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A review of phytoremediation

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Abstract
The environment consists of both biotic and abiotic components. It creates favorable conditions for existence and development of living organisms nowadays. Soil contamination with toxic metals such as Cd, Pb, Zn, Cr, Ni and Cr, as results of worldwide industrialization has increased noticeably within the past few years. Phytoremediation is a viable, relatively low cost approach to removing heavy metals from soil and groundwater. The mechanisms by which plants promote the removal of pollutants are varied, including uptake and concentration, transformation of pollutants, stabilization, and rhizosphere degradation, in which plants promote the growth of bacteria underground in the root zone that in turn break down pollutants. This research investigated the possibility of achieving soil clean-up using native plants that also provided aboveground benefits, including wildlife habitat. Recently, phytoremediation as a cost effective and environmentally friendly technology has been developed by scientists and engineers in which biomass/microorganisms or live plants are used to remediate the polluted areas. Phytoremediation can be classified into different application such as phyextraction, phytodegradation, phytostabilization, phytofiltration or rhizofiltration and phytovolatilization.

Keywords: phytoremediation, heavy metals, toxicity, soil pollution and techniques

Introduction
The term environment is considered as a composite term for conditions in which organisms live. The environment consists of air, water, soil, food and sunlight, which are the basic needs of all living beings to carry on their life function. In other words, the environment consists of both biotic and abiotic components. It creates favorable conditions for existence and development of living organisms nowadays. All organisms are mainly affected directly or indirectly because of the environmental pollution or contamination. The pollution problem has become a global one. Pollution is an undesirable change in the physical, chemical or biological characteristics of our air, water and land or soil that is harmful to human and other life, industrial processes, living conditions and cultural assets (Rand, C. and E. Around, 1997) [38]. The science, technology, industrial revolution and agricultural technology have no doubt improved our lifestyle, which could not be imagined a decade ago; but this advancement has simultaneously polluted the natural environment (Veeramani *et al.* 2005) [54]. The increasing use of a wide variety of heavy metals in industries and agriculture has caused a serious concern of environmental pollution (Sinhal *et al.* 2010) [48]. Uncontrolled use of sewage sludge, compost, mining waste, chemical fertilizers and industrial development results in accumulation of heavy metals in agricultural lands and remains as a threat for many years remain in the soil. Restoration of soils contaminated with potentially toxic metals and metalloids is of major global concern (Shelmerdine *et al.* 2009) [45]. Remediation of heavy metals polluted soil can be carried out using physico-chemicals processes such as ion-exchange, precipitation, reverse osmosis, evaporation and chemical reduction; however, these measures require external man-made resources and are costly (Mangkoedihardjo and Surahmaida 2008) [29]. Phytoremediation is a viable, relatively low-cost approach to removing heavy metals from soil and groundwater (January 2006) [24]. Phytoremediation is a developing technology that can potentially address the problems of contaminated agricultural land or more intensely polluted areas affected by urban or industrial activities. Three main strategies currently exist to phytoextract inorganic substances from soils using plants: (1) use of natural hyper accumulators; (2) enhancement of element uptake of high biomass species by chemical additions to soil and plants; and (3) phytovolatilization of elements, which often involves alteration of their chemical form within the plant prior to volatilization to the atmosphere (McGrath *et al.* 2002) [30]. Phytoremediation is a promising new method that uses green plants to assimilate or detoxify metals and organic chemicals. The phytoremediation of metal-contaminated soils offers a low cost method for soil remediation and some extracted metals may be recycled for value (Chaney *et al.* 1997) [8]. Plants that accumulate metals to high

concentrations are sometimes referred to as ‘‘hyperaccumulators’’ (Visoottiviseth *et al.* 2002) [55].

