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. EDTA and Citric acid are commonly used for induced phytoextraction of Pb. 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

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

Table 2. Heavy metal toxicity levels and symptoms in plants

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

Gupta and Gupta (1998)

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

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alyssum montanum</td>
<td>Cu, Ni</td>
</tr>
<tr>
<td>Brassica juncea</td>
<td>Pb, U</td>
</tr>
<tr>
<td>Brassica napus, AstraLegus sp., Pteris vitata</td>
<td>Se</td>
</tr>
<tr>
<td>Brassica nigra</td>
<td>Ni, Zn</td>
</tr>
<tr>
<td>Helianthus annuus</td>
<td>L, Cd, Cr, Cu, Mn, Ni, Pb, Se, Zn, U</td>
</tr>
<tr>
<td>Avena sp., polar trees</td>
<td>TNT</td>
</tr>
<tr>
<td>Sesbania acuminata (tree)</td>
<td>Ni</td>
</tr>
<tr>
<td>Thalasi caerulea</td>
<td>Cd, Cu, Ni, Zn, U</td>
</tr>
<tr>
<td>Typha sp.</td>
<td>Al, Cd, Fe, Mn, Ni, Pb, U</td>
</tr>
<tr>
<td>Zea mays</td>
<td>Pb</td>
</tr>
<tr>
<td>Scichhornea sp., Lemna minor, Azolla pinnata</td>
<td>Pb, Cu, Cd, Fe, Hg</td>
</tr>
</tbody>
</table>

(Lenza and Flathman, 2001)

Co, Cu, Se, Pb/10000 ppm of Zn and Mn (Brooks 1998 and Baker et al., 2000). These plants should possess 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 radionuclides 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 hyperaccumulators to accumulate, translocate, and resist high amounts of metals.

   The first hyperaccumulators characterized were number of Brassicaceae and Fabaceae. The accumulation of Zn in roots and shoots of two Thlaspi species was reported by Iazelet et al. (1996). Zn accumulation in roots of Thlaspi 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. caerulescens was the efficient hyperaccumulator of Zn. Thallium is extremely toxic to animals and humans although soil contamination is rare. Two plants species Thalassia intermedia and Biscutella laevigata of brassicaceae family, were reported to be hyperaccumulators (Anderson et al., 1999).

   Of 60 plant species examined, Indian mustard and sunflower were found to be hyperaccumulators (Shahandeh and Hosner, 2000). Brassica juncea was efficient 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 tolerance.

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 percent (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 juncea and Zea mays were reported to be Pb hyperaccumulators 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 sites. 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/m³), maximum Zn accumulated in mesophyll protoplast (60.1 nmol/g fw) followed by cytoplasm (55.7 nmol/g fw). While at higher concentration of Zn, accumulation of Zn was highest in mesophyll chloroplast (149.4 nmol/g fw) followed by vacuole (99.7 nmol/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. Serbertia 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 Absidicia sp. (Zygomycetes) fungi were most efficient depletors. Komives et al. (1994) reported that Benoxacor - a safener can protect maize from chloracetanilides by inducing increased metabolism 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 reduction 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 levles (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 selenium 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 ± 150 and 180 ± 100 µg of Se/m²/
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.

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.

RHIZOTRANSFORMATION

Rhizosphere microflora are involved in phytoremediation. They will play a vital role in degrading contaminants.
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 microorganisms, 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. acmophylla (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 anomaly.

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.

REFERENCES