- Phytoimmobilization is the use of plants to decrease the mobility and bioavailability of pollutants by altering soil factors that lower pollutant mobility by formation of precipitates and insoluble compounds, as well as by sorption on roots.
- **Rhizofiltration** - In rhizofiltration plant roots grown in water absorb, concentrate and precipitate toxic metals and organic chemicals from polluted effluents (Schmoger et al., 2000). The plants can be used as filters in constructed wetlands (Horne, 2000; Lytle et al., 1998) or in a hydroponic setup (Raskin et al., 1997), comprising a complex

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ecosystem of plants, microbes and sediment that together act as a biogeochemical filter, efficiently removing contaminants from wastewater. Constructed wetlands are useful for filtering large volumes of wastewater. Constructed wetlands have been used for a wide range of inorganics including metals, Se, perchlorate, cyanide, nitrate and phosphate (Hansen et al., 1998; Horne, 2000; Nzungu and McCutcheon, 2003). Recently two bacterial strains, *Bacillus mycoides* and *Stenotrophomonas maltophilia* have shown potential to detoxify Se and a model system for Se rhizofiltration based on *Astragalus bisulcatus* rhizobacteria interactions has also been proposed by Vallini et al. (2005).

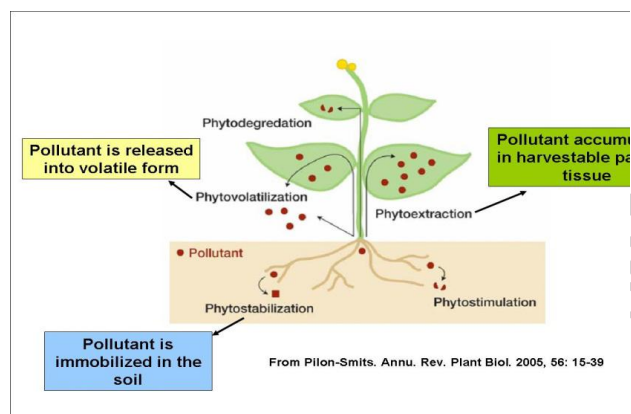


Fig.- 1. Phytoremediation mechanisms.

Factors affecting phytoremediation:

There are several factors which can affect phytoremediation –

- i. **The plant species:** Plants species or varieties are screened, and those with superior remediation properties are selected (Prasad and Freitas, 2003). The uptake of a compound is affected by plant species characteristic (J.H. Burken and J.L. Schnoor, 1996).
- ii. **Metal bioavailability:** For plants and their associated microbes to remediate

pollutants, they must be in contact with them and able to act on them. Therefore, the bioavailability of a pollutant is important for its remediation. Pollutant bioavailability depends on the chemical properties of the pollutant, soil properties, environmental conditions and biological activity

- iii. **The root zone:** The Root Zone is of special interest in phytoremediation. It can absorb contaminants and store or metabolize it inside the plant tissue. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism. A morphological adaptation to drought stress is an increase in root diameter and reduced root elongation as a response to less permeability of the dried soil (N. Merkl et al., 2005).
- iv. **Role of chelating agents:** As mentioned earlier, the complex root secretions from plants contain natural chelating agents that affect pollutant solubility and uptake. Inside plant tissues such chelator compounds also play a role in tolerance, sequestration and transport (Ross, 1994).
- v. **Plant microbe interactions:** The limited bioavailability of various metallic ions, due to their low solubility in water and strong binding to soil particles, restricts their uptake/accumulation by plants. However, root colonizing bacteria and mycorrhiza can significantly increase the bioavailability various heavy metal ions for uptake.

Fig.-2: factors which are affecting the phytoremediation mechanism of heavy metals

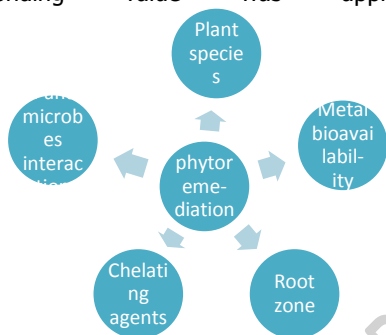
Phytoremediation by some plants:

There are many pteridophytes which are identified as heavy metals cleaners from soil and water. Among them most works have been done with different species of *Pteris sp.*



Among different species of *Pteris*, three accessions of *P. vittata*, two cultivars of *P. cretica*, *P. longifolia* and *P. umbrosa* were grown with 0~500 mg As/kg added to the substrate. The results show that in addition to *P. vittata*, *P. cretica*, *P. longifolia* and *P. umbrosa* also hyperaccumulate arsenic (As) to a similar extent. This study identified three new species of As hyperaccumulators in the genus *Pteris* (Zhao *et al.*, 2002).

In another study, the speciation and distribution of As of Braken fern was investigated by Zhang *et al.* (2002), which was grown for 20 weeks in As contaminated soil. The results show that As recoveries of 85% to 100% were obtained from most parts of the plant (rhizomes, fiddle heads, young fronds and old fronds), and for roots, the corresponding value was approximately



60%. The result also demonstrates the ability of Braken fern as As hyperaccumulator, which can transfer As rapidly from soil to above ground biomass with minimal As concentration in the roots. As is found to be predominantly as inorganic species.

