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# BIOREMEDIATION OF HEAVY METALS POLLUTED SOILS AND THEIR EFFECT ON PLANTS

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**ABSTRACT**

*Soils polluted by heavy metals are becoming common across the globe due to increase in manmade activities. Naturally heavy metals are present in the few amounts in earth crust. Plants growing in the metal polluted soils show a reduction in plant growth, performance and yield. Bioremediation is an effective and suitable method of heavy metal polluted soils. It is a cost effective and non disturbing method of soil remediation; it is useful for the treatment of heavy metal polluted soils. Microorganisms and plants employed different mechanisms for the bioremediation of polluted soils. Using plants for the treatment of polluted soils is a more common approach in the bioremediation of heavy metal polluted soils. Several microorganisms have been successfully used for reduce the toxicity of heavy metals. Both microorganisms and plants combining approach to bioremediation that ensures a more efficient clean-up of heavy metal polluted soils. Mostly soils reduced the heavy metal toxicity with using of Biochar, it is an organic material that is currently being exploited for its potential in the management of heavy metal polluted soils. It helps reduction in the availability of heavy metals when applied in the polluted soils and reduced absorption of the metals by plants. However, success of this approach largely depends on the species of organisms involved in the process.*

***Keywords*:** Bioremediation, Heavy metal Pollution, Microbes, Soil and Plant relation

Naturally heavy metals are present in the few amounts in earth crust; normally heavy metals are detained in manmade and anthropogenic activities increase in the concentration of soils, these metals are harmful to both plants and animals. Some of these activities include mining and smelting of metals, burning of fossil fuels, manufacture of batteries and other metal products in industries use of chemical fertilizers, pesticides, untreated sewage sludge and municipal waste used in agriculture for crop production. Land and water are valuable natural resources on which rely the sustainability of agriculture and the civilization of mankind. Unfortunately, they have been subjected to maximum exploitation and severely degraded or polluted due to anthropogenic activities (Table- 1). The pollution includes point sources such as emission, effluents and solid discharge from industries, vehicle exhaustion and metals from smelting and mining nonpoint sources such as soluble salts (natural and artificial), use of insecticides and pesticides, disposal of industrial and municipal wastes in agriculture and unnecessary use of fertilizers (Karaca, 2004).

Decreased growth of plants as a result of changes in physiological and biochemical processes in growing on heavy metal polluted soils has been recorded. Continued decline in plant growth reduces yield which eventually leads to food insecurity. Therefore, it is the various methods are using in Bioremediation of heavy metal polluted soils. This Bioremediation method is also considered as an economical remediation technique compared with other remediation techniques. Mainly physical and chemical methods (such as encapsulation, solidification, stabilization, electro-kinetics, vitrification, vapour extraction and soil washing and flushing) are expensive and do not make the soil suitable for plant growth. Biological approaches (bioremediation) are eco-friendly approach because it is achieved via natural processes and encourages the establishment or reestablishment of plants on polluted soils. In this paper attempts have been done to evaluate the nature and properties of heavy metals polluted soils for performance of plant growth. Biological approaches used for remediation of heavy metal polluted soils were also highlighted.

## Heavy metal Polluted Soil

Heavy metals are elements that exhibit metallic properties and characterized by comparatively high density and high relative atomic weight with an atomic number greater than 20. Some heavy metals such as Cu, Fe, Mn, Zn, Ni, Co and Mo are required in minute quantities by organisms (Khalid and Tinsley, 1990). However, excessive amounts of these elements can become harmful to organisms. Other heavy metals

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such as Pb, Cd, Hg, and As (a metalloid but generally referred to as a heavy metal) do not have any beneficial effect on organisms and are thus regarded as the "main threats" since they are very harmful to both plants and animals (Meena *et. al.*, 2005).

Metals exist each as break up entities or in combination with other soil components. These components may include exchangeable ions absorbed on the surfaces of inorganic solids, non exchangeable ions and insoluble inorganic metal compounds such as carbonates and phosphates, soluble metal compound or free metal ions in the soil solution, metal complex of organic materials, and metals attached to silicate minerals. Metals bound to silicate minerals, they cause contamination problems of soil and plants. Some heavy metals separate entities in soil that affect the soil properties with high concentration. Significant positive correlations have also been recorded between heavy metals and some soil physical properties such as moisture content and water holding capacity.

