International Journal of Research Studies in Biosciences (IJRSB)
Volume 1, Issue 2 November 2013, PP 17-23
www.arcjournals.org

Phytoremediation of Heavy Metals- A Review

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Abstract: *An excess level of heavy metals are exposed into environment by industrial waste and fertilizers causes serious concern in nature as they are non- biodegradable and accumulate at high levels. Heavy metals such as Pb, Zn, Cd, As etc. are one of the most toxic pollutants which show hazardous effects on all living livings. The prevailing purification technologies used for removal of contaminants from wastewater are not only very costly but causes negative impact on ecosystem subsequently. Phytoremediation, an ecofriendly technology which is both ecologically sound and economically viable is an attractive alternative to the current cleanup methods that are very expensive. This technology involves efficient use of aquatic plants to remove, detoxify or immobilize heavy metals. The purpose of this review was to assess the current state of phytoremediation as an innovative technology and to discuss its usefulness and potential in the remediation of contaminated water.*

1. Introduction

Heavy metal pollution is a global problem, although severity and levels of pollution differ from place to place. At least 20 metals are classified as toxic with half of them emitted into the environment that poses great risks to human health (Akpor and Muchie, 2010). The economic, agricultural and industrial developments that are often linked to polluting the environment (Ikhuoria and Okieimen, 2000). Since the beginning of the industrial revolution, soil pollution by toxic metals has accelerated dramatically. According to Nriagu (1996) about 90% of the anthropogenic emissions of heavy metals have occurred since 1900 AD; it is now well recognized that human activities lead to a substantial accumulation of heavy metals in soils on a global scale. Man's exposure to heavy metals comes from industrial activities like mining, smelting, refining and manufacturing processes.

A number of chemicals, heavy metals and other industries in the coastal areas have resulted in significant discharge of industrial effluents into the coastal water bodies. These toxic substances are released into the environment and contribute to a variety of toxic effects on living organisms in food chain (Dembitsky, 2003) by bioaccumulation and bio-magnification (Manohar *et al*., 2006). Heavy metals, such as cadmium, copper, lead; chromium, zinc, and nickel are important environmental pollutants, particularly in areas with high anthropogenic pressure (United States Environmental Protection Agency, 1997). The soil has been traditionally the site for disposal for most of the heavy metal wastes which needs to be treated. Currently, conventional remediation methods of heavy metal contaminated soils are expensive and environmentally destructive (Aboulroos *et al*., 2006). Unlike organic compounds, metals cannot degrade, and therefore effective cleanup requires their immobilization to reduce or remove toxicity. Phytoremediation has also been called green remediation, botano-remediation, agro remediation and vegetative remediation (Erakhrumen, 2007). The plant used in the phytoremediation technique must have a considerable capacity of metal absorption, its accumulation and strength to decrease the treatment time (Mudgal *et al.,* 2010).

2. SOURCES OF METAL POLLUTION

Geological and anthropogenic activities are sources of heavy metal contamination (Dembitsky, 2003). Sources of anthropogenic metal contamination include industrial effluents, fuel production, mining, smelting processes, military operations, utilization of agricultural chemicals, small-scale industries, brick kilns and coal combustion (Zhen-Guo *et al*., 2002). One of the prominent sources contributing to increased load of soil contamination is disposal of municipal wastage. Other sources can include unsafe or excess application of pesticides, fungicides and fertilizers (Zhen-Guo *et al*., 2002). Additional potential sources of heavy metals include irrigation water contaminated by sewage and industrial effluent leading to contaminated soils and vegetables (Bridge, 2004).

3. PROCESS OF PHYTOREMEDIATION

3.1. Phytoextraction

Phytoextraction refers to the ability of plants to remove metals and other compounds from the subsurface and translocate them to the leaves or other plant tissues. The plants may then need to be harvested and removed from the site. Even if the harvested plants must be landfilled, the mass disposed of is much smaller than the original mass of contaminated soil (EPA, 2000).

3.2. Phytovolatilization

Phytovolatilization also involves contaminants being taken up into the body of the plant, but then the contaminant, a volatile form thereof, or a volatile degradation product is transpired with water vapor from leaves (EPA, 2000). Phytovolatilization may also entail the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves (McCutcheon, 2003).

3.3. Phytodegradation

When the phytodegradation mechanism is at work, contaminants are broken down after they have been taken up by the plant. It has been observed to remediate some organic contaminants, such as chlorinated solvents, herbicides and munitions and it can address contaminants in soil, sediments, or groundwater (EPA, 2000).

3.4. Rhizodegradation

Rhizodegradation refers to the breakdown of contaminants within the plant root zone, or rhizosphere. Rhizodegradation is believed to be carried out by bacteria or other microorganisms whose numbers typically flourish in the rhizosphere (McCutcheon, 2003). Microorganisms may be so prevalent in the rhizosphere because the plant exudes sugars, amino acids, enzymes, and other compounds that can stimulate bacterial growth. The roots also provide additional surface area for microbes to grow on and a pathway for oxygen transfer from the environment.