Caille *et al.* (2005) conducted a pot experiment with 0~500 mg/kg As added as arsenate and another short term (8 h) uptake experiment with 5×10^{-6} arsenate under phosphorus sufficient conditions, and grew hyperaccumulator *Pteris vittata* and the nonhyperaccumulator *Pteris tremula*. The results show that in both experiments *P. vittata* accumulated much more As than *P. tremula* without any visual toxicity symptoms.

Srivastava *et al.* (2005) conducted an experiment under greenhouse conditions in a completely randomized design with four replications.

That experiment identified *Pteris biaurita* L., *P. quadriaurita* Retz and *P. ryukyuensis* Tagawa as hyperaccumulators of As and re-confirmed *Pteris cretica* as a hyperaccumulator. The average As concentration ranged from 1770 to 3650 mg kg⁻¹ DW in the fronds and 182 to 507 mg kg⁻¹ DW in the roots of *P. cretica*, *P. biaurita*, *P. quadriaurita* and *P. ryukyuensis* after having been grown in 100 mg As kg⁻¹ soil. There was a greater percentage of As (III) as compared to As (V) in the fronds of these plants. They identified *P. ryukyuensis*, as the most promising candidate to phytoremediate As contaminated soils compared to the other three species. They also found that the nutrient requirements or distributions within the *Pteris* species were altered distinctly when the plants were exposed to As.

Another fern species, *Pityrogramma calomelanos* commonly known as silverback fern has been discovered in Thailand as an As-hyperaccumulating fern for phytoextraction of As-contaminated soil (Visoottaviseth *et al.*, 2002).

Jankong *et al.* (2007) conducted both green house and field experiments with *Pityrogramma calomelanos*. They used soil in greenhouse experiment with As (136-269 $\mu\text{g g}^{-1}$) and found that phosphorus fertilizer significantly increased plant biomass and As accumulation of the experimental *P. calomelanos*. Rhizobacteria increased significantly the biomass and As content of the test plants. In contrast, rhizofungi reduced significantly As concentration in plants but increased plant biomass. Thus they concluded that phosphorus fertilizer rhizosphere bacteria enhanced As-phytoextraction in *P. calomelanos*.

Athyrium yokoscense is a lead hyperaccumulator, which is defined as a plant containing over 1000 $\mu\text{g g}^{-1}$ of lead in the dry matter (Baker and Brooks 1989). *A. yokoscense* often flourishes in mine sites and areas that are highly polluted with heavy metals, such as cadmium, copper and lead (Satomi 1958; Honjo *et al.* 1980; Nishizono *et al.* 1987b). It is well known that the fern accumulates a large amount of metals in the tissues, particularly in the roots (Honjo *et al.* 1980; Nishizono *et al.* 1987b). Nishizono *et al.* (1988,1989) have suggested that a 9.50-kDa cysteine-rich peptide, which was induced by exposure of the fern to copper,

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may contribute to the copper tolerance of the fern growing in copper contaminated soil. Kamachi et al.(2005) examined lead tolerance in *A. yokoscense* gametophytes and observed that spore germination in *A. yokoscense* was more tolerant to Pb^{2+} , compared to that in other fern species, such as *Pteridium aquilinum*, *Lygodium japonicum* and *Pteris vittata*.

Benaroya et al. (2004) characterized lead (Pb^{2+}) accumulation and storage by aquatic fern *Azolla filiculoides*. They observed that lead precipitates were detected in the vacuoles of mesophyll cells of *Azolla* plants cultured for 6 days in rich growth medium containing 20 mg/l Pb^{2+} . They also observed that lead content in *Azolla* whole plant increase by 200%, 100% and 22% after 2, 4 and 6 days of growth, respectively, when compared to *Azolla* apoplast.

Azolla filiculoides L. grown for 3-7 days in nutrient media containing 8-15 ppm of different heavy metals was found to contain 10000 ppm cadmium, 1990 ppm chromium, 9000 ppm, 9000 ppm nickel and 6500 ppm zinc. The content of heavy metal in the roots was two-to five-fold higher than in the shoots (Sela et al, 1988).

Several species of *Salvinia* including *S. herzogii*, *S. minima*, *S. natans*, *S. rotundifolia* show potential to remove various contaminants including heavy metals from wastewaters (Nichols et al., 2000; Olguin et al. 2002; Sun et al., 2007; Sánchez-Galván et al., 2008; Xu et al., 2009). Among various *Salvinia* species, *S. minima*, is considered as a hyperaccumulator of lead and cadmium (Olguin et al., 2002) which can reach in the range of 2000–2600 in batch systems and 4134 to 17170 in continuous systems.

