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(REVIEW ARTICLE)

Effectiveness of bio- phytoremediation on heavy metal contaminated soils: A review

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Abstract

The need to restore the environment contaminated with heavy metals to its original ornear original status has become necessary due to the harm high concentration of heavy metals cause to the environment and the food chain. In this review, different remediation approach was considered, their merits and short coming. Focus was more on bio-phytoremediation: use of some selected plants and micro-organisms to decontaminate heavy metals from contaminated sites. . Differentplant species especially hyper accumulative plants were used to decontaminate heavy metals from contaminated site. Vetiver grass (*Vetiveriazizanioides*) was more effective among all the plant species used. It is environmentally friendly and cost effective. Its ability to accumulate and uptake heavy metals from the soil and translocate same to the shoot was high. Combination of both plants and micro-organisms proved to be more effective with a faster result in remediating a heavy metal polluted soil. Amendment of the soil with organic manures significantly increased the percentage of heavy metals removed from the soil and reduced the uptake of contaminants (heavy metals) from the plant tissues.

Keywords: Remediation potentials; Bio-phytoremediation; Heavy metals; Vetiver grass; Contamination

1. Introduction

Environmental contamination by heavy metals is a major global concern because of their persistence in soil, toxicities and bioaccumulation in living organisms (Gardea-Fornesdey et al., 2004 and Singh et al., 2010). Soil contamination involves introduction of either physical, chemical, biological or radiological substances into soil which may cause harm or have the potential to cause harm (DEFRA, 2006).

Heavy metals enter the environment by natural and anthropogenic means such as natural weathering of earth crust, mining, soil erosion, industrial discharges, urban runoff, sewage effluents, petroleum exploration agrochemical activities applied to soil, air and water (Ming-Ho, 2005). Migration of these contaminants into non contaminated areas as dust, leachates through the soil and sewage sludge lead to heavy metal contamination of the ecosystem (ATSDR, 2005).

These metals pose long term environmental and health implications because of their non biodegradability and persistence. Ali and Khan, (2018) defined heavy metal as naturally occurring metals with atomic number greater than 20 and elemental density greater than $5g/cm^{3.}$

The most common heavy metals found at contaminated sites in order of abundance are Pb, Cr, As, Zn, Cd, Cu, and Hg (USEPA, 1996). These metals are capable of decreasing crop production due to the risk of bioaccumulation and biomagnification in food chain and ground water contamination. Some heavy metals such as Co, Cu, Fe, Mn, Mo, Ni, V and Zn are required in small quantities by organisms, However, excessive or high concentration of these elements can be harmful to the organisms. Other heavy metals like Pb, Cd, Hg and As (metalloid, generally referred to as heavy metal).

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Have no beneficial effect on organisms and so are regarded as main threats since they are harmful to both plants and animals (Ghaffa and Hikmat, 2018).

This review is aimed at evaluating different techniques of remediating heavy metal contaminated sites with focus on using different plant species.

2. Effect of heavy metal uptake by plants

Heavy metals enter food chain as a result of their uptake by edible plants due to their non biodegradability, they accumulate at high levels in the plant after their uptake in polluted soils (Udom et al., 2004). Their accumulation in plants depends on plant species and the efficiency of the plants in absorbing metals which is evaluated by soil to plant transfer factors of the metals (Khan et al., 2008).

The heavy metals that are available for plant uptake are those present as soluble components in soil solution or easily solubilized by root exudates (Blaylock et al., 2000). Plants require certain heavy metals for their growth, excessive amounts of these metals can become toxic to plants.Some of the direct toxic effects caused by high metal concentration include inhibition of cytoplasmic enzymes and damage to cell structure due to oxidative stress (Assche et al., 1990).

Indirect toxic effect is the replacement of essential nutrients at cation exchange sites of plants (Taiz and Zeiger, 2002). Heavy metals have negative influence on the growth and activities of soil micro-organisms which indirectly affect the growth of plants. A reduction in the number of soil micro-organisms as a result of high concentration of heavy metals may lead to a decrease in organic matter decomposition thus a decline in soil nutrients.

Heavy metals interference with soil micro-organisms may also affect the activities of some enzyme useful for plant metabolisms (Plant et al 2000); thus, affecting the growth of the plant.

When heavy metals enter food chain, they cause different health challenges such as damages to nervous system, endocrine, circulatory system, cancer, malignancy, benign prostatic hyperplasia (Yang et al 2002, Zokowskd and Biziuk, 2008 and Zhang et al., 2012).

