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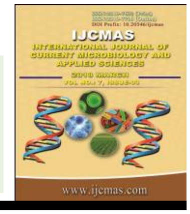

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Phytoremediation: A Plant - Based Technology

Mansoor Ali*, A.K. Bhat, Tsering Dolkar and M.A. Malik

Department of Soil Science, Sher-e-Kashmir University of Agriculture Science and Technology Shalimar, India

**Corresponding author*

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A B S T R A C T

Heavy metal contamination has increased rapidly since the early 20th century. A Large part of the world has been contaminated by organic and inorganic pollutants. Phytoremediation involves the use of plants to remove, transfer, stabilize and/or degrade contaminants in soil, sediment, and water. This plant-based technology has gained acceptance in the past ten years as a cheap, efficient and environmentally friendly technology especially for removing toxic metals. Currently, 6-8 billion US dollars are spent annually for environmental cleanup alone in the United States and worldwide it is 25-50 billion US dollars per year. *Sebera acuminate* and *Thlaspi caerulescens* (Cunningham and Ow 1996), *Arabidopsis thaliana* (Delhaize 1996), *Typha latifolia*, and *Phragmites australis* (Ye *et al.*, 2001) are some identified plants which are known for heavy metals accumulation in their tissues. In zinc and lead mine's *Typha latifolia* and *Phragmites australis* have been successfully used for phytoremediation in China. Water hyacinth (*Eichhornia crassipes*, Kay *et al.*, 1984; Zhu *et al.*, 1999), pennywort (*Hydrocotyle umbellata L*., Dierberg *et al.*, 1987), and duckweed (*Lemna minor L*., Mo *et al.*, 1989) are some important aquatic species known for the remediation of aquatic ecosystem. Further explorations are needed in the field of Phytoremediation to address technical issues and to find out the geographically suitable plant species for effective phytoremediation. Accumulation of heavy metals by plants is affected by many factors, variations in plant species, plants growth stage and element characteristics control absorption, accumulation and translocation of metals.

Introduction

Heavy metals constitute a heterogenous group of elements; a relatively high density of approximately 6 g cm^{-3} is their common characteristic with atomic weight more than that of iron (Alloway, 1997). Heavy metal contamination has increased rapidly since the early 20th century (Nriagu, 1979; Ensley, 2000). A Large part of the world has been contaminated by organic and inorganic pollutants. Organic pollutants are mainly spread through anthropogenic activities and are released into the environment through industrial activities, agricultural practices, military operations and fuel spills. Some organic pollutants such as trichloroethane (TCE) known as common ground water pollutant (Newman *et al.*, 1997), atrazine used as herbicides (Burken and Schnoor, 1997), trinitrotoluene (TNT) used as an explosive material (Hughes *et al.,* 1997), hydrocarbons such as oil, gasoline, benzene, toluene, and polycyclic aromatic hydrocarbons (PAHs) (Schnoor *et al.*, 1995, Aprill and Sims, 1990), fuel additives such as methyl tertiary butyl-ether (MTBE) (Hong *et al.*, 2001) and polychlorinated biphenyls (PCBs) (Harms *et al.*, 2003). Plant macronutrients such as nitrates and phosphates, micronutrients such as Cr, Cu, Fe, Mn, Mo, Ni and Zn, nonessential elements such as As, Cd, Co, F, Hg, Se, Pb, V, and W, and radionuclides such as ^{238}U, ^{137}Cs, and ^{90}Sr are commonly known as inorganic pollutants (Dushenkov, 2003). Sources of heavy metal contaminants in soils include metalliferous mining and smelting, metallurgical industries, sewage sludge treatment, warfare and military training, waste disposal sites, agricultural fertilizers and electronic industries (Alloway, 1995). Toxic heavy metals cause DNA damage, and their carcinogenic effects in animals and humans are probably caused by their mutagenic ability (Knasmuller *et al.,* 1998; Baudouin *et al.,* 2002). Metal-contaminated soil can be remediated by chemical, physical or biological techniques (McEldowney *et al.,* 1993). Chemical and physical treatments irreversibly affect soil properties, destroy biodiversity and may render the soil useless as a medium for plant growth. While as biological techniques include the phytoremediation has proved to be very efficient and environmentally friendly technique. The cost involved in the cleanup of heavy metal contaminated sites is huge not only for the developing nations but also for the developed countries like the United States. Currently, 6-8 billion US dollars are spent annually for environmental cleanup alone in the United States and worldwide it is 25-50 billion US dollars per year (Tsao, 2003). Bioremediation is another microbe-based technology along with the phytoremediation plant-based technology can be used for the cost-effective remediation of the contaminated sites (Pilon-Smits, 2005). Because of its low cost technology phytoremedation can become a very useful technology for the developing nations like India where there is shortage of funds for the environmental cleanups. Phytoremedation can also become an income generating technology by extracting some useful metals from the plants which are used to remove the metals from the soil particularly known as the phytomining (Brooks *et al.*, 1998; Angle *et al.*, 2001). Numerous research are currently carried out to find out the potential of these technology (Ghosh and Singh, 2005) with several plants are identified suitable for the phytoremediation and phytomining of Ni, Co, Tl, Pb, Cu, Zn (Anderson *et al.*, 1999; Chaney *et al.*, 1997; Brooks *et al.*, 2001; Boominathan *et al.*, 2004).

