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Review Article

Status on Phytoremediation of Heavy Metals in India- A Review

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Abstract

Since the dawn of the industrial revolution, mankind has been introducing numerous hazardous compounds into the environment at an exponential rate. These hazardous pollutants consist of a variety of organic compounds and heavy metals (Cu, Pb, Cd, Ni, Fe, Mn, and Zn), which increasingly pose serious risks to human health. Heavy metal contamination is of special concern due to widespread reports emanating both from India and abroad about various diseases and disorders observed both in human and livestocks due to metal toxicity. The pollution of environment particularly from hazardous heavy metals is also considered as a vital societal problem. Thus, understanding the existing heavy metal pollution in India required a special attention for remediation through eco-friendly approach by using plants called phyto-remediation. In this review, we have highlighted the major research outcomes by Indian researchers working in the area of technologies like *phytoextraction*, *phytoaccumulation*, *rhizofiltration* and *phytostabilization*. Finding the suitable hyperaccumultor plant species is of first and foremost step for successful application of this economic and useful technology. This review attempts to address the major works done in India and will give readers a vivid idea of scope of phytoremediation with its possible benefits on agriculture. This technique hold a great promise for decontamination of heavy metals from soil and water bodies with successful intervention of interdisciplinary researchers, but challenges remain before commercialization and field scale application. Phytoremediation, a new-generation technology for both agricultural and environmental sustainability also widens up many new areas of researches for generations to come.

1. Introduction

Heavy metals are conventionally defined as elements with metallic properties (ductility, conductivity, stability as cations, ligand specificity *etc*.) and having density of >5.0 g cm^{-3} and atomic number >20. The most common heavy metals found at hazardous waste sites are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn). Heavy metals can be categorized as i.e., beneficial heavy metals and toxic heavy metals. Beneficial heavy metals include elements like Fe, Zn, Cu, Co, Cr, Mn and Ni are needed in small quantities for human metabolism, but may be toxic at higher levels. Some of these are trace elements (e.g., iron, copper, manganese and zinc).

Many metals such as Zn, Mn, Ni and Cu are termed as essential micronutrients. In non-accumulator plants, accumulation of these micronutrients does not exceed their metabolic needs (<10 ppm). In contrast, metal hyperaccumulator plants can accumulate exceptionally high amounts of metals (thousands of ppm). Since metal accumulation is eventually an energy consuming process, one would wonder what evolutionary advantage does metal hyperaccumulation give to these species? Studies have revealed that metal accumulation in the foliage may allow hyperaccumulator species to evade predators including caterpillars, fungi and bacteria (Pollard and Baker, 1997).

In this review, an effort has been made to represent the current status of heavy metal pollution of soil and water bodies and the role of plant species in alleviating the contamination as a part of remediation strategy in Indian context.

2. Sources of Heavy Metals in the Soil

Heavy metal reaches the soil environment through both geogenic and anthropogenic processes. The heavy metals that occur naturally in soil parent materials are released into the soil system by the natural weathering processes are not readily available for plant uptake. One typical example of geogenic contamination is the extensive arsenic contamination of ground waters in Bangladesh and West Bengal in India (Mahimairaja et al., 2005).

Another source of heavy metals is anthropogenic origin the contribution of which has increased tremendously in the recent past because of rapid strides in industrialization, consumerist life style, urbanization and explosion of population growth. Due to this, huge amount of effluents are generated which has a serious problem of disposal and it is posing a constant threat of environmental pollution. Agricultural activities in peri-urban areas and at the periphery of industrial units are under scanner due to potential threat of metal pollution through sewage effluents and sludge coming out as waste from such units leading to their subsequent entry to the food chain through various crops (primarily vegetables) that are grown on fields with these wastes (Purakayastha, 2007). Further, the long-term applications of sewage effluents and sludge have also been reported to increase the concentrations of trace metals significantly in large areas under peri-urban agriculture (Mitra and Gupta, 1999).