3. Toxicity of heavy metals on plant

Toxicity of heavy metal on the growth and performance of plants varied according to the heavy metal involved in the process. Heavy metals such as Pb, Hg, As and Cd do not have beneficial role in plant growth, therefore very little concentration of these metals in growth medium could cause adverse effect to the plant. Study has shown that 5 mg/l of Cd in soil solution led to a reduction in shoot and root growth of wheat plant (Ahmad et al., 2012).

Some plants not only accumulate metals in the roots but also translocate metals from root to leaves and shoots. For those metals which are beneficial to plants, small concentrations of the metals in soil can improve plant growth and development; however, higher concentrations may lead to reduction of plant growth (Baker et al., 2000).

Manivasagaperumal et al., (2011) reported in his study that zinc concentration of 25mg/l of soil solution improved growth and physiology of cluster beans, as the concentration increased to 50mg/l of zinc growth reduction and adverse effect on plant physiology was observed.

In a situation where the environment is polluted with more than one heavy metal such as sewage sludge disposal, metal mining waste, crude oil drilling, there will be both synergistic and antagonistic relationship between the heavy metals which may affect plant metal toxicity.

Study has shown that combination of Pb and Cu at both high concentration (1000mg/kg each) and low concentration (500mg/kg) resulted to a rapid and complete death of the leaves and stem of *Lythrumsalicaria* (Nicholls and Mal, 2003). Their result revealed no synergistic interaction between these heavy metals probably because the concentrations used in the study were too high for interactive relationship to be noticed between the metals.

Ghani, (2010) in his work examined the effect of six heavy metals (Cd, Co, Mn, Cr, Pb and Hg) on the growth of maize on soil. The results showed a reduction in the growth and protein content of maize. The toxicity of the heavy metals occurred in the order of Cd>Co>Hg>Mn>Pb>Cr. His study also showed that the combined effect of two or more heavy metals was as harmful as the effect of the most toxic heavy metal. This he attributed to be due to the antagonistic relationship which exists between heavy metals.

4. Heavy metals on plants and organisms

Plant roots absorb heavy metals in the soil especially in soil where there is contamination (Jordao et al., 2006). When these heavy metals are taken up by plant roots, it leads to chlorosis, weak plant growth, yield reduction, reduced nutrient uptake, disorders in plant metabolism and reduced ability to fix molecular nitrogen in leguminous plants (Guala et al., 2010). Uptake of these heavy metals by plants and accumulation in food chain becomes a threat to animal and human health (Sprynskyy et al., 2007).

High level ingestion of toxic metals has undesirable effect on humans which becomes obvious only after several years of exposure to it (Khan *et al*., 2008). A decrease in bacterial species richness and a relative increase in soil actinomycetes or even decreases in both the biomass and diversity of the bacterial communities in contaminated soils are caused by presence of heavy metals (Jordao*et al*., 2006). The need to investigate activities of soil microorganisms in eco-systems that have been exposed to long-term contamination by heavy metals has been suggested (Wang *et al*., 2007). The general increase of heavy metal content in the soil has been largely caused by crude oil spillage (Anoliefo and Vwioko., 1995). Heavy metal pollution of the soil is caused by various metals especially copper, Nickel, Cadmium, Zinc, Chromium, and lead (Hinojosa et al., 2004). It has been observed that the pollution caused by heavy metal does not only results in adverse effects on various parameters relating to plant quality and yield but also causes changes in the size, composition and microbial activities (Yao *et al.,* 2003)

5. Effect of pH on heavy metals

Soil pH just like most chemical properties of the soil affects the accumulation as well as the uptake of compounds. The importance of pH in metal solubility is well known as it influences heavy metal adsorption, retention and movement (Sauve et al., 1997). Soil pH is an indication of the acidity and alkalinity of the soil and is measured in pH units. One of the most important Pb source in an urban environment is vehicle emissions. Soil pH has a great effect on the solubility or retention and lower solubility of metal cations occurring at high pH (Barrow, 1992). The soil pH has been defined as the parameter most widely accepted as exerting a controlling influence on the availability of micronutrients to plants (Sanders, 1982). Soil pH for instance is very important for most heavy metals since metal availability is relatively low when the pH is around 6.5 to 7. Jia *et al.,* (2009) reported that crude oil pollution reduced soil pH. With the exception of molybdenum (Mo), Selenium (Se) and Arsenic (As), the mobility of trace elements is reduced with increasing soil pH because of the precipitation of these elements as insoluble hydroxides, carbonates and organic complexes. At high pH, ion hydrolysis is favored, and the energy barriers that must be overcome when these ions approach the surface of soil particles decreases (Yu *et al*., 1997).