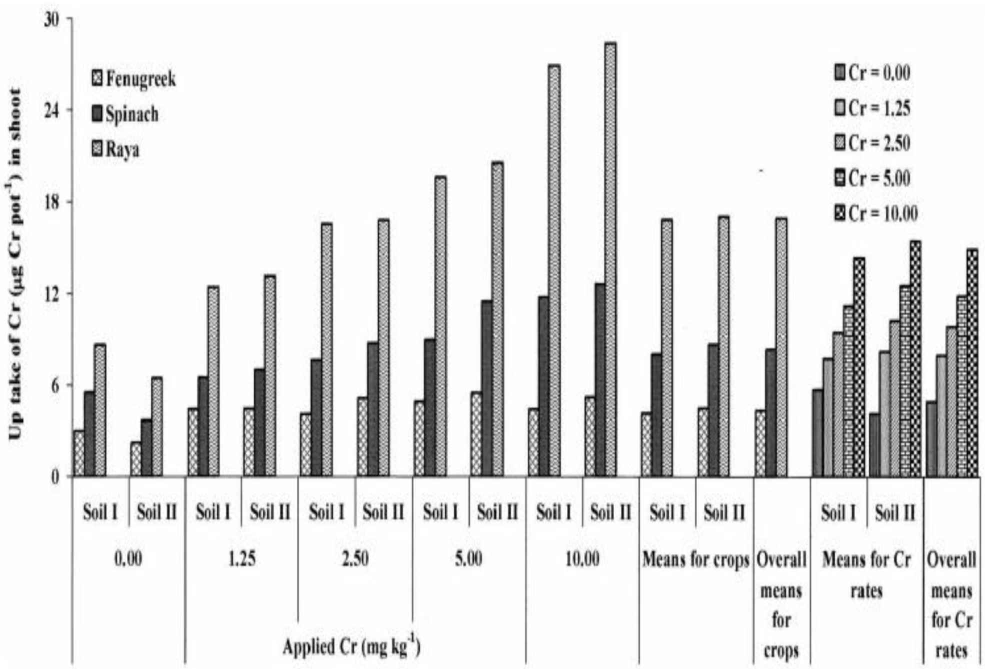
Plants for Phytoremediation

Phytoremediation involves the use of plants to remove, transfer, stabilize and/or degrade contaminants in soil, sediment, and water (Hughes *et al.,* 1997). This plant-based technology has gained acceptance in the past ten years as a cheap, efficient and environmentally friendly technology especially for removing toxic metals. Phytoremediation is the ability of plants to concentrate elements and compounds from the contaminated soils and water bodies and to metabolize molecules in their tissues appears very promising method for removal of pollutants from the soil and water (Gurbisu and Alkorta, 2003). Plant roots are mostly located in the soil, they can play a very crucial role in metal removal via filtration, adsorption and cation exchange, and chemical changes that takes place in the rhizosphere through plant roots (Dunbabin and Bowmer, 1992; Wright and Otte, 1999). *Sebera acuminate* and *Thlaspi caerulescens* (Cunningham and Ow, 1996), *Arabidopsis thaliana* (Delhaize, 1996), *Typha latifolia*, and *Phragmites australis* (Ye *et al.,* 2001) are some identified plants which are known for heavy metals accumulation in their tissues. In zinc and lead mine's *Typha latifolia* and *Phragmites australis* have been successfully used for phytoremediation in China (Ye *et al.,* 1997a, b). Water hyacinth (*Eichhornia crassipes*, Kay *et al.,* 1984; Zhu *et al.,* 1999), pennywort (*Hydrocotyle umbellata L*., Dierberg *et al.,* 1987), and duckweed (*Lemna minor L*., Mo *et al.,* 1989) are some important aquatic species known for the remediation of aquatic ecosystem. However, because of their small and slow growing roots, these plants have limited potential for rhizofiltration (Dushenkov *et al.,* 1995). The two most promising terrestrial species for removing metals from water are Sunflower (*Helianthus annus L*.) and Indian mustard (*Brassica juncea Czern*.). Dushenkov *et al.,* (1995) reported that Indian mustard is effective in accumulating Cd, Cr, Cu, Ni, Pb, and Zn, whereas sunflower efficiently removes Pb (Dushenkov *et al.,* 1995), U (Dushenkov *et al.,* 1997a), ^{137}Cs, and ^{90}Sr (Dushenkov *et al.,* 1997b) from hydroponic solutions. A glasshouse investigation was undertaken to evaluate the natural potential of fenugreek (*Trigonella foenumgraecum L*.), spinach (*Spinacia oleracea L*.), and raya (*Brassica campestris L*.) for cleanup of chromium (Cr)–contaminated silty loam and sandy soils. Figure 1 and 2 summarized the Cr uptake in fenugreek, spinach, and raya increased with increasing level of added Cr in both soils. The findings indicated that family *Cruciferae* (Raya) was most tolerant to Cr toxicity, followed by *chenopodiacea* (spinach) and *Leguminosae* (fenugreek). Because raya removed the highest amount of Cr from the soil, it could be used for phytoremediation of mildly Cr-contaminated soils (Dheri *et al.,* 2007).

A comparative study was carried out in order to find Cr extraction in five different weeds and two Brassica species was in ascending order: *Ipomeia. Carnea, Dhatura innoxia, Cassia tora, Phragmytes karka, Brassica juncea, Lantana camara and Brassica campestris* respectively (Ghosh and Singh, 2005). Among the all *Phragmytes karka* showed much greater tolerance to metals but the uptake was less as compared to other plants. Other than *Lantana camara*, all the tested weeds were better for chromium extraction than the accumulator *Brassica species.* This indicates that weeds can be used in place of *brassica species* and it requires very less cure (Fig. 3). Deepali and Gangwar (2009) found in their study that the Cr accumulation in the roots and shoots of *Spinacea olaracea* in percent are shown in Figure 4 were higher at minimum concentration.

