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PHYTOREMEDIATION - A REVIEW

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ABSTRACT

The pollution of environment i.e., soil, water and air is not uncommon. The contamination of first two with metals, heavy metals and radio nuclei has been on the increase since starting of industrial revolution. The primary sources of pollution include burning of fossil fuels, mining and smelting of metalliferous ores, municipal wastes, fertilizers, pesticides and sewage. The pollution of soil and water is posing threat to human, animal and plant life in various ways. Soil which is called a natural resource base for plant growth is becoming unfit for cultivation mainly due to contamination of heavy metals. These include Cd, Pb, Cr, Au, As, Cu, Zn, Se and Ni. Phytoremediation is the best option for cleaning up environment as it is the ecologically sustainable and environmentally viable technology. The *Brassica* species are identified as good candidates for phytoextraction of heavy, metals especially Zn. EDTAand Citric acid are commonly used for induced phytoextraction ofPb. Rabbit foot grass was identified as suitable species for phytovolatilisation of Se from constructed wetlands. The aquatic plant species are regarded as best species for removing metals from contaminated water. Poplar trees are used for phytodegradation of harmful compounds like TNT. This green cure technology no doubt has the ability to clean up contaminated soil and water but slowly.

Degradation of present day environment is mainly due to pollution caused by increased human activities such as industrialisation, mining and smelting of metalliferous ores, municipal wastes, fertilizers, pesticides, sewage, transportation and urbanisation. These activities release large quantities of hazardous chemicals like metals, metalloids and radionuclei. Accumulation of these toxic wastes in soil and water is a serious concern as they enter food chain and pose threat to plant, human and animal health. (Salt *et al.,* 1995).

Heavy metal contamination and pollution of environment is unavoidable due to growing industrialization. Soil is the highly valuable and most suffering environmental segment due to heavy metal pollution. Table 1 shows the major heavy metals and their respective sources in the environment.

Heavy metals (density >6g/cc) are the natural elements present in the soil or lithosphere, but when their concentration exceeds certain critical level, it is said to be toxic to plants and other biological organisms. Table 2 shows critical limits for heavy metal toxicity and toxicity symptoms in plants, animals and human beings.

In order to overcome above said health hazards on plants, animals and humans, phytoremediation is widely acknowledged as the most promising ecologically sustainable and environmentally viable technology (Ramanjaneyulu and Giri, 2004).

What is phytoremediation?

It can be loosely defined as use of plants to improve the environment. It is **the use of green plants and their associated rhizosphere microflora to remove, degrade, or stabilize complex environmental contaminants.** Various types of vegetation, including trees, grasses and aquatic plants, are used *in situ* to decontaminate air, soil and surface and groundwater systems (Table 3).

The concept of hyper accumulator plants to take up and remove heavy metals from. contaminated soils was first discussed by Chancy (1983). A hyperaccumulator refers to those plant species which accumulate a minimum of 100 ppm thallium/1000 ppm of

Table 1. Major sources of heavy metal contamination in soil

Element	Major sources
Arsenic	Pesticides, plant desiccants, mining, coal, petroleum, detergents
Cadmium	Electroplating, pigment, plastic, batteries, paints
Chromium	Stainless steel industries, chrome-plating
Copper	Fertilizer, fly-ash, mining
Lead	Combustion of oil, gasoline, coal, iron and steel production
Nickel	Electroplating, batteries
Zinc	Rubber manufacturing, batteries, galvanizing iron and steel
Se	Agrochemicals, sewage, domestic waste (Dandruff Shampoo)

Table 2. Heavy metal toxicity levels and symptoms in plants

Element	Toxicity level (ppm)	Symptoms in plant
Cu	10-70	Chlorotic leaves and reduced branching. Thickening and dark coloration in the rootlets
Mn	400-7000	Stunting, general chlorosis and necrotic leaf spots and brown spotting of older leaves
Mo	100-1000	Yellow or orange chlorosis, seedling injury and delayed maturity
Ni	8-147	Chlorosis, stunted growth
Zn	95-340	Severe leaf scorching, reduced yield and decreased net assimilation rate

Gupta and Gupta (1998)

Element	Toxicity limit	Problematic areas	Symptoms
Se	0.5 ppm (soil)	Karnal (Haryana)	Snow white chlorosis (Wheat)
	>0.1 ppm (fodder)	Jalpaiguri (WB)	Deformed horns and hooves in animals
		Jaintia hills (Assam and Meghalaya)	Deformed nails in humans
As	50 ppm (water)	WB and	Hypo and Hyper pigmentation
	20 ppm (soil)	Bangladesh	Hyper keratosis