Soil pH is the main responsible factor affecting the availability of heavy metal in soil. Increases in soil pH decreased with availability of Cd and Zn to the plant roots. Organic matter and hydrous ferric oxide have been shown to decrease heavy metal availability through immobilization of these metals. The large boundary and specific surface areas provided by soil colloids help in controlling the concentration of heavy metals in natural soils. In addition, soluble concentrations of metals in polluted soils may be reduced by soil particles with high specific surface area, though this may be metal specific. Soil aeration, microbial activity, and mineral composition have also been shown to influence of heavy metal availability in soils. Soil microbiological and biochemical properties after contamination can be used to evaluate the heavy metals in soil pollution. Heavy metals affect the number, diversity and activities of soil microorganisms. The toxicity of these metals on microorganisms depends on a number of factors such as soil temperature, pH, texture, structure, organic matter, inorganic cations & anions and chemical forms by the metal. The presence of one heavy metal may affect the availability of plant nutrients. In other words, antagonistic and synergistic behaviors exist surrounding by heavy metals. Arya and Ray (2011) reported that the inhibitory effect of Mn on the total amount of mineralized Carbon was antagonized by the presence of Cd. Similarly, Cu and Zn as well as Ni and Cd have been reported to compete for the same membrane carriers in plants. In contrast, Cu was reported to increase the toxicity of Zn in spring barley. Different species of the same metal may also interact with one another. Presence of arsenite strongly suppressed the uptake of arsenate by rice plants growing on a polluted soil.

**Bioremediation of heavy metal polluted soils**

Bioremediation is the use of microorganisms and beneficial plants for the treatment of metal polluted soils. It is a broadly usual method of soil remediation because it is clear to occur via natural processes. It is a cost effective and non disturbing method of soil remediation, it used for the treatment of heavy metal polluted soils. Heavy metals can't be degraded during bioremediation but can only be transformed from one organic complex or oxidation state to another. Due to a change in their oxidation condition, heavy metals can be transformed to become either less toxic, easily volatilized, more water soluble can removed through leaching whereas less water soluble can be precipitate and easily removed from the polluted soils. For Bioremediation of heavy metals polluted soils combination of both microorganisms and plants can be use (White *et. al.*, 2006).

**Remediation of heavy metals polluted soils use by microbes**

Several microorganisms especially bacteria (*Bacillus subtilis, Pseudomonas putida*, and *Enterobacter cloacae*) have been successfully used for the reduction of the high toxicity of Cromium to the less toxic Cr (VI to III) (Ajmal *et.al.*, 1996). *Bacillus thuringiensis* have been shown to increase extraction of Cd and Zn from Cd-rich soil and soil polluted with effluent from metal industry. It is assumed that the production of siderophore (Fe complexing molecules) by bacteria may have facilitated the extraction of these metals from the soil; and reproduce the production of siderophore and this consequently affects their bioavailability (Khan, 2005). Bioremediation can also occur indirectly through bioprecipitation by sulphate reducing bacteria (*Desulfovibrio desulfuricans*) which converts sulphate to hydrogen sulphate which subsequently reacts with heavy metals such as Cd and Zn to form insoluble forms of these metal sulphides. The controversies surrounding genetically modified organisms and the fact that the heavy metal remains in the soil are major limitations to this approach for bioremediation.

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Making the soil favorable for soil microbes is one strategy employed in bioremediation of polluted soils. This process known as bio-stimulation involves the addition of nutrients in the form of manure or other organic amendments which serve as carbon source for microorganisms present in the soil. Added nutrients increase the growth and activities of microorganisms involved in the remediation process and thus this increases the efficiency of bioremediation.

Biochar is one organic material that is currently being exploited for its potential in the management of heavy metal polluted soils (Namgay *et al*., 2010). It is a reduction in the availability of heavy metals when the polluted soil was amended with biochar; this in turn reduced plant absorption of the metals. The ability of biochar to increase soil pH unlike most other organic amendments, it is important to note that, since the characteristics of biochar vary widely depending on its method of production and the feedstock used in its production. The effect of different biochar amendments depends on the availability of heavy metals present in soil. Further, more research is needed in order to understand the effect of biochar on soil microorganisms and how the interaction between biochar and soil microbes influences remediation of heavy metal polluted soils because such studies are rarely found in the literature.

