Original Research Article

Phytoremediation technology – Eco friendly approach to remove heavy metals from contaminated soil

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Abstract

Heavy metals are found naturally in the earth. They become concentrated as a result of human caused activities such as from mining and industrial wastes, vehicle emissions, lead-acid batteries, fertilizers, paints, treated woods, aging water supply infrastructure and micro plastics floating in the world's oceans. Arsenic, cadmium and lead may be present in children's toys at levels that exceed regulatory standards. These heavy metals can enter plant, animal, and human tissues via inhalation, diet, and manual handling. Although some heavy metals are essential trace elements, most of them can be toxic to all forms of life at high concentrations due to formation of complex compounds within the cell. Toxic heavy metals can bioaccumulate in organisms as they are hard to metabolize. Unlike organic pollutants, heavy metals once introduced into the environment cannot be biodegraded. They persist indefinitely and cause pollution of air, water, and soils. Thus, the main strategies of pollution control are to reduce the bioavailability, mobility, and toxicity of metals. Soils contaminated by heavy metals can be remediated by several methods such as isolation, immobilization, toxicity reduction, physical separation or extraction and phytoremediation. But most of them are costly and difficult to get optimum results. Phytoremediation is an effective and affordable method to remove pollutants from contaminated soil and water. This technology is environmental friendly and potentially cost effective It is a green solution to the problem of heavy metal pollution. Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments. It is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater. There are several different types of phytoremediation mechanisms such as Rhizosphere biodegradation, Phyto-stabilization, Phyto-accumulation (also called phyto-extraction), Rhizofiltration it is similar to phyto-accumulation, Phyto-volatilization, Phyto-degradation Phytoremediation process of land contaminated with heavy metals (Cd, Zn, and Pb) can be done by using trees species: Scots pine (Pinus silvestris L.), Norway spruce (Picea abies L.), and oak (Quercus ro bur L.). Phytoremediation techniques may also be more publicly acceptable, aesthetically pleasing, and less disruptive than the current techniques of physical and chemical process. Advantages of this technology are its effectiveness in contaminant reduction, low-cost, being applicable for wide range of contaminants, and in overall it is an environmental friendly method. Phytoremediation is the cleanest and cheapest technology can be employed in the remediation of selected hazardous site. It is a low-cost option and inexpensive approach for remediating environmental media, particularly suited to large sites that have relatively low levels of contamination. There are certain limitations to phytoremediation system such as time-consuming method, the amount of produced biomass, the root depth, soil chemistry, level of contamination, the age of plant, the contaminant concentration, the impacts of contaminated vegetation, and climatic condition. Heavy metals uptake, by plants using phytoremediation technology, seems to be a prosperous way to remediate heavy-metals-contaminated environment.

Key Words: Phytoremediation, heavy metals, immobilization, contaminant, environmental friendly.

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Access this article online	
Quick Response Code:	Website: www.statperson.com
	Accessed Date: 26 March 2018