Table 3. Selected plant/tree species for phytoremediation of contaminants

Plant species	Contaminants
Alyssum montanum	Cu, Ni
Brassica juncea	Pb, U
Brassica napus, Astralagus sp., *Pteris vttata*	Se
Brassica nigra	Ni, Zn
Helianthus annus	L, Cd, Cr, Cs, Mn, Ni, Pb, Se, Zn, U
Avena sp., *polar* trees	TNT
Sebertia acuminata (tree)	Ni
Thalaspi caerulescens	Cd, Cu, Ni, Zn, U
Typha sp.	Al, Cd, Fe, Mn, Ni, Pb, U
Zea mays	Pb
Ecichhornea sp., *Lemma minor, Azolla pinnata*	Pb, Cu, Cd, Fe, Hg

(Lanza and Flathman, 2001)

Co, Cu, Se, Pb/10000 ppm of Zn and Mn (Brooks 1998 and Baker *et al.*, 2000). These plants should posses the characters like faster growth, ability to tolerate high concentration of toxic metals, high accumulation capacity and producing more biomass.

Phytoremediation is a wide concept which includes technologies as mentioned below.

PHYTOEXTRACTION of metals

It is the uptake of contaminants, particularly toxic metals and radio nuclei by plant roots and the translocation of these contaminants into plant biomass, including shoots, leaves, and woody tissue. Specially selected plants, known as hyperaccumulators, can extract and accumulate exceptionally high levels of contaminants from soil. Phytoextraction of heavy metals from the soil can be achieved by two methods:

1. Continuous phytoextraction

It is based on the phytological processes that allow plants to accumulate metals over the complete growth cycle. It is based on the genetic and physiological capacity of hyper accumulators to accumulate, translocate and resist high amount of metals.

The first hyper accumulators characterized were number of *Brasicaceae* and *Fabaceace.* The accumulation of Zn in roots and shoots of two *Thalaspi* species was reported by Lasat *et al.* (1996). Zn accumulation in roots of *Thalaspi arvense* was 3 micro mol/g compared to 2.5 micromol/g in *T. caerulescens.* On *the* contrary, translocation of Zn from roots to shoots was approximately 10-fold greater in *T. caerulescens* vis-a-vis *T. arvense,* over a 96-hr uptake period. Hence *T. caendescence* was the efficient hyperaccumulator of Zn. Thallium is extremely toxic to animals and humans although soil contamination is rare. Two plants species *Iberis intermedia* and *Biscutella laevigata* of brassicaceae family, were reported to be hyperaccumulatrors (Anderson *et al.,* 1999). Of 60 plant species examined, Indian mustard and sunflowef were found to be hyper accumulators (Shahandeh and Hosner,2000). *Brassica juncea* was efficinet in phytoextraction of Pb, Zn and Cd than *B. carinata* (Rio *et al.,* 2000). As reported by Baker (1987), graminaceous members had exhibited significant heavy metal tolernace.

2. Induced phytoextraction

It is also known as chelate assisted phytoextraction. Synthetic metal chelates such as EDTA addition to soil increase the heavy metal accumulation by plants. Metal accumulation efficiency of plants is directly related to the affinity of chelates for a particular metal. For eg. EDTA for Pb and EDTA for Cd and citrate for U is normally recommended for induced phytoextraction. Of all the chelates applied at 5 and 10 mmol/kg to soil, EDTA @ 10 mmol/kg could induce the phytoextraction of Pb up to 16000 and 12000 ppm, respectively. Phytoextraction of Pb was increased in maize and pea plants by 50 per cent (Vassil *et al.*, 1998), while Huang *et al.* (1998) noticed thousand fold increase in uranium concentration in citric acid amended soils. Fourteen taxa including *Brassica jimcea* and *Zea mays* were reported to be Pb hyperaculdulators with Pb concentration ranging from 1000 to 20000 μg g^{-1} in the presence of EDTA (Reeves and Baker, 2000). As reported by Ma *et al.* (1999), Brake fern (*Pteris vittata*) has removed 22630 μg g^{-1} As in six weeks in amended soil against 4980 μg g^{-1} As. Uranium contamination of surface soils has resulted from the development of nuclear industry, which evolved the mining, milling and fabrication of various U products. U contamination poses significant health risks to both human and animals and limits the future use of many sties. These sites require decontamination for their sustainable use. Huang *et al.* (1998) estimated the shoot uranium concentration in different plant spp. In normal phytoaccumulation method (control), corn has accumulated U to the extent of 10 ppm and was higher than other crops. But in case of induced phytoextraction by applying citric acid to soil, the accumulation could be increased manifold in all crop spp. It was highest in *Brassica chinensis* (1300 ppm) followed by *B. juncea* (750 ppm) and *Amaranthus spp.* (600 ppm).