3.5. Rhizofiltration

It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate and contaminants from polluted aqueous sources in their roots (Jadia and Fulekar, 2009). Terrestrial plants are more preferred because they have a fibrous and much longer root system, increasing amount of root area that effectively removed the potentially toxic metals (Nandakumar *et al.,* 1995).

3.6. Phytostabilization

Phytostabilization takes advantage of the changes that the presence of the plant induces in soil chemistry and environment. These changes in soil chemistry may induce adsorption of contaminants onto the plant roots or soil or cause metals precipitation onto the plant root. The physical presence of the plants may also reduce contaminant mobility by reducing the potential for water and wind erosion.

4. METAL TOXICITY

All plants have the ability to accumulate “essential” metals (Ca, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Se, V and Zn) from the soil solution. Plants need different concentrations for growth and development. This ability also allows plants to accumulate other “non-essential” metals (Al, As, Au, Cd, Cr, Hg, Pb, Pd, Pt, Sb, Te, Tl and U) which have no known biological function (Djingova and Kuleff, 2000). Moreover, metals cannot be broken down and when concentrations inside the plant cells accumulate above threshold or optimal levels, it can cause direct toxicity by damaging cell structure (due to oxidative stress caused by reactive oxygen species) and inhibit a number of cytoplasmic enzymes (Assche and Clijsters, 1990). In addition, it can cause indirect toxic effects by replacing essential nutrients at cation exchange sites in plants (Taiz and Zeiger, 2002). Baker (1981) proposed, however, that some plants have evolved to tolerate the presence of large amounts of metals in their environment by the following three ways:

- ***Exclusion,*** whereby transport of metals is restricted and constant metal concentrations are maintained in the shoot over a wide range of soil levels.
- ***Inclution,*** whereby shoot metal concentrations reflect those in the soil solution in a linear relationship.
- ***Bioccumulation,*** whereby metals are accumulated in the roots and upper plant parts at both high and low soil concentrations.
- ***Plant response to heavy metals***
- Plants have three basic strategies for growth on metal contaminated soil (Raskin *et al.,* 1994).
- ***Metal excluders***
- They prevent metal from entering their aerial parts or maintain low and constant metal concentration over a broad range of metal concentration in soil; they mainly restrict metal in their roots. The plant may alter its membrane permeability, change metal binding capacity of cell walls or exude more chelating substances.

TABLE 1. *Several metal hyperaccumulator species with respective metal accumulated*

S.No.	Plant species	Metal	References
1.	Thlaspi caerulescens	Zn, Cd	Baker and Walker (1990)
2.	Ipomea alpina	Cu	Baker and Walker (1990)
3.	Sebertia acuminata	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 (2002b)
7.	Thlaspi goesingens	Ni	Kramer et al. (2000)
8.	Brassica oleracea	Cd	Salt et al. (1995b)
9.	Arabidopsis halleri	Zn, Cd	Cosio et al. (2004)
10.	Sonchus asper	Pb, Zn	Yanqun et al. (2005)
11.	Corydalis pterygopetala	Zn, Cd	Yanqun et al. (2005)
12.	Alyssum bertolonii	Ni	Li et al. (2003);
13.	Astragalus bisulcatus	Se	Vallini et al. (2005)
14.	Stackhousia tryonii	Ni	Bhatia et al. (2005)
15.	Hemidesmus indicus	Pb	Chandra Sekhar et al. (2005)
16.	Salsola kali	Cd	De la Rosa et al. (2004)
17.	Sedum alfredii	Pb, Zn	Li et al. (2005)
18.	Pteris vittata	As	Tu and Ma (2005)
19.	Helianthus anus	Cd, Cr, Ni	Turgut et al. (2004)

Metal indicators

Species which actively accumulate metal in their aerial tissues and generally reflect metal level in the soil. They tolerate the existing concentration level of metals by producing intracellular metal binding compounds (chelators), or alter metal compartmentalisation pattern by storing metals in non-sensitive parts.

Metal accumulator plant species

They can concentrate metal in their aerial parts, to levels far exceeding than soil. Hyperaccumulators are plants that can absorb high levels of contaminants concentrated either in their roots, shoots and/or leaves (Cunningham and Ow, 1996).