INTRODUCTION

Soil is loose material that lies on top of the land. It is a mixture of many different things including rock, minerals, water and air. Soil also has living things and dead things in it Soil is important for life on Earth. Because soil holds water and nutrients, it is an ideal place for plants to grow.[(1)] Soil holds the roots, and lets plants stand above the ground to collect the light they need to live. This helps plants grow. Fungi and bacteria also live in the soil. They eat the dead plants and animals. The broken down material becomes food for plants (nutrients).[2] The soil also has many microorganisms living in it. Many of them eat the organic material in the soil. They use oxygen and release carbon dioxide. They also release mineral nutrients into the soil.[3] While a nearly infinite variety of substances may be found in soils, they are categorized into four basic components: minerals, organic matter, air and water. The ideal soil (ideal for the growth of most plants) as being composed of 45% minerals, 25% water, 25% air, and 5% organic matter. In reality, these percentages of the four components vary tremendously. There are 17 most important nutrients for plants. Plants must obtain the following mineral nutrients from their growing medium-acromacronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg), carbon (), oxygen(O), hydrogen (H) the micronutrients (or traceminerals): iron (Fe), boron (B), chlorine (Cl), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), nickel (Ni).[4] Heavy metals are generally defined as metals with relatively high densities, atomic weights, or atomic numbers. Some heavy metals are either essential nutrients (typically iron, cobalt, and zinc), or relatively harmless (such as ruthenium, silver, and indium), but can be toxic in larger amounts or certain forms. Other heavy metals, such as cadmium, mercury, and lead, are highly poisonous. Potential sources of heavy metal poisoning include mining, tailings, industrial wastes, agricultural runoff, occupational exposure, paints and treated timber. Trace amounts of some heavy metals are required for certain biological processes. These are iron and copper (oxygen and electron transport); cobalt (complex syntheses and cell metabolism); zinc (hydroxylation)[5] vanadium and manganese (enzyme regulation or functioning); chromium (glucose utilization); nickel (cell growth); arsenic (metabolic growth in some animals and possibly in humans) and selenium (antioxidant functioning and hormone production).[6] Molybdenum is required for the catalysis of redox reactions[7] admium is used by some marine diatoms for the same purpose; and tin may be required for growth in a few species.[8] Tungsten is required by some archaea and bacteria for metabolic processes.[9]A deficiency of any of these essential heavy metals may increase susceptibility to heavy metal poisoning[10] (conversely, an excess may also have adverse biological effects). An average 70 kg human body is about 0.01% heavy metals (~7 g, equivalent to the weight of two dried peas, with iron at 4 g, zinc at 2.5 g, and lead at 0.12 g comprising the three main constituents), 2% light metals (~1.4 kg,) and nearly 98% nonmetals (mostly water)[11] A few non-essential heavy metals have been observed to have biological effects. Gallium, germanium (a metalloid), indium, and most lanthanides can stimulate metabolism, and titanium promote growth in plants [(12)] (though it is not always considered a heavy metal).

Effects Of Heavy Metals On The Environment: The non-biodegradability of heavy metals makes it hard to remove them from contaminated biological tissues and this is a major concern for global health because of their lethal nature Heavy metals such as cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and molybdenum (Mo) are required in small quantities for the survival of living organisms, but at higher concentrations, they could become detrimental. The heavy metals Hg, Cr, As, Zn, Cd, Ur, Se, Ag, Au and Ni are hazardous heavy metals that contaminate the environment and adversely affect the quality of the soil, crop production as well as public health. Moreover, high metal toxicity inhibits cytoplasmic enzymes in plant cells and causes damage to cell structures due to oxidative stress which consequently affects plant growth and metabolism. Heavy metals are often assumed to be highly toxic or damaging to the environment.[13] Some are, while certain others are toxic only if taken in excess or encountered in certain forms. Heavy metals can degrade air, water, and soil quality, and subsequently cause health issues in plants, animals, and people, when they become concentrated as a result of industrial activities.[14] Common sources of heavy metals in this context include mining and industrial wastes; vehicle emissions; lead-acid batteries; fertilizers; paints; and treated timber[(15)] aging water supply infrastructure[16] and micro plastics floating in the world's oceans.[17]

Heavy Metal Contamination in The Soil: It refers to the excessive deposition of toxic heavy metals in the soil caused by human activities. Heavy metals in the soil include some significant metals of biological toxicity, such as mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr) and arsenic (As), etc. They also include other heavy metals of certain biological toxicity, such as zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), vanadium (V), and so on. In recent years, with the development of the global economy, both type and content of heavy metals in the soil caused by human activities have gradually increased, resulting in the deterioration of the environment(18) Heavy metals are highly hazardous to the environment and organisms. It can be enriched through the food chain. Once the soil suffers from heavy metal contamination, it is difficult to be remediated.[19] In recent years the soil contamination in developed countries becomes to be serious.

Sources of Heavy Metals: Excess heavy metals in the soil originate from many sources, which include atmospheric deposition, sewage irrigation, improper stacking of the industrial solid waste, mining activities, the use of pesticides and fertilizers. Heavy metals in the atmosphere are mainly from gas and dust produced by energy, transport, metallurgy and production of construction materials. Excepting mercury, heavy metals basically go into the atmosphere in the form of aerosol and deposit to the soil through natural sedimentation and precipitation, etc..

Techniques of Remediation of Heavy Metals From Contaminated Soil: There are several methods of remediation such as physical remediation, chemical remediation and biological remediation.