Das et al. (2013) investigated the extent of cadmium (Cd) accumulation with its possible impact on physiological and biochemical basis of heavy metal tolerance in *Marsilea minuta* Linn. They allowed Cd salt (0 μ M, 50 μ M and 100 μ M) to absorb by the plants for prolong days in hydroponic culture and a significant deterioration of the plant biomass was recorded. They also noted that root absorbed more metals than the leaves.

The multiple metal accumulation and metal transfer factors from soil (TFS) of *Marsilea sp.* have

been studied and recorded that *Marsilea sp.* Shows TFS ≥ 1 for Fe, Cu and Cd. conducted a laboratory study in hydroponics to test different levels of Cd on the growth and Cd uptake by three hydrophytes: *Gladiolous*, *Isoetes taiwanenses* Dwvol and *Echinodorus amazonicus*. The data show that the biomass of all the plants decreased with an increase in Cd concentration from 5 to 20 mg/L. However, Cd toxic effect was greater on *Isoetes taiwanenses* Dwvol and *Echinodorus amazonicus* than that on *Gladiolous*. In addition, the accumulation of Cd was higher in *Gladiolous* than the other two plants.

To identify plant populations with the ability to accumulate heavy metals, 300 accessions of 30 plant species were tested by Ebbs et al.(1997) in hydroponics for 4 weeks, having moderate levels of Cd, Cu and Zn. The results indicate that many *Brassica* spp. such as *B. juncea*, *B. juncea*, *B. napus*, *B. rapa* exhibited moderately enhanced Zn and Cd accumulation. They were also found to be most effective in removing Zn from the contaminated soils. To date, more than 400 plant species have been identified as metal hyperaccumulators, representing less than 0.2% of all angiosperms (Brooks, 1998; Baker et al., 2000). The plant species that have been identified for remediation of soil include either high biomass plants such as Willow (Landberg and Greger, 1996) or those that have low biomass but high hyperaccumulating characteristics such as *Thlaspi* and *Arabidopsis* species.

The hyperaccumulators that have been most extensively studied by scientific community include *Thlaspi* sp., *Arabidopsis* sp., *Sedum alfredii* sp. (both genera belong to the family of Brassicaceae). *Thlaspi* sp. are known to hyperaccumulate more than one metal, i.e., *T. caerulescens* for Cd, Ni, Pb and Zn, *T. goesingense* for Ni and Zn, *T. ochroleucum* for Ni and Zn, and *T. rotundifolium* for Ni, Pb and Zn (Prasad and Freitas, 2003). Robinson et al.(1998) found *T. caerulescens* as hyperaccumulator for Cd and Zn could remove as high as 60 kg Zn/ha and 8.4 kg Cd/ha. It can accumulate as high as 2600×10^{-6} Zn without showing any injury (Brown et al., 1995) and extract up to 22% of soil exchangeable Cd from the contaminated site. It also showed remarkable Cd tolerance (Sneller et al., 2000; Escarre et al., 2000; Lombi et al., 2000). The hyperaccumulation of metals



in various plant species has been extensively investigated. It becomes clear that different mechanisms of metal accumulation, exclusion and compartmentation exist in various plant species. Rhizofiltration is the removal of pollutants from the contaminated waters by accumulation into plant biomass. Several aquatic species have been identified and tested for the phytoremediation of heavy metals from the polluted water. These include sharp dock (*Polygonum amphibium*), duck weed (*Lemna minor*), water hyacinth (*Eichhornia crassipes*), water lettuce (*P. stratiotes*), water dropwort (*Oenathe javanica*), calamus (*Lepironia articulata*), pennywort (*Hydrocotyle umbellata*) (Prasad and Freitas, 2003).

Wang *et al.* (2002) conducted a pot experiment to test five wetland plant species, i.e., sharp dock, duckweed, water hyacinth, water dropwort and calamus for their possible use in remedying the polluted waters. The results show that sharp dock was a good accumulator of N and P. Water hyacinth and duckweed strongly accumulated Cd with a concentration of 462 and 14200 mg/kg, respectively. Water dropwort achieved the highest concentration of Hg, whereas the calamus accumulated Pb (512 m/kg) substantially in its roots. Ingole and Bhole (2003) conducted hydroponic studies to investigate the uptake of As, Cr, Hg, Ni, Pb and Zn by water hyacinth from the aqueous solution at the concentrations ranging from 5 to 50 mg/L, and observed that in aqueous solutions containing 5 mg/L of As, Cr and Hg, the maximum uptake was 26, 108 and 327 mg/kg dry weight of water hyacinth, respectively.

CONCLUSION

The contamination of heavy metals to the environment, i.e., soil, water, plant etc. is of great concern due to its potential impact on human and animal health. The use of physicochemical cleaning technologies are not economically feasible. Thus cheaper and effective technologies are needed to protect the precious natural resources and biological lives and phytoremediation is such a processes. The mechanisms of metal uptake, accumulation, exclusion, translocation, osmo-regulation and copartmentation vary with each plant species and determine its specific role in phytoremediation. Variations exist for hyperaccumulation of different

metals among various plant species. Nevertheless, the recent advances in plant biotechnology have created a new hope for the development of hyperaccumulating species.

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