**Bioremediation of polluted soils by plants**

Bioremediation of polluted soils by plants is also known as *Phytoremediation* is the use of green plants to clean-up hazardous waste from the contaminated soil polluted by heavy metals. It is an important portion of bioremediation with use of different types of plants for the treatment of polluted soils. It is suitable for the pollutants cover a large area and when they are within the root zone of the plant (Padmavathiamma and Li, 2007).

***Mechanisms of Bioremediation by Plants***

**(1). Phytoextraction**

Phytoextraction is primarily used for the treatment of contaminated soils. In this method plants absorb the concentrated metals and after precipitated from contaminated soils these metals accumulate were into the above ground parts of plants. There are few plants species known for higher accumulator and show their potential towards the removal of metals from contaminated soils (USEPA, 2000). (Padmavathiamma and Li, 2007) found that plants have the capability to extract large concentrations of heavy metals into their roots, translocation them into the surface and produce a large quantity of plant biomass.

Plants used for phytoextraction usually have the following characteristics: rapid growth rate, high biomass, extensive root system, and ability to accept high amounts of heavy metals. Generally use for the different criteria of the hyper accumulator.

1. The concentration of metal in the shoot must be higher than 0.1% for Al, As, Co, Cr, Cu, Ni, and Se, higher than 0.01% for Cd, and higher than 1.0% for Zn.
2. The ratio of shoot to root concentration must be consistently higher than 1; this indicates the capability to transport metals from roots to shoot and the existence of hyper tolerance ability
3. The ratio of shoot to root concentration must be higher than 1; this indicates the degree of plant metal uptake.

In most cases, plants absorb metals that are readily available in the soil solution and some metals are present in soil in the soluble forms for plant uptake, others occur as insoluble precipitate and are thus unavailable for plant uptake.

**(2). Phytostabilization**

Phytostabilization is the method used for the remediation of soil, sediment and sludges. In this method the use of plant roots may limit the contaminant in the soil through mobility and bioavailability process. The plants decrease the amount of water percolating through the soil matrix, which may act as a barrier and prevent direct contact with the contaminated soil. It may also prevent soil reducing their bioavailability through erosion, leaching and distribution of the toxic heavy metal to other areas. It is helpful in the treatment of contaminated land areas affected by mining activities. Plants help in stabilizing the soil through their root systems equally prevent leaching via reduction of water percolation through the soil thus, they prevent erosion. Plants used for phytostabilization should have the following characteristics: dense rooting system, ability to tolerate soil conditions, ease of establishment and maintenance under field conditions, rapid growth to provide adequate ground coverage, and longevity and ability to self-propagate.

Soil and organic amendments are used for contaminated soil reduce the toxicity of heavy metals

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and the other benefits they provide such as condition of nutrients for plant growth and improvement of soil physical properties. Phytostabilization is commonly used to treat the metals (arsenic, cadmium, chromium, copper and zinc) contaminants (Sharma and Sharma, 1993).

**(3). Phytovolatilization**

Phytovolatilization involves the use of plants to take up contaminants from the soil, transforming them into volatile forms into the atmosphere transpiration. It is basically used for mercury contaminated soil. In this method the growing trees and other plants may take up the contaminants with water and the contaminants may pass through the xylem vessels towards the leaves and converted into non-toxic forms and it may finally volatilize into the atmosphere.

**Remediation of heavy metals polluted soils through combination of plants and microbes**

The combined use of both microorganisms and plants for the remediation of polluted soils results in a faster and more efficient clean-up of the polluted area. Mycorrhizal fungi have been used in several remediations of heavy metals polluted soils. Phytoextraction is the best method of the accumulation of heavy metals in plants and others methods improved phytostabilization through metal immobilization and a reduced metal concentration in plants (Abhilash *et. al.*, 2012).

In general, the benefits derived from mycorrhizal associations—which range from increased nutrient and water acquisition to the provision of a stable soil for plant growth and increase in plant resistance to diseases are believed to aid the survival of plants growing in polluted soils and thus help in the vegetation and re-vegetation of remediated soils. In addition of certain species of mycorrhizal fungi (*Arbuscular mycorrhizal* fungi) can be more sensitive to pollutants compared to plants. Other microorganisms apart from mycorrhizal fungi have also been used in conjunction with plants for the remediation of heavy metal polluted soils. Most of these microbes are the plant growth-promoting rhizobacteria that are usually found in the rhizosphere. Several microbes stimulate plant growth by some mechanisms such as production of phytohormones and supply of nutrients production of siderophores and other chelating agents specific enzyme activity and N fixation and reduction in ethylene production which encourages root growth (Divya and Kumar, 2011).