1. Physical remediation It includes soil replacement method and thermal desorption. The soil replacement means using clean soil to replace or partly replace the contaminated soil with aim of dilute the pollutant concentration, increase the soil environmental capacity, and thus remediate the soil[2]
2. Chemical remediation it includes
3. Chemical leaching which is washing the contaminated soil using fresh water, reagents, and others fluids or gas [21],[22]that can leach the pollutant from the soil. Trough the ions exchange, precipitation, adsorption and chelation, the heavy metals in soil was transferred from soil to liquid phase, and then recovered from the leachate. The leachate using mainly include inorganic eluent, chelation agents, and surfactant, etc
4. Chemical fixation is adding reagents or materials into the contaminated soil and using them with heavy metals to form insoluble or hardly movable, low toxic matters, thus decreasing the migration of heavy metals to water, plant and other environmental media and achieving the remediation of soil[23]
5. Electro kinetic remediation is a new remediation technology (24) which is mainly applying voltage at the two sides of soil and then forming electric field gradient. The pollutant was carried to two poles treatment room via electro migration, electro osmotic flow or electrophoresis and then treated further It is suitable for low permeable soil.
6. Vitrify technology is heating the soil at temperature of 1400~2000°C, in which process the organic matters volatilize or decompose. The steam produced and pyrolysis product was collected by off-gas treatment system. The melt after cooling forms rock shape vitreous, sieges the heavy metals and make it lose migration. It was reported that the strength of the vitreous is high 10 times than concrete. In this remediation, the energy can be supplied by fossil fuel burning or electrode directly heating, and then through arc, plasma and microwave transferring energy. For in-situ remediation, the heat can be through electrodes inserted into the contaminated soil. In summary, this technology can remove the heavy metal and the efficiency was high. However, it is complicated and need lots of energy in the melting, which makes it cost a lot and limited in application[25]

Biological remediation The biological remediation includes phytoremediation Phytoremediation It deals with the cleanup of organic pollutants and heavy metal contaminants using plants and rhizospheric microorganism. It is the use of living green plants to fix or adsorb contaminants, and cleaning the contaminants or making their risk reduction or disappearance. The phytostabilization, phytovolatilization and phytoextraction are the main three types of phytoremediation (26).Phytofiltration is also considered as biological remediation. Phytostabilization is fixing heavy metals by plants through the adsorption, precipitation and reduction of root, and thus reducing their migration and bioavailability and preventing them migrating into the groundwater and food chain[27]. Phytovolatilization is transferring the heavy metals into volatile state or adsorbing the metals and transferring into gaseous matter, using special matters secreted by root[28]. Mercury is the most studied heavy metals. To explore the potential of plants to extract and detoxify mercury, Bizily *et al*[29] engineered a model plant, Arabidopsis thaliana, to express a modified bacterial gene, merBpe, encoding organomercurial lyase

(MerB) under control of a plant promoter. However, this technology is only suitable for volatile contaminants, and the application is limited[30] Phytoextraction/Phytoaccumulation It involves the uptake and movement of metal pollutants in the soil through plant roots into above-ground components of the plants, based on the mechanism of hyper accumulation. Hyper accumulator plants take up metals in large quantities from contaminated soils, then transport and accumulate them in organs above the ground at concentrations from 100 to 1000 times higher than those found in non-hyper accumulating species without suffering any apparent phytotoxic effect hence they are very suitable for phytoremediation. These plants are usually found growing in areas with long-lasting metal contamination in soil over time and produce abundant biomass that can be easily harvested Phytoextraction is adsorbing the heavy metals using tolerant and accumulating plants, and then transferring, storing at the over ground parts. Studying the adsorption characterization of different plants and screening high uptake plants is the key of this technology. According to the rules of U.S. department of energy, the high uptake plants screened should have the following characterizations: 1) Have high accumulating efficiency under the low contaminants concentration; 2) Accumulate high concentrations of the contaminants; 3) Accumulate many different kinds of heavy metals; 4) Grow fast and with large biomass; 5) Have pest and disease resistance. Phytofiltration It is the cleanup of polluted environments using plant roots or seedlings from aqueous wastes. For the effective use of Phytofiltration as a phytoremediation technique, more studies have to be carried out to identify the parts of the plant that would be more efficient in accumulating the metal contaminants. It includes Rhizofiltration which involves the elimination of toxic substances or pollutants from ground water through filtration by the roots of plants. The process of rhizofiltration is based on the mechanism of rhizospheric accumulation by plants. Terrestrial plants are more efficient for rhizofiltration compared to aquatic plants. Several processes are used to remove heavy metals from contaminted soils by some plants as illustrated in figure[31]