What is phytoremediation

Phytoremediation is a word made from the Greek prefix “Phyto” meaning plant, and the Latin suffix “remedium” meaning clean or restore (Cunningham *et al*. 1997) [12]. The term really refers to a diverse assemblage of works-based technologies that use either naturally occurring or genetically engineered plants for cleaning contaminated environments (Flathman and Lanza, 1998) [16]. The idea of using metal-accumulating plants to get rid of heavy metals and other compounds was first introduced in 1983, but the concept has actually been carried out in the past 300 years on wastewater discharges (Blaylock, 2008) [6]. Phytoremediation is the name given to a set of technologies that use different plants as a containment, destruction, or an extraction technique. This technology has received attention lately as an advanced, cost-effective alternative to the more established treatment methods used at hazardous waste sites (Pulfor and Watson, 2003; Susarla *et al*. 2002; Jadia and Fulekar, 2009; Zhang *et al*. 2010) [37, 49, 10, 57]. Phytoremediation is an emerging technology that uses various plants to degrade, extract, contain, or immobilize contaminants, including metals, pesticides, hydrocarbons, and chlorinated solvents from soil and water. Phytoremediation, also called green remediation, botano-remediation, agroremediation, or vegetative remediation is considered a publicly appealing (green) remediation technology that uses vegetation and associated microbiota, soil amendments and agronomic techniques to remove, contain, or render the heavy metals harmless in the soil (Cunningham and Ow, 1996; Vyslouzilova *et al*, 2003; Helmisari *et al*, 2007) [11, 56, 21]. Phytoremediation is a novel, less expensive, efficient, environment and eco-friendly remediation strategy with good public acceptance (Turan and Esringu, 2007; Singh *et al*. 2009; Saier and Trevors, 2010; Revathi *et al*. 2011) [52, 46, 40, 39].

Significance of phytoremediation

Phytoremediation is the lower capital costs, aesthetic benefits, minimization of leaching of contaminants and soil stabilization. The operational cost of phytoremediation is also substantially less and involves mainly fertilization and watering for maintaining plant growth.

Advantages of phytoremediation

A significant advantage of phytoremediation is that a variety of organic and inorganic compounds are amenable to the phytoremediation process. Phytoremediation can be used either as an in situ or ex situ application. In situ applications are frequently-considered because it minimizes disturbance of the soil and surrounding environment and reduce the spread of contamination via air and waterborne wastes. It is a green technology and when properly implemented is both environmentally friendly and aesthetically pleasing to the public. Phytoremediation does not require expensive equipment or highly-specialized personnel, and it is relatively easy to implement. It is capable of permanently treating a wide range of contaminants in a wide range of environments. The greatest advantage of phytoremediation is its low cost compared to conventional clean-up technologies.

Disadvantages and limitations of phytoremediation

It is restricted to the rooting depth of remediative plants. Remediation with plants is a lengthy process, thus it may take several years or longer to clean up a hazardous waste site, and the contamination may still not be fully remediated. The use of invasive, nonnative species can affect biodiversity. The consumption of contaminated plants by wildlife is also a remarkable concern. The harvested plant biomass produced from the process of phytoextraction may be classified as hazardous waste, therefore subject to proper handling and disposal. Unfavorable climate can limit plant growth and phytomass production, thus decreases process efficiency.