6. Remediation techniques

When heavy metals are released into the soil and mud water bodies, they may cause harmful effects on soil, crop and human health (Ayesanmi, 2005). There is therefore need to remediate the soil to restore it back to its original or near original status.

There are physical, chemical and biological measures for remediating sites contaminated with heavy metals. Whichever technique selected depends upon the contaminants, the site characteristics, regulatory requirements, cost and time constraints (Ram et al., 1993). Remediation is therefore any measures that can be used to eradicate or reduce the effect of contaminants (heavy metals) from the environment and/or to clean completely the contaminants and bring back the soil/environment to near its original condition.

Several methods have been in use to decontaminate heavy metal contaminated environment, most of these techniques are either costly or far away from their optimum performance, the chemical technologies may generate large volume sludges which may also increase cost (Rakhshaez et al., 2009). The chemical and thermal methods are both technically difficult and expensive. All these methods can also degrade the valuable components of the soil (Hinchman et al., 1995).

Conventionally, remediation of heavy metals contaminated soil involves either onsite management or excavation and disposal to land fill site. The method has the disadvantage of shifting the contaminants to another place, transportation of contaminated soil and moving of the contaminants from land fill to adjacent environment. An alternative method to excavation is Soil Washing where the heavy metal contaminated soil are removed and disposed to land fill. This method is costly, the residue produced rich in heavy metal may require further treatment; more so use of the area for crop production may be affected due to the removal of the soil with all its biological activities (Gaur et al., 2004).

7. Bioremediation of heavy metals polluted soil

Bioremediation is another method of remediating heavy metals contaminated sites. It is the use of organisms (microorganisms and/or plants) for the treatment of polluted soils. It is a widely accepted method of soil remediation because it is perceived to occur via natural processes. It is equally a cost-effective method of soil remediation. Blaylock et al. (1997) reported 50% to 65% saving when bioremediation was used for the treatment of one acre of Pb polluted soil compared with the case when a conventional method (excavation and landfill) was used for the same purpose. Although bioremediation is a non destructive method of soil remediation, it is usually time consuming and its use for the treatment of heavy metal polluted soils is sometimes affected by the climatic and geological conditions of the site to be remediated (Schmoger*et al.,* 2000).

Heavy metals cannot 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 state, heavy metals can be transformed to become either less toxic, easily volatilized, more water soluble (and thus can be removed through leaching), less water soluble (which allows them to precipitate and become easily removed from the environment) or less bioavailable (Garbisu*et al.*, 2003). Bioremediation of heavy metals can be achieved via the use of microorganisms, plants, or the combination of both.

8. Using micro-organisms for remediation of heavy metal polluted soils

Microorganisms such *Bacillus cereus and Bacillus. thuringiensis*have been shown to increase extraction of Cd and Zn from Cd-rich soil and soil polluted with effluent from metal industry (Ajaz HajaMohideena *et al*., 2010). It is assumed that the production of siderophore (Fe complexing molecules) by bacteria may have facilitated the extraction of these metals from the soil; this is because heavy metals have been reported to simulate the production of siderophore and this consequently affects their bioavailability (Van der Lelie*et al*., 1999). For instance, siderophore production by *Azotobactervinelandii* was increased in the presence of Zn (II) (Huyer and Page. 1988). Hence, heavy metals influence the activities of siderophore-producing bacteria which in turn increases mobility and extraction of these metals in soil.

Bioremediation can also occur indirectly via bio precipitation by sulphate reducing bacteria (*Desulfovibriode sulfuricans*) 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 (White et al 1998). Genetic engineering can be adopted in microbe assisted remediation of heavy metal polluted soils. For instance, Valls *et al*., (2000) reported that genetically engineered *Ralstoniaeutropha* can be used to sequester metals (such as Cd) in polluted soils. This is made possible by the introduction of metallothionein (cysteine rich metal binding protein) from mouse on the cell surface on this organism. Although the sequestered metals remain in the soil, they are made less bioavailable and hence less harmful. The controversies surrounding genetically modified organisms (Urgun-Demirtas*et al.,* 2006) and the fact that the heavy metal remains in the soil are major limitations to this approach to bioremediation.