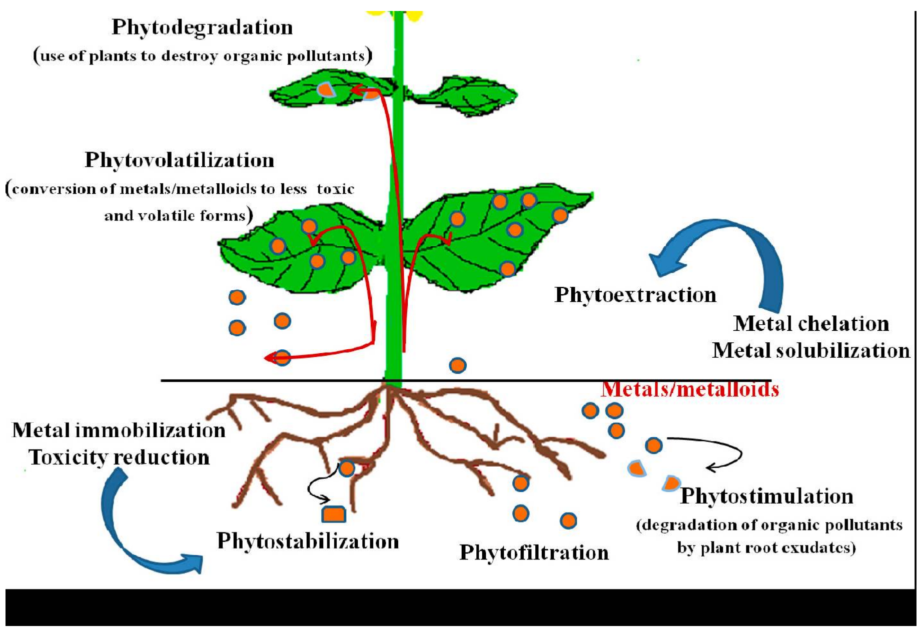

Figure 1: Plant showing phytoremediation Some hyper accumulator plants used in phytoextraction of heavy metals.

Family Species Heavy Metals

- Asteraceae Berkheya coddii Ni
- Asteraceae Helianthus annuus Pb, Cd, Zn
- Brassicaceae Arabidopsis halleri Zn, Cd
- Poaceae Spartina argentinensis Cr
- Violaceae Viola boashanensis Pb, Zn, Cd

CONCLUSION

Phytoremediation is the cleanest and cheapest technology can be employed in the remediation of selected hazardous site. It is a low-cost option and inexpensive approach for remediating environmental media, particularly suited to large sites that have relatively low levels of contamination. There are certain limitations to phytoremediation system such as time-consuming method, the amount of produced biomass, the root depth, soil chemistry, level of contamination, the age of plant, the contaminant concentration, the impacts of contaminated vegetation, and climatic condition. Heavy metals uptake, by plants using phytoremediation technology, seems to be a prosperous way to remediate heavy-metals-contaminated environment.. It is inexpensive, eco-friendly and an efficient means of restoration of polluted environments especially those that of heavy metals. Nonetheless, the level of soil contamination, the quantity of metal contaminant in the soil, as well as the ability of plants to aggressively take up metals from the soil, determine the success of phytoremediation at any polluted site. Plants utilized in phytoremediation are the hyper accumulators with a very high heavy metal accumulation potential and little biomass efficiency, and non-hyper accumulators which possess lesser extraction capacity than hyper accumulators, but whose total biomass yield is substantially higher and are fast-growing species. Thus Phytoremediation technology –Eco friendly approach to remove heavy metals from contaminated soil.

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Source of Support: None Declared
Conflict of Interest: None Declared