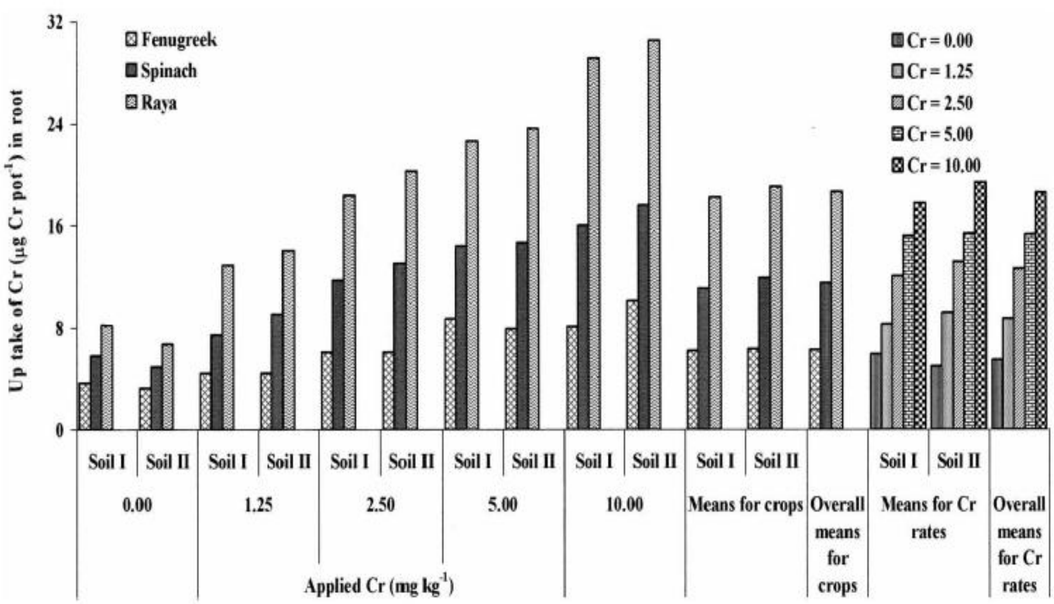
Hyperaccumulators are that of special category of plants that can accumulate extraordinary levels of metals, the idea of using these plants for phytoextraction only appeared in the literature in the Zn up to levels that are 100 to 1,000 times of those normally accumulated by plants grown under the same conditions (Baker *et al.,* 2000; Ma *et al.,* 2001; Brooks, 1998). A number of these species are members of Brassicaceae, including a species of Arabidopsis, *A. halleri*, which can hyper accumulate Zn in its shoots (Reeves and Backer, 2000). Recently, Sonchus asper and Corydalis pterygopetata grown on lead – zinc mining area in China have been identified as heavy metal hyperaccumulators (Yanqun *et al.,* 2005). A list of 775 plant species database (PHYTOREM) has been developed by Environment Canada with capabilities to accumulate or hyperaccumulate one or several key metallic elements. So far only one hyperaccumulator species, the Ni hyperaccumulator. *Alyssum bertolonii*, has been used for phytoremediation in the field (Chaney *et al.,* 2000; Li *et al.,* 2003). *Pteris vittata*, an Arsenic (As) hyperaccumulating fern may also show promise for phytoextraction of As.