Heavy metals toxicity

Heavy metals include the transition-metal elements essential to plant nutrition, iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), nickel (Ni) and molybdenum (Mo), cobalt (Co), which is required for nitrogen fixation in legumes, and the non-essential elements, chromium (Cr), cadmium (Cd), mercury (Hg) and lead (Pb). All these elements are toxic to crop plants at high tissue concentrations. In agriculture, deficiencies of essential heavy metal elements are more common than their toxicities. Heavy metals can be poisonous for macro- and micro-organisms through direct influence on the biochemical and physiological procedures, reducing growth, deterio-rating cell organelles, and preventing photosynthesis. In other word, humans and ecosystem may be exposed to chemical hazards such as heavy metals (lead, chromium, arsenic, zinc, cadmium, copper, mercury and nickel) through the direct ingestion of contaminated soils, consumption of crops and vegetables grown on the contaminated lands or drinking water that has percolated through such soils (McLaughlin *et al*. 2000) [31]. For example, in their assessment, Chaney *et al*. (2005) [9] indicated that subsistence farmers eating rice grain grown on contaminated sites throughout their lifetime are at risk from dietary exposure to cadmium. Also, Kuzovkina *et al*. (2004) [26] mentioned that cadmium is not an essential element for plant metabolism and can be strongly phytotoxic, causing rapid death. The world's most polluted places threaten the health of more than 10 million people in many countries, according to a report released by a U.S. environmental action group (Chhotu *et al*. 2009) [10]. Regarding the role of heavy metals in living systems, they are divided into two classes: Essential and nonessential. Essential heavy metals are those, which are needed by living organisms for their growth, development and physiological functions like Mn, Fe, Ni, Cu and Zn (Gohre and Paszkowski, 2006) [19] while non-essential heavy metals are those, which are not needed by living organisms for any physiological functions like Cd, Pb, Hg and As (Mertz, 1981; Suzuki and Sano, 2001; Bidar *et al*. 2006; Peng *et al*. 2009) [32, 50, 5, 35]. Regarding the transportation of metals from the roots to the aerial parts of the plants, some metals (especially Pb) tend to be accumulated in roots more than in aerial parts, because of some barriers that prevent their movement. However, other metals, such as Cd, moves easily in plants (Garbisu and Alkorta, 2001) [17]. Schmidt (2003) [43] reported that elevated heavy metal concentrations in the soil can lead to enhanced crop uptake and negative effect on plant growth. At higher concentrations, they interfere with metabolic processes and inhibit growth, sometimes leading to plant death (Schaller and Diez, 1991) [42]. In plants Cd damages the light harvesting complex II and photosystems II, and I, which are active in photosynthesis. Total chlorophyll content is decreased by Cd treatment, and nonphotochemical quenching is increased in *Brassica napus*. Probably Cd also interferes with movement of K^+, Ca^{2+} and abscisic acid in guard cells, while inhibiting stomal opening (Shaw, 1995) [44]. Heavy metal phytotoxicity may be due to changes in physiological processes at the cellular and molecular level as a result of enzyme deactivation or the blocking of functional groups of metabolically important molecules (Ahmadpour, *et al*. 2012) [1].

Application of plants for phytoremediation

Approximately 400 plant species from at least 45 plant families have been so far, reported to hyperaccumulate metals (Lasat, 2000; Ghosh and Singh, 2005) [27, 18]. Some of the families are *Brassicaceae, Fabaceae, Euphorbiaceae*, *Asterraceae*, *Lamiaceae* and *Scrophulariaceae* (Salt *et al*, 1998; Dushekov, 2003) [41, 14]. Crops like alpine pennycress (*Thlaspi caerulescens*), *Ipomea alpine*, *Haumaniastrum robertii*, *Astragalus racemosus*, *Sebertia acuminate* have very high bioaccumulation potential for Cd/Zn, Cu, Co, Se and Ni, respectively (Lasat, 2000) [27]. Willow (*Salix viminalis* L.), maize (*Zea mays* L.), Indian mustard (*Brassica juncea* L.), and sunflower (*Helianthus annuus* L.) has reportedly shown high uptake and tolerance to heavy metals (Schmidt, 2003) [43]. species, such as cabbage (*Brassica oleracea* L.), lettuce (*Latuca sativa* L.) and tobacco (*Nicotiana tabacum* L.), accumulate high levels of Cd in leaves rather than in roots and increases or decreases the bioavailability of metal ions. The root of Indian mustard is found to be effective in the removal of Cd, Cr, Cu, Ni, Pb, and Zn, and sunflower can remove Pb, U, Cs and Sr from hydroponic solutions (Lone *et al*. 2008) [28]. Tang *et al*. (2003) [51] reported the increase in uptake of copper by Indian mustard and sunflower plant. The success of phytoremediation depends mainly on the choice of plant, which must obviously possess the ability to accumulate large amounts of heavy metals (Hyperaccumulation).

Remediation techniques

Phytoremediation can be classified into different application such as phyextraction, phytodegradation, phytostabilization, phytofiltration or rhizofiltration and phytovolatilization.

Phytoextration

Phytoextration is a subpurpose of phytoremediation in which plant removes dangerous elements or compounds from soil and water. This technology is referred that plant absorb metals from soil and translocation them to the hevestable shoots where they accumulate. Plant roots generally contain higher metal concentrations that the shoots despite the translocation mechanisms, but an upper limit to the metal concentration within the root can occur. Root uptake of Pb by hydroponically grown plants reached a maximum concentration and did not increase further as the Pb concentration of the solution increased (Deepa, *et al*. 2006) [13]. Jiang *et al*. (2004) [25] determined the growth performance and ability for Cu phytoextraction of *Elsholtzia splendens*. Zhang *et al*. (2009) [58] expressed that as Cd phytoextraction is observed by maize, the percentage of exchangeable form of Cd decreased in the planted soil. Nascimento and Xing (2006) [34] expressed that phytoextraction may be considered as a commercial technology in the future. According to the report, in the presence of vegetation, the exchangeable form of Cd was partly removed by plant uptake that accompanied with the intake of nutrition (Zhang *et al*. 2009) [58].