Fertilizers also add a large number and quantity of heavy metals to the soil. For eg., phosphate compounds contain metals like Cd. Further, a large quantities of Cu is used in agriculture, horticulture and animal industries as a trace element nutrient, in many formulations of Cu-containing fungicides such as copper oxychloride and Bordeaux mixture and as a growth promoter in piggery and poultry units. The different sources of heavy metals in the soil are given in Table 1. The major heavy metal contaminated sites in India are given in Table 2.

3. Effects of Heavy Metal Contamination on Agriculture

The heavy metals are being introduced into soils from various sources, including atmospheric pollution by metal-bearing particles, application of sewage sludge, waste water irrigation, phosphate fertiliser, pesticides and pig slurry, where they exist in several chemical forms. As consequence of the heavy metal contamination of agricultural soils has become one of the most significant environmental problems. Excessive amount of heavy metal accumulation in agricultural soils through wastewater irrigation, may not only cause soil contamination, but also leads to elevated heavy metal uptake by crops, and thus affect food quality and safety (Muchuweti et al., 2006). Heavy metal accumulation in soils and plants is of increasing concern because of the potential human health risks associated with soil-crop-food chain transfer. Accumulation of toxic metals in edible parts of crops grown in contaminated soils has been reported from number of crops including rice, soybean, wheat, maize, and vegetables. In fact plants may have their growth sharply reduced can result in decreased crop yield too due to the inhibition of plant metabolic processes (Singh and Aggarwal, 2006). The accumulation of metals in agricultural crops and thresholds of dietary toxicity in soil-crop system may vary with several factors like crop management practices (Cooper et al., 2011) and soil properties (Islam et al., 2007). As reported by Islam et al. (2007), the interactions of soil-plant roots-microbes play important roles in regulating heavy metal movement from soil to the edible parts of the crops. The soil contamination with heavy metals such as Cd, Cr, Pb, Zn and Cu in the waste water irrigated soils of Varanasi, India and substantial bioaccumulation was found in the agricultural products especially vegetables (Mishra and Tirpathi, 2008). Rattan et al. (2005) studied the long term impact of irrigation with sewage effluents on heavy metal content in soil, crops and ground water. Masto et al. (2008) observed change in soil quality indicators under long term sewage irrigation in a sub-tropical environment and concluded that the long term sewage irrigation resulted into significant build-up of heavy metals. A number of reports are available on heavy metal contamination of vegetables may also occur due to irrigation with contaminated water (Singh et al., 2004; Sharma et al., 2006, 2007; Singh and Kumar, 2006).

4. Phytoremediation and its Advantage

Phytoremediation is defined by Cunningham and Lee (1995) as "the use of green plants to remove, contain, or render harmless environmental contaminants". This applies to all plant-influenced biological, microbial, chemical and physical process that contribute to the remediation of contaminated site. It is also known as green technology and proper implementation make it eco-friendly and aesthetically pleasing to the public. Phytoremediation does not require any expensive equipment or highly-specialized personnel, thus, it is relatively easy to implement. It is capable of permanently treating a wide range of contaminants in a wide range of environments. Thus, phytoremediation of contaminated environment offers an environmentally friendly, cost effective, and carbon neutral approach for the cleanup of toxic pollutants in the environment. Plants with abilities to hyperaccumulate, accumulate, exclude and indicate heavy metals are important in environmental remediation. Most phytoremediation studies are aimed at inorganic pollutants through different approaches defined as phytoextraction (the used of metal accumulating plants to transport and concentrate metals from the soil to roots and above ground biomass), rhizofiltration (the use of plant roots to absorb, precipitate, and concentrate toxic metals from polluted effluents), and phytostabilization (the use of plants to reduce the mobility of metals).