Fig.1 Chromium uptake in shoots of different crops grown in two Cr contaminated soils (soil 1 texture- silty loam and soil 2 – sandy soils)



Source (Dheri *et al.*, 2000)

Fig.2 Chromium uptake in the roots of different crops grown in two Cr contaminated soils (soil 1 texture- silty loam and soil 2 – sandy soils)



Source (Dehri *et al.*, 2000)

Fig.3 Average dry biomass (g) grown in chromium treated soils (n= 6) on 90th day;

Table 1. *Average Dry biomass (g) grown in chromium treated soils (n = 6) on 90th day.*

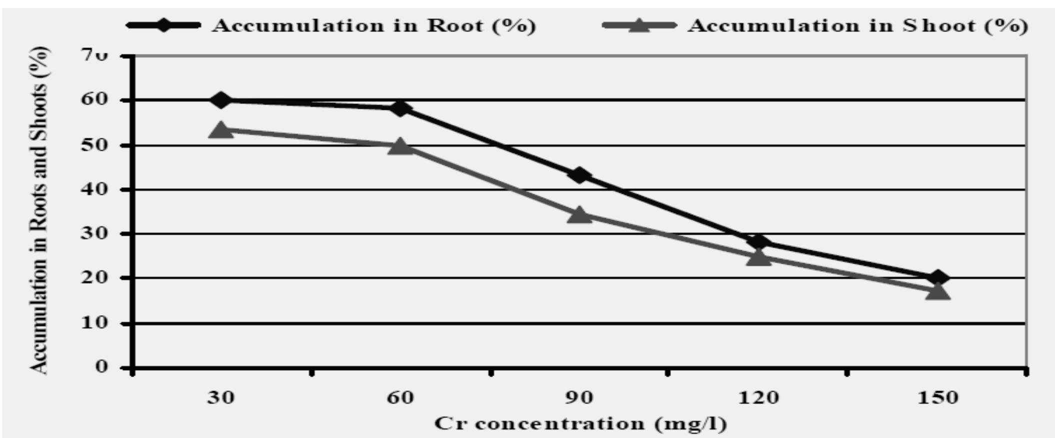
Total Cr added in Soil (mg kg $^{-1}$)	*Brassica campestris*	*Brassica juncea*	*Dhatura innoxia*	*Ipomoea carnea*	*Phragmytes karka*	*Cassia tora*	*Lantana camara*
Control	3.28	3.31	12.32	19.59	11.46	12.45	5.43
5	1.86**	2.89*	8.57**	15.01**	7.66**	7.90**	2.27**
10	1.47**	2.16**	7.24**	11.33**	5.93**	7.30**	1.93**
20	1.36**	1.17**	6.49**	10.50**	7.64**	7.21**	1.76**
50	NG	NG	NG	NG	1.51**	NG	1.09**
100	NG	NG	NG	NG	1.06**	NG	NG
200	NG	NG	NG	NG	0.78**	NG	NG

Significantly different * ($p \le 0.05$) & ** ($p \le 0.005$) in comparison to control plant.