Enhanced accumulation of heavy metals such as Cd and Ni by hyperaccumulators (*Brassica juncea* and *Brassica napus*) has been observed when the plants were inoculated with *Bacillus spp.* (Khalid and Tinsley, 1990). On the other hand, increased plant growth due to a reduction in the accumulation of Cd and Ni in the shoot and root tissues of tomato plant when it was inoculated with *Methylobacterium oryzae*. Increased mycorrhizal efficiency which in turn decreased metal accumulation and increased the growth of white clover growing on a heavy metal (Zn) polluted soil.

**Effect of heavy Metal polluted soil on plant**

The heavy metals those are available for plant uptake that the present as soluble components in the soil solution these are easily solubilized by root zones. Although, plants require certain heavy metals for their growth and maintenance, unnecessary amounts of these metals can become toxic to plants. The capability of plants to accumulate essential metals similarly enables them to acquire other nonessential metals. As metals cannot be broken down, when concentrations within the plant exceed optimal levels, they adversely affect the plant both directly and indirectly.

Some of the direct toxic effects caused by high metal concentration include inhibition of cytoplasmic enzymes and damage to cell structures due to oxidative stress. An example of indirect toxic effect is the replacement of essential nutrients at cation exchange sites of plants. Further, the negative pressures of heavy metals have on the growth and activities of soil microorganisms may also indirectly affect the growth of plants. For example, a reduction in the number of beneficial soil microorganisms due to high metal concentration may lead to decrease in organic matter breakdown, important to a reject in soil nutrients. Enzyme activities useful for plant metabolism may also be disadvantageous due to heavy metal interference with activities of soil microorganisms. Which sometimes results in the death of plant due to direct and indirect toxic effects on heavy metals in plant growth.

Effect of Cd was observed by Ghosh and Singh (2005) and found a reduction in shoot and root growth in wheat plants when level of Cd in the soil solution was as low as 5 mg/L. Most of the reduction in growth parameters of plants growing on polluted

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soils can be attributed to reduced photosynthetic activities, plant mineral nutrition, and reduced activity of some enzymes. For other metals which are beneficial to plants, concentration in small amount of these metals in the soil could actually improve plant growth and development. However, at higher concentrations of these metals, reductions in plant growth have been recorded. Uptake of low amount of heavy metals increased in plant growth, nutrient content, biochemical content and antioxidant enzyme activities for plant. Improvements in growth and physiology of cluster beans have also been reported by Manivasagaperumal *et. al.* (2011) at medium Zn concentration of the soil solution. On the other hand, excess concentration of Zn adverse effect on the plant growth. It is also reported that the combination of Pb and Cu at both high concentration and low concentration resulted in a rapid and complete death of the leaves and stem of Lythrum salicaria (Das *et.al.*, 1999). Some plants are able to tolerate these metals through three mechanisms.

(i) *Exclusion:* restriction of metal transport and maintenance of a constant metal concentration in the shoot over a wide range of soil concentrations.

(ii) *Inclusion:* metal concentrations in the shoot reflecting those in the soil solution through a linear relationship.

(iii) *Bioaccumulation:* accumulation of metals in the shoot and roots of plants at both low and high soil concentrations.

**Table-1: Heavy metals and their source of contamination in the soil**

| Heavy metal | Sources of contamination |
|---|---|
| Cd | Electroplating, batteries and fertilizers |
| Pb | Batteries, metal products |
| Cr | Timber treatment, leather tanning, pesticides and dyes |
| Cu | Timber treatment, fertilizers, fungicides, electrical and pigments |
| Zn | Dyes, paints, timber treatment, fertilizers and mine tailings |
| Mn | Fertilizer |
| Mo | Fertilizer |
| As | Timber treatment, paints and pesticides, |
| Ni | Alloys, batteries and mine tailings |
| Hg | Instruments, fumigants and fertilizers |

## CONCLUSION

The increase global population, industrialization and urbanization are the some major reasons to contaminate the environment. Release of heavy metals from industries causing the serious health problem to human and other animals, this also pollutes the environments due to their persistence and bio-accumulative nature. In this regards, bioremediation process provides effective innovative measures for treatment of a wide variety of contaminants. Phytoextraction is the most common method of phytoremediation used for treatment of heavy metal polluted soils. It ensures the complete removal of the pollutant. Combining both plants and microorganisms in bioremediation increases the efficiency of remediation.

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