Table 1: Sources of heavy metals in soils

Name of the contaminant	Source
Arsenic (As)	Timber treatment, paints, pesticides, geothermal, geogenic/natural processes, smelting operations, thermal power plants, fuel burning etc.
Cadmium (Cd)	Electroplating, batteries, fertilizers, Zinc smelting, waste batteries, e-waste, paint sludge, incinerations & fuel combustion
Chromium (Cr)	Timber treatment, leather tanning, pesticides, dyes, Mining, industrial coolants, chromium salts manufacturing
Copper (Cu)	Fungicides, electrical, paints, pigments, timber treatment, fertilizers, mine tailings, electroplating, smelting operations
Lead (Pb)	Batteries, metal products, preservatives, petrol additives, paints, e-waste, Smelting operations, coal-based thermal power plants, ceramics, bangle industry
Manganese (Mn)	Fertilizer
Mercury (Hg)	Instruments, fumigants, geothermal, chlor-alkali plants, thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
Molybdenum (Mo)	Fertilizer, spent catalyst
Nickel (Ni)	Alloys, battery industry, mine tailings, smelting operations, thermal power plants,
Zinc (Zn)	Galvanization, dyes, paints, timber treatment, fertilizers, mine tailings, smelting, electroplating

Source: Lone et al., 2008

Table 2: Major heavy metals contaminated sites in India

Chromium	Lead	Mercury	Arsenic	Copper
Ranipet, Tamil Nadu	Ratlam, Madhya Pradesh	Kodaikanal, Tamil Nadu	Tuticorin, Tamil Nadu	Tuticorin, Tamil Nadu
Kanpur, Uttar Pradesh	Bandalam-ottu Mines, Andhra Pradesh	Ganjam, Orissa	West Bengal	Singbhum Mines, Jharkhand
Vadodara, Gujarat	Vadodara, Gujarat	Singrauli, Madhya Pradesh	Ballia and other districts UP	Malanj-khand, Madhya Pradesh
Talcher, Orissa	Korba, Chattisgarh	-	-	-

Source: Ministry of Environment and Forest, Govt. of India press release, 2011

5. Studies on Phytoremediation of Heavy Metals in India

Very few reports are available on phytoremediation under field conditions in India and, most of the studies are confined to water bodies. In India, phytoremediation technology has been used only on certain areas *i.e.*, revegetation of mine spoils. Plant species of ecological and economic importance (Table 3) were planted on mine spoil dumps using appropriate blends of organic waste along with site-specific biofertilizers. There is also lack of scientific studies on phytoremediation of heavy metal contaminated soils in India (Chhonkar et al., 2004). Therefore, in the present review, we have attempted to highlight the work done on phytoremediation of soils and water contaminated with heavy metals in Indian context.

5.1. Phytoremediation of water bodies contaminated with heavy metals

Water body contamination reached a serious dimension due to human activities. The natural contamination of ground water originates from excessive weathering of minerals from rocks or displacement from the groundwater or subsurface layers of the soil. Major cause of pollution is the increasing urbanization, intensive practice of agriculture and industrial developments. During the recent years, urbanization has forced us to utilize marginal lands and aquatic plants are being cultivated more intensively in ponds which are not suitable for agriculture. Despite the exploitation of such aquatic resources to meet increasing demand of food, contamination of these water bodies with toxic metals has become a frequent phenomenon (Rai et al., 1996).

The studies of Ali et al. (1999) indicated that *S. acmophylla* could be used as bio-monitoring tool for identifying metal contamination (Cu, Ni, Pb) in soil and water bodies and also highly suitable for phytoremediation of metal contamination from lakes and soils. Kumar et al. (2008) studied the heavy metal accumulation in certain aquatic macrophytes, used as biomonitors, in comparison with water and sediments (abiotic monitors) for phytoremediation. The study revealed that greater accumulation of heavy metals was in *Nelumbo nucifera* and the poor content in *Echinochloa colonum*. Ghosh (2010) reported that aquatic plant like *Hydrilla verticillata* has strong appetite for both As and Cd and less for Pb and hence this macrophyte is an effective accumulator of As and Cd but less effective to extract Pb from contaminated water. At the same time, another species *Ipomoea aquatica* is a potential accumulator of Cd and slightly less potential accumulator of Pb.