Compartmentation of zinc and Ni compilation

Brune *et al.* (1994) studied the Compartmentation of Zn in barley leaves. At low concentration of Zn in nutrient solution (2 mmol/m^3), maximum Zn accumulated in mesophyll protoplast (60.1 mmol/g fw) followed by cytoplasm (55.7 mmol/g fw). While at higher concentration of Zn, accumulation of Zn was highest in mesophyll chloroplast (149.4 mmol/g fw) followed by vacuole (99.7 mmol/g fw). In case of *Thalaspi caerulescence,* Zn is sequestered mainly in vacuoles of epidermal cells of leaves.

Any plant which is able to accumulate Ni in concentrations of more than 1% dry weight is referred to hyper nickelophore (Jaffre, 1980) e.g. *Sebertia acuminata, Psychotria douarrei, Alyssum* sp. Ni-citrato complexes were involved in complexation of Ni in *Serbertia acuminata,* while Ni-malate complex was found in *Psychotria douarrei.* In Alyssum leaf extracts, malic acid was supported to bind Ni and transport it into the vacuole (Sanger *et al.,* 1998). They analysed and reported Ni accumulation in different parts of *Serbertia acuminata.* This tree with an estimated weight of 1980 kg and height of 15 m accumulated 37 kg of Ni. Maximum per cent of Ni (18.5%) was observed in latex i.e. laticifer cells while little Ni in phloem (1.2%), fruit (0.5%) and Xylem (0.1%) was recorded.

Phytoremediation of pesticide contaminated soils

Herbicide usage in Agriculture is gaining momentum in plantation crops, wheat, and rice etc. Indiscriminate usage of these chemicals are contaminating the soil and water and residue build up is taking place. Such accumulation is threatening the base for crop growth and development. Phytoremediation is the best way to decontaminate these soils which some fungi and poplar tree were found to be efficient.

Bordjiba *et al.* (2001) estimated the depletion per cent of metribuzin and metobromuron from non-contaminated and contaminated soils of liquid culture medium by using different fungi, and found that *Byssochleamys* sp. and *Sordaria* sp. (Ascomycetes), *Botrytis* sp. (Dematiaceae) and *Abscidia* sp. (Zygomycetes) fungi were most efficient depletors. Komives *et al.* (1994) reported that Benoxacor - a safener can protect maize from chloracetanilides by inducing increased metabloism via conjugation.

PHYTOVOLATILISATION

Contaminants taken up by plant roots will be translocated within its plant either in unaltered or altered form to the leaves from where they are lost into atmosphere through transpiration.

Major phytovolatilable metals are in mercury, selenium and arsenic. Volatilization is based on different biological processes including reducfton to volatile elemental forms and synthesis of methylated compounds of same metals and metalloids (Wenzer *et al.,* 1999). Indian mustard was found to reduce Se concentration to non toxic levies (Banuelos and Meek, 1990 , Banuelos *et al.*, 1997). Burken and Schnoor (1999) characterised the distribution and volatilisation of selected organic contaminants by using hybrid poplar trees and reported that volatilisation of contaminants (e.g., benzene, ethylbenzene, m-xylene, nitrobenzene, toluene and TCE) as a function of contaminant vapour pressure (Vp). According to Hansen *et al.* (1998), constructed wetlands are highly effective in removing Se from selenite contaminated waste waters. They recorded maximum rates of Se volatilization from five vegetated wasteland sites. The most efficient phytovolatilizers of Se were rabbit foot grass and cattail as they attained volatilization rate of 190 $\pm$ 150 and 180 $\pm$ 100 µg of Se/m^2/

day.

PHYTOSTABILISATION

It envisages use of plants along with agronomic techniques to stabilize contaminated sites. Typically, soil amendments are applied to contaminated soil to reduce the bioavailability of contaminants, and the site is planted into vegetation which reduces off-site migration of the contaminated soil. For example, a variety of alkalizing agents, phosphates, mineral oxides, organic matter, and biosolids can be used as soil amendments to render Pb more insoluble and unavailable to leaching, mammalian ingestion, or plant uptake. Plant varieties that can develop a substantial root biomass capable of binding and retaining toxic metals in contaminated soils without transporting metal to the shoots are good candidates for phytostabilization.

PHYTODEGRADATUION

It is the metabolism of contaminants within plant tissue. Plant root, stem, and leaf enzymatic metabolic activities can convert and detoxify contaminants removed from air, soil, and water.