NG = No Growth observed
n = number of plants

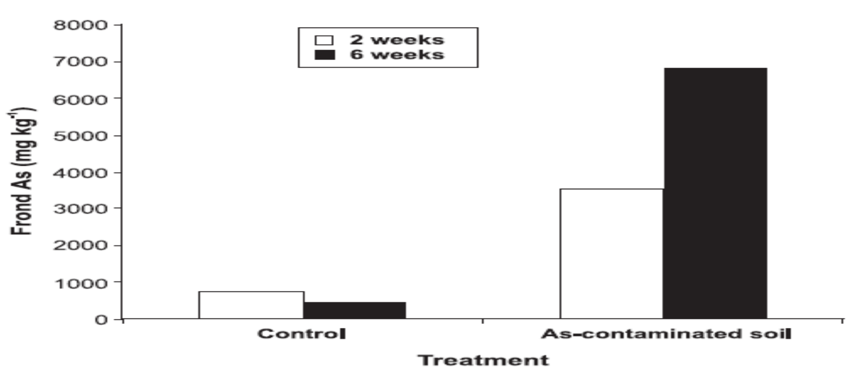
Source (Gosh and Singh, 2005)

Fig.4 Cr accumulation (%) in root and shoot of spinaches olaracea



Source (Deepali and Gangwar 2009)

Fig.5 Arsenic (As) concentration in the fronds of *Pteris vittata* after growing in uncontaminated soil (6 ppm As) and arsenics contaminated soil (400 ppm As)



Source (Ma *et al.*, 2001)

Table.1 Several metal hyperaccumulator species with respective metal accumulated

S.no	Plant species	Metal	References
1	*Thlaspi caerulescens*	Zn, Cd	Reeves and Brooks (1983); Baker and Walker (1990)
2	*Ipomea alpine*	Cu	Baker and Walker (1990)
3	*Sebertia acuminate*	Ni	Jaffre *et al.*, (1976)
4	*Haumaniastrum robertii*	Co	Brooks (1977)
5	*Astragalus racemosus*	Se	Beath *et al.*, (2002)
6	*Arabidopsis thaliana*	Zn, Cu, Pb, Mn, P	Lasat (2002)
7	*Brassica oleracea*	Cd	Salt *et al.*, (1995)
8	*Hemidesmus indicus*	Pb	Chandra Sekhar *et al.*, (2005)
9	*Pteris vittata*	As	Ma *et al.*, (2001); Zhang *et al.*, (2004); Tu and Ma (2005)
10	*Helianthus anus*	Cd, Cr, Ni	Turgut *et al.*, (2004)

Source (Vinita Hooda, 2007)

Table.2 Heavy metal hyperaccumulator (HMH) and non-HMH plant species used in phytoextraction studies included in the meta-analysis and the metals used in phytoextraction.