Rai (2008) studied the phytoremediation capacity of a small water fern, *Azolla pinnata* for heavy metals. The study revealed an inhibition of *Azolla pinnata* growth by 27.0-33.9% with the highest in the presence of Hg (II) ions at 0.5 mg L^{-1} in comparison to the control. After 13 days of the experiment, metal contents in the solution were decreased up to 70-94%. Adhikari et al. (2010) evaluated the phytoextraction potential of Pb by two wetland plant species i.e., *Typha angustifolia* L. of Typhaceae and Behaya plant (*Ipomoea carnea* L.) of the Convolvulaceae family and reported that both the plants show promise for the removal of Pb from contaminated wastewater. Chandra and Yadav (2010) also evaluated *Typha angustifolia* for phytoremediation potential of various heavy metals (Cu, Pb, Ni, Fe, Mn, and Zn) and concluded that the plant could be a potential phytoremediator for heavy metals from metal, melanoidin, and phenol containing industrial wastewater at optimized condition.

Unnikannan et al. (2013) assessed the phytotoxicity of Cr in some aquatic weeds (*Salvinia natans, Pistia stratiotes* and *Eichhornia crassipes)* and found that these plants accumulated huge concentrations of Cr in their tissues and classified them as hyperaccumulators for Cr. Kumar et al. (2012) evaluated the phytoremediation of heavy metal contaminated soil using five native macrophytes viz. *Bacopa monnieri*, *Eichhornia crassipes, Hydrilla verticillata, Ipomoea aquatic* and *Marsilea minuta* and suggested that *E. crassipes* can be used for phytoremediation of Cu and Ni whereas *M. minuta* and *H. verticillata* can be applied for removal of Cr and Pb respectively from the contaminated water bodies. Susselan et al. (2006) identified the utility of *Mimosa pudica* for rhizofilteration of Cd, Hg, U and Zn.

5.2. Phytoremediation of soils contaminated with heavy metals

The process of hyperaccumulation of heavy metals by higher plants involves several steps, such as (a) transport of metals across the plasma membrane of root cells; (b) xylem loading and translocation; and (c) detoxification and sequestration of metals at the whole plant and cellular levels (Lombi et al., 2002). More than 400 plant species have been reported so far that hyperaccumulate metals (McIntyre, 2003).

Das et al. (2005) studied the phytoremediation of As contaminated soils using several weed species (*Ludwigia parviflora; Enhydra* sp., *Eleusine indica, Filmbristylis* sp., *Ageratum conyzoides, Croton sparsiflorus, Lantana camara, Vitis trifolia, Asteracantha longifolia*) and found that there was increased accumulation of arsenic by the above-ground parts of these weed flora growing in soils loaded with 2-14 mg As kg^{-1} and indeed possessed great potentiality to act as hyperaccumulator plants for arsenic. Mandal et al. (2012a) reported that two successive harvests with DAP as the phosphate fertilizer emerged as the promising management strategy for amelioration of arsenic contaminated soil of West Bengal through phytoextraction by *Pteris vittata*. The

Table 3: Suitable plant species for mine spoil sites in India

Mine spoil category	Suitable plant species
Bauxite mined area of Madhya Pradesh	*Grevillea pteridifolia. Eucalyptus camaldulensis, Shorea robusta*
Coal mine spoils of Madhya Pradesh	*Eucalyptus hybrid*, *Eucalyptus camaldulensis, Acacia auriculiformis, Acacia nilotica, Dalbergia sissoo, Pongamia pinnata*
Lime stone mine spoils of outer Himalayas	*Salix tetrasperma, Leucaena leucocephala, Bauhinia retusa, Acacia catechu, Ipomea carnea, Eulaliopsis binata, Chrysopogon fulvus, Arundo donax, Agave americana, Pennisetum purpureum, Erythrina subersosa*
Rock-phosphate mine spoils of Mussoorie	*Pennisetum purpureum, Saccharum spontaneum, Vitex negundo, Rumex hastatus, Mimosa himalayana, Buddleja asiatica, Dalbergia sissoo, Acacia catechu, Leucaena leucocephela and Salix tetrasperma* etc.
Lignite mine spoils of Tamil Nadu	*Eucalyptus species, Leucaena leucocephala, Acacia and Agave*
Mica, copper, tungsten, marble, dool, mite, limestone, and mine spoils of Rajasthan	*Acacia tortilis, Prosopis juliflora, Acacia senegal, Salvadora oleiodes, Tamarix articulata, Ziziphus nummularia, Grewia tenax, Cenchrus setigerus, Cymbopogon, Cynodon dactylon,Sporobolus marginatus, D. annulatum*
Iron ore wastes of Orissa	*Leucaena leucocephala*
Haematite, magnetite, manganese spoil from Karnataka	*Albizia lebeck*