Although bio stimulation is usually employed for the biodegradation of organic pollutants (Abioye. 2011), it can equally be used for the remediation of heavy metal polluted soils. Since heavy metals cannot be biodegraded, bio stimulation can indirectly enhance remediation of heavy metal polluted soil through alteration of soil pH. It is well known that the addition of organic materials reduces the pH of the soil (McCauley *et al*., 2009); this subsequently increases the solubility and hence bioavailability of heavy metals which can then be easily extracted from the soil (Karaca, 2004).

9. Phytoremediation technology

Presently phytoremediation is an emerging technology that uses selected plants to clean up heavy metals contaminated soils, sediments and water from hazardous contaminants to improve the quality of the environment. It is environmentally friendly, cost effective, plants with exceptional metal accumulating capacity are known as hyperaccumulators, naturally occurring, fast growing (Cho-Ruk et al., 2006, Chukwumati and Kamalu, 2021).

Phytoremediation involves depolluting contaminated soil, water or air with plants capable to degrade, contain, eliminate heavy metals, pesticides, solvents, explosives, crude oil and its derivatives from the medium that is contaminated (Pivetz, 2001). Different forms of phytoremediation application exist and are classified based on fate of contaminants and the mechanisms involved.

10. Mechanisms of phytoremediation

Some essential processes involved in phytoremediation technology (USEPA, 2000, Prasad et al., 2003) are Phyto stabilization and Phytoextraction for inorganic contaminants and Phyto transformation/Phytodegradation, Rhizofiltration and Phytodegradation for organic contaminants

10.1. Phytoextraction

Also known as phytoaccumulation, phytoabsorption or phytosequestration involves use of metal or salt accumulating plants to translocate and concentrate the contaminants unto the above ground (roots, shoots and leaves) portion of the plants. The plants are harvested and incinerated, disposed or composted (ITRC WG, 2001; Pivetz,2001). This mechanism is a good option for removal of Ag, Cd, Co, Cu, Cr, Hg, Mn, Ni, Pb, Zn, Metalloids (Salt et al., 1995).

Studies has shown that proper disposal of plant biomass containing heavy metals is a major problem in phytoremediation technology due to the fact that the heavy metals may move or transform in different disposal process. Therefore disposal methods such as heat treatment, extraction treatment, microbial treatment, compression land fill and synthesis of nanomaterials could be adopted (Zhongchuang, L and Khanh-Quang, T. 2021).

10.2. Rhizofiltration/phytofiltration

This mechanism is used to remove contaminants from ground water, surface water, waste water or extracted ground water rather than soil through adsorption or absorption into the root of the plants. Pivetz, (2001) reported that absorbed contaminants may remain on the root, within the root or taken up and translocated to other parts of the plant depending on the concentrations, the contaminants and pH of the species. Hence the need for proper method of disposal.

11. Summary of phytotechnology application

Ideal plant species for phytoremediation should have the following characteristics: High biomass with enhanced metal uptake potential and should thrive even on infertile soils, low biomass with very high metal accumulation capacity, Metal tolerant plants with lower metal accumulation are preferred for Phyto stabilization while hyper-accumulator are the best choice for phytoextraction as they tolerate high metal ions and must have high growth rates. They are of good acceptance by the public. (Jachym et al., 2018).

They must also have high Degrading enzyme production and must have ability to accumulate and tolerate contaminants (Roongtanakiat and Chairoj, 2002).

12. Phytoremediation grasses

Several plant species have been used in phytotechnology to clean and decontaminate heavy metals contaminated environment, among these grasses are Vetiver grass (*Vetiveria zizanioides*), Guinea grass (*Panicum maximum)*, Elephant grass (*Pennisetum purpureum*), St. Augustine grass (*Stenotaphrum secundatum*), Bahia grass (*Paspalum notatum*)*,* Bana grass (*Pennisetum glaucum*), Sun flower etc (Chukwumati and Kamalu 2021., Fakayode Onianwa, 2004.,Hanping and Honghua, 2003).

Most of these plants are herbaceous plants that belonged to the grass family as lemon grass, sugar cane, sorghum and maize compared to trees and shrubs. It has a characteristic of rapid growth, large degraded and heavy metal contaminated land in tropics and subtropics with light temperature and precipitation (Xia et al., 1999, Ye et al., 2000 and Loch, 2000).

Research carried out by Roechan et al., (2000) on the use of vetiver grass to remediate contaminated soils in Bekasi West Java showed that vetiver can grow well on soil contaminated with high concentration of Pb and Cd. They inferred that by concentrating the contaminants in its roots, reduced the concentration of Pb in the soil by as much as 38 - 60% and 35 - 42% for Cd.