Phytodegreation

Phytodegration is the use of plants and microorganism to uptake, metabolize and degrade the organic contaminant. In this approach plant roots are used in association with microorganisms to detoxify soil contamination with organic compounds (Garbisu ans Alkorta, 2001) [17]. It is also known as phytotransformation. Cacador and Duarte reported photoconversion of Cr (VI) toxic from the less toxic Cr (III) by halophytes (Cacador and Duarte, 2015) [7]. some plants are able to decontaminate soil, sludge, sediment and ground and surface water by producing enzymes. This approach involves organic compounds including herbicide, insecticides chlorinated solvents and inorganic contaminants (Pivetz, 2001) [36]. Various bacterial and fungal microorganisms can facilitate transformation of toxic metals totheir less toxic states. Plant-produced enzymes metabolize contaminants which may be released into the rhizosphere, where they can remain active (Singh and Labana, 2003) [47].

Phytostabilization

Phytostabilization involves the reduction of the mobility of heavy metals in soil. Immobilization of metals can be accomplished by decreasing windblown dust, minimizing soil erosion and reducing contaminant solubility or bioavaibility to the food chain. Most important site revegetation also improves the physicochemical and biological properties of the contaminated soil by increasing the organic matter, content, nutrient levels, cation exchange capacity and biological activity (Arie, *et al*. 2004) [3]. Phyttostabilization is a suitable technique to remediate Cd, Cu, As, Zn and Cr. Alvarenga *et al*. (2009) [2] investigated the effect of three organic residues, sewage sludge, municipal solid waste compost and garden waste compost on the phytostabilization of an extremely acidic metal contaminated soil. Some advantages associated with his technology are that the disposal of hazardous material is not required (United States Protection Agency, 2000) [53] and it is very effective when rapid immobilization is needed to preserve ground and surface waters (Chhotu, *et al*. 2009) [10].

Rhizofiltration

Rhizofiltration is primarily used to remediated extacted groundwater, surface water and waestewater with low contaminant concentrations (Ensley, 2000). Rhizofiltration involves the use of plants to clean various aquatic environments. Young plants of *Berkheya coddii* growing in pots on ultramatic soil enriched with Cd, Ni, Zn or Pb substantially accumulated a considerable amount of these metals. Whereas excised shoots in solutions containing the same heavy metals accumulates a high amount of these metals in the leaves (Mesjasz-Przybylowicz, *et al*. 2004). Sunflower, Indian mustard, Tobacco, Rye, Spinach and Corn have been studied for their ability to remove lead from water, with sunflower having the greates ability (Chhotu *et al*. 2009) [10]. rhizofiltration can be used for Pb, Cd, Cu, Ni, Zn and Cr which are primarily retained within the roots (United States Protection Agency, 2000) [53].

Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with the release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water along with the contaminants. Some of these contaminants can pass through the plants to the leaves and volatilizes into the atmosphere at a comparatively low concentration (Ismail, 2012) [12]. Banuelos (2000) [4] perceived that some plants were able to transform Se in the form of dimethylselenide and dimethyldiselenide in high selenium media. Unlike other remediation techniques, once the contaminats have been removed via volatilization, one has no control over their migration to other areas. Hg uptake and evaporation are achieved by some bacteria.

Conclusion

Heavy metals are one of the most critical threats to the soil and water resources, as well as to human health. The concentrations of heavy metals increase in the environment from year to year (Govindasamy, 2011) [20]. Phytoremediation is a new cleanup concept that involves the use of plants to clean or stabilize contaminated environments.

Phytoremediation of metals is the most effective plant-based method to remove pollutants from contaminated areas. This green technology can be applied to remediate the polluted soils without creating any destructive effect of soil structure. Some specific plants, such as herbs and woody species, have been proven to have noticeable potential to absorb toxic metals. These plants are known as hyperaccumulators.

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