Source: Prasad (2007)

phytoextraction of arsenic contaminated soil by *P. vittata* was beneficial for growing rice resulted in decreased As content in rice grain of <1 ppm. There was a mean improvement in rice grain yield 8% after the one growing cycle and 14% after two growing cycle of brake fern (Mandal et al., 2012b).

Purakayastha et al. (2009) screened five species of *Brassica*, (1) *B. juncea* (Indian mustard) cv. Pusa Bold, (2) *B.campestris* (Yellow mustard) cv. Pusa Gold, (3) *B.carinata* (Ethiopian mustard) cv. DLSC-1, (4) *B.napus* cv. Early napus, (5) *B. nigra* cv. IC-247 for identifying a suitable species for hyperaccumulation of heavy metals, *viz.* Zn, Cu, Pb, Ni and Cd It was concluded that *Brassica carinata* cv. DLSC1 could reduce the metal load by 15% for Zn, 12% Pb and 11% for Ni from a naturally contaminated soil from peri-urban Delhi, while *Brassica juncea* cv. Pusa Bold emerged promising that reduced soil Cu content by 21% in a single cropping. Castor (*Ricinus communis* L.*)* was reported to accumulate large amount of Ni and therefore, it could be used as a potential plant for phytoremediation of Ni-contaminated soils (Adhikari and Ajay, 2012).

The potential of fenugreek (*Trigonella foenumgraecum* L.), spinach (*Spinacia oleracea* L.), and rye (*Brassica campestris* L.) for cleanup of Cr contaminated silty loam and sandy soils was reported by Dheri et al. (2007). The findings indicated that family Cruciferae (raya) was the most tolerant to Cr toxicity, followed by Chenopodiacea (spinach) and Leguminosae (fenugreek). Ramasamy (1997) observed that *Jasminum auriculatum* was relatively tolerant up to 1000 μg g^{-1} Cr in soil than *Crossandra infundibuliformis* and *Jasminum sambac*, which were found very sensitive at this concentration. Anandhkumar (1998) examined the level of Cr accumulation in flower plants, *Viz., Jasminum sambac,* (Gundumalli), *Jasmium grandiflorum* (Jathimalli), *Polyanthus tuberose* (Tuberose) and *Nerium oleander* (Nerium) and found that a considerable amount of Cr was accumulated in flower crops due to irrigation with tannery effluent.

Chandra et al. (1997) reported that when *Scirpus lacustris*, *Phragmites karka* and *Bacopa monnieri* were grown in tannery effluent and sludge containing 2.3 mg L^{-1} and 214 mg kg^{-1} Cr, respectively, there was significant reduction in Cr concentrations. The plant, *Ocimum tenuiflorum* L. was reported to withstand Cr stress and protect them from phytotoxicity of Cr by altering various metabolic processes (Rai et al., 2004). Later, on the phytoremediation capacity of three aromatic grasses (*Cymbopogan martinii*, *Cymbapogan flexuosus* and *Vetiveria zizanoides*) was studied for Cd and found that *Vetiveria zizanoides* holds potential for detoxification of Cd contaminated soils (Lal et al., 2008b). Saktivel et al. (2000) examined the potential of three plantation trees (*Eucalyptus* spp, *Acacia* and *Casuarina*) for their ability to remediate soils contaminated with Cr. The study revealed that *Eucalyptus* spp. was found highly sensitive to tannery effluent irrigation, whereas *Acacia* and *Casuarina* were found to withstand effluent irrigation moderately. Shankar et al. (2005) conducted a pot culture experiment to study the potential of Cr phytoaccumulatory capabilities of four promising agroforestry tree species viz., *Albizia amara*, *Casuarina equisetifolia*, *Tectona grandis*, and *Leucaena luecocephala*. The results suggested that *Albizia amara* is a potential Cr accumulator with citric acid as soil amendment.