5. MECHANISM OF PHYTOREMEDIATION OF HEAVY METALS

The metal must mobilise into the soil solution, for the plants to accumulate metals from soil. The bioavalability of metals is increased in soil through several means. One way plants achieve it by secreting phytosidophores into the rhizosphere to chelate and solublise metals that are soil bound. Both acidification of the rhizosphere and exudation of carboxylates are considered potential targets for enhancing metal accumulation. Following mobilization, a metal has to be captured by root cells. Metals are first bound by the cell wall, it is an ion exchanger of comparatively low affinity and low selectivity. Transport systems and intracellular high-affinity binding sites then mediate and drive uptake across the plasma membrane. Uptake of metal ions is likely to take place through secondary transporters such as channel proteins and/or H+- coupled carrier proteins. The membrane potential that is negative on the inside of the plasma membrane and might exceed –200 mV in root epidermal cells provides a strong driving force for the uptake of cations through secondary transporters.

Once inside the plant, most metals are too insoluble to move freely in the vascular system, so they usually form carbonate, sulphate or phosphate precipitates immobilizing them in apoplastic (extracellular) and symplastic (intra cellular) compartments (Raskin *et al.*, 1997). Unless the metal ion is transported as a non-cationic metal chelate, apoplastic transport is further limited by the high cation exchange capacity of cell walls (Raskin *et al.*, 1997). The apoplast continuum of the root epidermis and cortex is readily permeable for solutes. Apoplastic pathway is relatively unregulated, because water and dissolved substance can flow and diffuse without having to cross a membrane. The cell walls of the endodermal cell layer act as a barrier for apoplastic diffusion into the vascular system.

In general, solutes have to be taken up into the root symplasm before they can enter the xylem (Tester and Leigh, 2001). Subsequent to metal uptake into the root symplasm, three processes govern the movement of metals from the root into the xylem: sequestration of metals inside root cells, symplastic transport into the stele and release into the xylem. The transport of ions into the xylem is generally a tightly controlled process mediated by membrane transport proteins. Symplastic transport of heavy metals probably takes place in the xylem after they cross the casparian strip. It is more regulated due to the selectively permeable plasma membrane of the cells that control access to the symplast by specific or generic metal ion carriers or channels (Gaymard, 1998). Symplastic transport requires that metal ions move across the plasma membrane, which usually has a large negative resting potential of approximately 170 mV (negative inside the membrane). This membrane potential provides a strong electrochemical gradient for the inward movement of metal ions. Most metal ions enter plant cells by an energy dependent saturable process via specific or generic metal ion carriers or channels (Bubb and Lester, 1991).

The vacuole is an important component of the metal ion storage where they are often chelated either by organic acid or phytochelatins. Insoluble precipitates may form under certain conditions. Precipitation compartmentalisation and chelating are the most likely major events that take place in resisting the damaging effects of metals (Cunningham *et al.*, 1995). Transporters mediate uptake into the symplast, and distribution within the leaf occurs via the apoplast or the symplast (Karley *et al.,* 2000). Plants transpire water to move nutrients from the soil solution to leaves and stems, where photosynthesis occurs. Willows, hybrid poplar are also good phytoremediators, because they take up and process large volumes of soil water.

Benefits of Phytoremediation

- Phytoremediation can be less invasive and destructive than other technologies.
- It may result in a cost savings of 50 to 80 percent over traditional technologies.
- It may provide habitat to animals, promote biodiversity, and help speed the restoration of ecosystems that were previously disrupted by human activity at a site (Wilson, 2004).

- Phytoremediation installations can improve the aesthetics of brownfields or other contaminated sites.
- It may promote better air or water quality in the vicinity of the site and it reduce the erosion by wind or water (Wilson, 2004).
- Planted trees may also provide shade to buildings, helping to decrease energy consumption (Nowak, 2002).

Limitations of Phytoremediation

- Extremely high contaminant concentrations may not allow plants to grow or survive; phytoremediation is likely to be more effective or reasonable for lower concentrations of contaminants (EPA, 2000).
- For remediation to be successful, contamination must generally be shallow enough that plant roots can reach the contaminants, or contamination must be brought to the plant (EPA, 2000).
- Phytoextraction techniques can cause contaminants to accumulate in plant tissues, which could cause ecological exposure issues or require harvesting (EPA, 2000).
- Phytovolatilization may remove contaminants from the subsurface, but might then cause increased airborne exposure (EPA, 2000).
- If non-native species are selected for phytoremediation, the consequences of introducing them to the ecosystem may be unknown or unexpected (EPA, 2000).
- The time required to achieve the remedial goals may be longer with phytoremediation than with other treatment technologies.

6. Conclusion

Phytoremediation of pollutants is a growing technology. It is necessary for scientist in this field to pool resources and share knowledge gained from both laboratory and field researches. Plants and their associated microbes can remediate pollutants via stabilization, degradation in both rhizosphere and plants, extraction in harvestable plant part, or volatilization. Phytoremediation is obviously more cost-effective and environmentally friendly than other remediation alternatives. Further research is hereby recommended to improve the existing technology especially in the use of transgenic plants and fungi.

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