Hanping and Honghua, (2003) in their study on four grass species Vetiver (*Vetiveria zizanioides*) grass, St Augustine grass (*Stenotaphrum secundatun*), Bahia grass (*Paspalum notatum*) and Bana grass (*Pennisetum glaucum*) to rehabilitate the degraded ecosystem of an oil shale mined land of Maoming Petrochemical company in South west Province of China, reported that vetiver had the highest times survival rate of 98.6%, Bahia had 96.5%, St Augustine 90.9% while Banahad

61.7% concentration of Pb, and Cd in the four grasses showed a disparity of only 1.6-3.8, but that the uptake of the two heavy metals were apart to 16-35 times. This significant difference they inferred was due to their different biomass.

Top soil of guinea grass (*Panicum maximum)* samples obtained around Ikeja industrial Estate in Lagos, Nigeria were analyzed for heavy metals contents: the levels of heavy metals observed were significantly higher than the background control site (Fakayode and Onianwa, 2004). According their report, an average concentration of Cd was 2.9, Pb 143.2, Cu 25.6, Zn 247.4, Ni 17.0, Cr 26.6 and Mn 282.9 (mg/kg) for soils; while on plants: Cd was 0.93, Pb 2.9, Cu 0.39, Zn 0.72, Ni 2.3, Cr 2.3 and Mn 3.7 (mg/kg). A strong correlation between soil and plant contents Cd, Pb, Ni, and Mn was reported.

Similar study carried out by Chukwumati and Kamalu, (2021) using Vetiver grass (*Vetiveriazizanioides*) and Guinea grass (*Panicum maximum)* to remove some heavy metals (Fe, Zn, Cd and Pb) on hydrocarbon contaminated soil revealed that vetiver grass removed the concentration of Fe from soil to 28.4%, Zn 37.3%, Pb 35.8% and 23.1% for Cd; while percent heavy metals removed by Guinea grass was 25.9% for Fe, 32.8% for Zn, 30.8% for Pb and 38.5% for Cd. There was no significant ($P>0.05$) difference between vetiver and guinea grass in the quantity of Fe removed from the soil while a significant ($P<0.05$) difference was observed between vetiver and guinea grass in the quantity of zinc and lead removed. The amount of cadmium removed from the soil was significantly higher in guinea grass than vetiver. The result therefore showed that vetiver has higher capability of removing heavy metals from hydrocarbon contaminated soils than guinea grass.

Similarly, the concentration of heavy metals (Fe, Zn, Pb and Cd) absorbed in vetiver tissues were significantly higher than those absorbed in guinea grass tissues from the study. The two grasses have the capability of removing heavy metals from contaminated soils. Amendment of the soil with organic manure significantly increased the percent heavy metals removed from the soil and reduced the uptake of the contaminants (heavy metals) from the plant tissues (Chukwumati and Kamalu, 2021)

13. Combining plants and microbes for the remediation of heavy metal polluted soils

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 site (Weyens *et al*., 2009). Mycorrhizal fungi have been used in several remediation studies involving heavy metals and the results obtained show that mycorrhizae employ different mechanisms for the remediation of heavy metal polluted soils. For instance, while some studies have shown enhanced phytoextraction through the accumulation of heavy metals in plants [Joner and Leyval. 2001], others reported enhanced phytostabilization through metal immobilization and a reduced metal concentration in plants (Heggo*et al*., 1990).

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 (Wright et al., 2007) are believed to aid the survival of plants growing in polluted soils and thus help in the vegetation/revegetation of remediated soils (Chibuike., 2013). It is important to note that mycorrhiza does not always assist in the remediation of heavy metal polluted soils (Díaz*et al*.,1996) and this may be attributed to the species of mycorrhizal fungi and the concentration of heavy metals (Chibuike.,2013). Studies have also shown that activities of mycorrhizal fungi may be inhibited by heavy metals (Chao and Wang. 1990). In addition, Weissenhorn and Leyval, (1996) reported that certain species of mycorrhizal fungi (arbuscular mycorrhizal fungi) can be more sensitive to pollutants compared to plants.

14. Conclusion

Among the different methods available for remediation of heavy metal contaminated environment, phytoremediation appears to be more effective due to its cost effectiveness, environmentally friendly. Vetiver grass (*Vetiveriazizanioides*) stands out as one of the best plant species for remediation of heavy metal contaminated sites.

It has high biomass with fast growth rate with the ability to accumulate heavy metals in their tissues. Combining the plants with micro-organisms or organic manures enhances the ability of the plants to accumulate heavy metals in their tissues.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declared no conflict of interest.

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