Plant species	Family	Common name	Target metal	Reference
Heavy metal hyperaccumulator				
Alyssum murale	Brassicaceae	Yellowtuft	Ni	Abou-Shanab *et al.*, 2006
Alyssum serpyllifolium	Brassicaceae		Ni	Ma *et al.*, 2011
Noccaea caerulescens	Brassicaceae	Alpine penny-cress	Cd, Zn	Karimzadeh *et al.*, 2012; Whiting *et al.*, 2001
Pteris vittata	Pteridaceae	Chinese brake fern	As	Lampis *et al.*, 2015; Yang *et al.*, 2012
Sedum alfredii	Crassulaceae		Cd, Zn	Li *et al.*, 2007; Zhang *et al.*, 2012
Sedum plumbizincicola	Crassulaceae	Cd, Pb, Zn		Liu *et al.*, 2015; Ma *et al.*, 2013
Non-heavy metal hyperaccumulator				
Brassica juncea	Brassicaceae	Indian mustard	Ni, Cu	Rajkumar *et al.*, 2013; Ma *et al.*, 2011, Ma *et al.*, 2009a; Zaidi *et al.*, 2006
Brassica napus	Brassicaceae	Canola	Cd	Dell'Amico *et al.*, 2008; Sheng and Xia, 2006; Sheng *et al.*, 2008
Brassica oxyrrhinaa	Brassicaceae	Smooth-stemmed turnip	Ni	Ma *et al.*, 2009a
Glycine max	Fabaceae	Soybean	Cu	Khan and Lee, 2013
Helianthus annuus	Asteraceae	Sunflower	Cd, Zn	Marques *et al.*, 2013; Prapagdee *et al.*, 2013
Hordeum vulgare	Poaceae	Barley	Cd, Pb	Belimov *et al.*, 2004
Lens culinaris	Fabaceae	Lentil	Ni	Wani and Khan, 2013
Luffa cylindrica	Cucurbitaceae	Sponge gourd	Ni	Rajkumar *et al.*, 2013
Lycopersicon esculentum	Solanaceae	Tomato	Cd, Pb	He *et al.*, 2009; Sheng *et al.*, 2008
Ricinus communis	Euphorbiaceae	Castor oil plant	Cu, Ni, Zn	Rajkumar and Freitas, 2008
Sinapis alba	Brassicaceae	White mustard	Cd, Cu, Zn	Płociniczak *et al.*, 2013
Solanum nigrum	Solanaceae	Black nightshade	Cd	Gao *et al.*, 2010
Sorghum halepense	Poaceae	Sorghum	Cd, Ni	Rajkumar *et al.*, 2013; Sheng et
Thlaspi arvensea	Brassicaceae	Field penny cress	Zn	Whiting *et al.*, 2001
Vigna radiata	Fabaceae	Mung bean	Cd, Ni, Zn	Rani *et al.*, 2013; Wani *et al.*, 2007
Zea mays	Poaceae	Corn	Cd	Malekzadeh *et al.*, 2012; Sheng *et al.*, 2008

Source (Jennifer, L.W *et al.*, 2016)

A fast-growing plant *Pteris vittata* (Fig. 5) is reported to tolerate arsenic contaminated soils of around 1500 p.p.m and its fronds concentrate the toxic metal to 22,630 p.p.m in just 6 weeks (Ma *et al.*, 2001).

Table 1 and 2 lists some important hyperaccumulators and non-hyper accumulators including the recently discovered ones.

Trees have been suggested as a low-cost, sustainable and ecologically sound solution to the remediation of heavy metal-contaminated land (Dickinson., 2000), Studies of tree establishment on contaminated land have considered a number of different species, e.g. Salix (*Willow*), Betula (*Birch*), Populus (*Poplar*), Alnus (*Alder*) and Acer (*Sycamore*).For the purposes of phytoremediation, most attention has been paid to fast-growing species, such as willow. A characteristic of willow, which makes it a very suitable tree for use in phytoremediation, is that it can be frequently harvested by coppicing, yielding as much as 10–15 dry t ha^{-1} $year^{-1}$ (Riddell-Black., 1993). Transgenic (genetically engineered) plants might be another improved way for phytoremediation include *Brassica juncea* for phytoremediation of heavy metals from soil (Dushenkov *et al.*, 1995), Helianthus anus (Dushenkov *et al.*, 1995) and *Chenopodium amaranticolor* (Eapen *et al.*, 2003) for rhizofiltration of uranium. It is not yet clear how applicable these transgenic are for environmental cleanup, since no field studies have been reported except one using transgenic Indian mustard plant that overexpresses enzymes involved in sulfate/ selenate reduction (Pilon Smits *et al.*, 1999; Zhu *et al.*, 1999).

Further explorations are needed in the field of Phytoremediation to address technical issues and to find out the geographically suitable plant species for effective phytoremediation. Accumulation of heavy metals by plants is affected by many factors, variations in plant species, plants growth stage and element characteristics control absorption, accumulation and translocation of metals. Moreover, physiological adaptations also control toxic metal accumulations by sequestering metals in the roots (Guilizzoni 1991). As a result, metal removal by vegetation can be greatly enhanced by the judicious selection of plant species. The knowledge about the abilities of different plant species or tissues to absorb and transport metals under different conditions will provide insight into choosing appropriate plants for phytoremediation of the polluted regions.

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