Mahimairaja et al. (2011) examined the phytoremediation potential of some floriculture plants (*Jasminum sambac*, *J. grandiflorum*, *Polianthus tuberosa* and *Nerium oleander*) for the remediation of soils contaminated with Cr and found that *Jasminum* species showed a high degree of tolerance towards soil Cr. Among the field crops, mustard could not survive under high soil Cr level, while sunflower crop exhibited higher tolerance to soil Cr. Application of biological wastes namely, coir pith and poultry manure, to Cr-contaminated soil was found effective in reducing the bioavailable fractions of Cr mainly by forming organic complexes and demonstrated their potential in bioremediating the Cr-contaminated soil (Mahimairaja et al., 2011). Extensive studies were also conducted by Ramana et al. (2008a, 2008b, 2009, 2012a, 2012b) for the remediation of soils contaminated with heavy metals (such as Cd, Pb and Cr) using aster, calendula, tuberose, dahlia, nerium, rose marigold, chrysanthemum and gladioulus, mestha, and xerophytic plants like *Euphorbia milli, Agave angustifolia, Furcraea gigantea,* succulent fern *etc.* They identified that marigold and tuberose possess the characters of Cd hyperaccumulation and these two crops could be grown for the phytoextraction of Cd from soils contaminated with low to medium level of contamination. Further, chrysanthemum could be useful for phytostabilization of Cd- contaminated soils.

The production potential and Cd removal by three flower crops, viz.: marigold (*Tagetes erecta*), chrysanthemum (*Chrysanthemum indicum*) and gladiolus (*Gladiolus grandiflorus*) were studied at Karnal and found that gladiolus has the highest tolerance and Cd-content in saleable parts holds the potential to clean up moderately contaminated soils (Lal et al., 2008a). The Cd-phytoextraction ability of high biomass producing weeds (*Ipomoea carnea, Dhatura innoxia* and *Phragmytes karka*) in comparison to indicator plant species *B. juncea* and *B. campestris*) was studied by Ghosh and Singh (2005a) and reported that, among the five species, *B.juncea* accumulated maximum Cd, followed by *I. carnea* but *D. innoxia* and *P. karka* were the most suitable species for phytoextraction of Cd from soil, if the whole plant or above ground biomass is harvested.

Tiwari et al. (2008) collected plants of two species of portulaca *i.e. P. tuberosa* and *P. oleracea* from field sites in Gujarat, irrigated with tube well water and industrial waste water. Analysis of heavy metals revealed that both species of portulaca hyperaccumulated more than one heavy metal *viz*., Cd, Cr and As and reported that portulaca plants have good biomass and high regeneration potential, hence suitable for the remediation of effluent (metal) contaminated areas. Mani et al. (2007) investigated the interaction between Cd and Ca, Zn and organic matter for Cd-phytoremediation in sunflower and suggested the phytoremediation of Cd-contaminated soil through soil-plant-rhizospheric processes.

The use of soil amendments like manures could be one of the approaches to immobilize metal in soil for reducing its toxicity to plants. In this regard, Singh et al. (2007) assessed the effectiveness of farm yard manure (FYM) to ameliorate Cr toxicity in spinach grown in two texturally different soils (silty loam and sandy) contaminated artificially with five levels of Cr and found that FYM application to the soil could be an effective measure for reducing Cr toxicity to crop plants.

6. Conclusion

Phytoremediation successfully curbs the ill-effects of toxic heavy metals, but yet to become a commercially viable technology in India. Globally, phytoremediation is still in the evolving stage while the pros and cons of this technology at field level are not clearly understood. Being a slow process, biotechnological and classical hybridization with efforts from interdisciplinary researchers can develop more efficient hyperaccumulator species of desirable traits, thus revealing new potential. Further, remediation of mixed organic and inorganic pollutants through roots-microbes interaction also demands attention.

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