Some of the plant spp. are efficient in degrading the pollutant within plant system into less (no) harmful compounds e.g. Poplar tree for Atrazine and TNT. According to Burken and Schnoor (1997), Atrazine is degraded into less harmful compounds -Anneline and dehydroxylated dealkylated products. The explosive like TNT (2,4,6-Trinitroluene) is degraded into less or no harmful product 2,4-diamino-6-dinitrotoulene . Glycerol Trinitrite (GTN), heaxahydro-l,3,5-trinitro-l,3,5-triazine (RDX) and 2,4,6-trinotro toluene (TNT) are common explosives that contaminate soil and groundwater. The plants like *Avena sativa* and *Beta vulgaris* were identified as suitable species for decontamintion of TNT and GTN, respectivley. Besides, seeds of transgenic tobacco which will release an enzyme pentaertrythritol tetranitrate reducase (FETR), are able to germinte and grow in the presence of GTN and TNT, can be used phytoremdiation (Gong *et al.,* 1999).

RHIZOFILTRATION

Use of plants that are raised hydroponically and then relocated to sites for the purpose of removing metal contaminants from aqueous waste-streams. Hydroponic plant roots suspended in contaminated water take up and accumulate contaminants. When the plants become saturated with the contaminants, they are harvested for disposal.

It is assuming lot of importance in decontamination of polluted water due to anthropogenic and industrial activities. Panda (1996) worked on rhizofiltration of Zn and Ni in liquid culture medium by using aquatic plant spp. Water lettuce and water hyacinth were found to be efficient hyper accumulators of Zn (18041 and 14423 ppm) and Ni (7850 and 5315 ppm).

The auquatic macroflora like *Hydrilla vericillata* and *Nymphea sp* were effective in reducing Cr concentration in tannery effluent by more than 50 per cent (Malena, 1999). Azolla, free floating water fern which occurs in association with N_2 fixing blue green algae has high rate of multiplication, present varied conditions from dilute to polluted water bodies (Singh and Mahapatra, 2000) remove metals. It has the capacity to accumulate Cr, Co, Hg, Zn, Ni, Cd, Cu, As and U without any detrimental effect on it's growth (Yong-huang and Weizhen, 1985). As reported by Tel (1999), azolla has the ability to reclaim saline soils. Deng-hui *et al.* (1985) has observed that desalinisation rate with Azolla was 71.4 per cent higher than water leaching and salt content could be reduced to 0.1 per cent from 0.35 per cent with in two years.

RHIZOTRANSFORMATION

Rhizosphere microflora are involved in phytoremediation. They will play a vital role in detoxification or enhancing the translocation of toxic elements to different parts of plant body. Salt *et al.* (1995) carried out hydroponics study using rhizospheric microorganisms and studied Cd accumulation in the shoots of 2 week old *Brassica juncea* seedlings. Among microorg anisms, *Pseudomonas putida* and *Bacillus thuringiensis* were efficient in enhancing Cd accumulation in shoots of *B. juncea*. All the rhizosphere microorganisms were efficient than control.

Phytoremediation studies and prospects in India

Very few reports are available on phytoremediation in India, and all are confined to studies on water bodies. The decontamination of water of lake Nainital was carried out by using *S. babylonica* and *S. acrophylla* (Ali *et al.,* 1999). Now the research has initiated in several institutes including IARI, New Delhi.

The *Brassica* sp. which is widely cultivated over Indo-Gangetic plains is found to have hyper accumulating capacity can be effectively used for remediating the polluted soils in and around metro cities including Delhi. Phytoremediation of aquatic bodies like polluted holy rivers, canals, tanks and sewage ponds such as Hussain sagar lake in Hyderabad, should be taken up so that water could be utilised for domestic and other uses. The extensive study conducted by Salim All centre for Ornithology and Natural History (SACON) under the aegis of United Nations Development Programme (UNDP) revealed that almost wetlands in 14 states are polluted and all 1249 specimens of fish drawn contained pesticides or heavy metals. All these water bodies need immediate attention of policy makers and research scientists. Phytoremediation is the best eco friendly option to overcome this anamoly.

Potential Limitations to Phytoremediation Technologies

1. Many hyperaccumulators exist as relatively small populations with slow growth rates and low biomass production
2. It slower than traditional methods and may require several growing seasons
3. Climate may be a limiting factor for plant growth and season length
4. Plants used may provide an entry for the biomagnification of contaminants in food, chains (e.g. herbivore grazing)
5. The methods for the disposal of contaminated biomass may have environmental impacts and
6. Genetically engineered phytoremediation systems may pose unacceptable ecological and environmental health risks.

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