

PHYTOREMEDIATION OF LEAD FROM WASTEWATER USING AQUATIC PLANTS

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ABSTRACT

Increasing urbanization, industrialization and over population is one of the leading causes of environmental degradation and pollution. Heavy metals such as Pb, Zn, Cd, As etc. are the most toxic pollutants which show hazardous effects on all living things. Lead is one such pollutant which disrupts the food chain and is lethal even at low concentrations. The prevailing purification technologies used for removal of contaminants are not only very costly but causes negative impact on ecosystem subsequently. Phytoremediation, an eco-friendly 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 is to assess the current state of phytoremediation as an innovative technology and to discuss its usefulness and potential in the remediation of lead contaminated water.

KEY WORDS: Heavy metals, Lead, Wastewater, Phytoremediation, Aquatic plants.

1. INTRODUCTION

Excess level of heavy metals are exposed into environment by means of various sources like industrial waste and fertilizers which causes serious concern in nature as they are non- biodegradable and accumulate at high levels¹. 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 health². Common heavy metals like Cd, Pb, Co, Zn and Cr etc. are phytotoxic at both low concentration as well as very high concentration and are detected in waste

water from mining operations, tanneries, electronics, electroplating, batteries and petrochemical industries as well as textile mill products³. If such metals are present in sediments then they reach the food chain through plants and aquatic animals. In small quantities, certain heavy metals are nutritionally essential for a healthy life, but large amounts of any of them may cause acute or chronic toxicity (poisoning).

Lead is one of the very toxic heavy metals that not only accumulate in individual but also have the ability to affect the entire food chain and disrupt the health system of human beings, animals and phytoplanktons⁴.

Hence, proper treatment of lead from soil and industrial wastewaters is very important. Several conventional methods used for the removal of lead from wastewater includes chemical precipitation, ion exchange and reverse osmosis etc. but major drawbacks related with such treatments are production of large amount of sludge, ineffectiveness or high cost. So, the search for a new, simple, effective and eco-friendly technology involving the removal of toxic heavy metal from wastewater has directed attention towards phytoremediation.

Some of the aquatic plants used for removal of lead are *Lemna minor* (Duckweed), *Eichhornia crassipes* (Water hyacinth) and *Hydrilla verticillata* (Hydrilla) etc. This paper revealed at reviewing the potential use of different aquatic plants for remediation of lead contaminated water.

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2. SOURCES OF LEAD

Lead is a crucial toxic metal. It either reaches water system through urban runoff or discharges such as sewage treatment plants and industrial plants. Industrial production processes and their emissions, mining operation, smelting, combustion sources and solid waste incinerators are the primary sources of lead⁷. Other sources are paint, batteries, metal plating, automobiles exhausts, lead piping and fertilizers pesticides used in water distribution system⁸.

3. EFFECTS OF LEAD

Lead is one of the most abundant toxic metals that pose a serious threat to animals and plants. In human, it is absorbed directly into the blood stream and is stored in soft tissues, bones and teeth (95% in bones and teeth). It can also affect the kidney and most importantly the nervous system and brain. Thus, lead can accumulate over a lifetime and cause diseases such as anemia, encephalopathy, hepatitis and nephritic syndrome^{5,3}. It exceeds the WHO (2004)⁹ allowable standard 0.15 mg/L in drinking water and constant exposure may lead to delay in physical or mental development in infants and children while adults may have kidney problems and high blood pressure. Lead contaminates water by the corrosion of household plumbing system and erosion of natural deposits. Permissible limits for Pb in drinking water is 0.015 mg/L and for wastewaters is 0.1 mg/L given by United State Environmental Protection Agency¹⁰.

Lead also influences the aquatic system. Certain communities of aquatic invertebrate's populations are more sensitive than others. However, populations of invertebrates from polluted areas can show more tolerance for lead than those from non polluted areas. In other aquatic invertebrates, adaptation to low oxygen conditions can be hindered by high lead concentration. Young fish are more susceptible than adults or eggs. Typical symptoms of lead toxicity in aquatic organisms include spinal deformity and blackening of the tail region¹¹. Lead at 500 ppm in soil or solid waste qualifies the substance as "hazardous waste". Thus, lead contamination is extremely dangerous, and lead polluted waters need to be cleansed⁵.

4. CONVENTIONAL METHODS FOR TREATMENT OF LEAD

Heavy metals such as lead, mercury, arsenic, copper, zinc and cadmium are highly toxic when adsorbed into the body¹². Lead, one of the earliest metals recognized and used by humans, has a long history of beneficial use to humankind. But it has been recognized as toxic recently and poses a widespread threat to humans and aquatic life¹³. Treatment of lead from polluted water and wastewater has received a great deal of attention. Lead in these waters should be reduced to levels in correspondence to the rules of regulatory agencies. A number of conventional methods used for the removal of lead from polluted water are summarized in Table 1.

A range of different methods can be used for the removal of Lead from water that contains this hazardous element. Some factors such as cost effective and simple technology must be considered to settle this problem over conventional methods.

5. PHYTOREMEDIATION

Bioremediation is the most applicable method for destruction of contaminants by biological mechanisms, including microorganisms (e.g. yeast, fungi, or bacteria) in contaminated soil and water. Because heavy metals are not subject to degradation, several scientists have suggested that bioremediation have limited potency to remediate metal from contaminated soil and water¹⁴. Since last thirty years, scientists and engineers have been investigating the potential of live plants and inactivated biomaterials as remediation alternatives¹⁵.

Phytotechnologies is an emerging technique during the last two decades. Plant based bioremediation technologies

have been collectively termed as phytoremediation. This refers to the use of the green plants to clean up contaminated soil and groundwater. The idea of using metal accumulating plants to remove heavy metals and other compounds were first introduced in 1983, but the concept was actually being implemented since last 300 years¹⁶. The generic term "Phytoremediation" consists of the Greek prefix phyto (plant), attached to the Latin word remedian (to correct or remove an evil)¹⁷. Phytoremediation is an attractive alternative or complementary technology that can be used along with or, in some cases in place of mechanical conventional cleanup treatments that often require high capital inputs, more labor and energy intensive¹⁸.

Phytoremediation has also been called green remediation, botano-remediation, agro remediation and vegetative remediation¹⁹. It is less destructive to the environment, cost effective, aesthetically environmental pollutants removal approach most suitable for developing countries²⁰. The plant used in phytoremediation technique must have a considerable capacity of metal absorption, its accumulation and strength to decrease the treatment time of polluted water²¹.

There are several ways by which plants cleanup or remediate contaminated sites.

5.1. Phytoextraction

Phytoextraction is the uptake of contaminants by plant roots and translocation within the plants. Contaminants are generally removed by harvesting the plants. It is the best approach to remove contaminants from soil, sediment and sludge²².

5.2. Rhizofiltration

It is defined as the use of plants, both terrestrial and aquatic, to absorb and

concentrate contaminants from polluted aqueous sources in their roots¹⁵. Terrestrial plants are more preferred because they have a fibrous and much longer root system, increasing amount of root area that effectively remove the potential toxic metals²³.

5.3. Phytostabilization

In this phenomenon, use of plants is to reduce the mobility or bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into food chain¹⁸.

5.4. Phytovolatilization

The use of plants in the uptake of contaminants from soil and waste water, transforming them into volatilized compound and then transpiring into the atmosphere is known as phytovolatilization²⁰.

When using different forms of phytoremediation there are many positive and negative aspects to consider. The advantages and disadvantages are listed in table 2.

6. POTENTIAL OF DIFFERENT AQUATIC PLANTS IN IMPROVING WATER QUALITY

Phytoremediation involves the use of plants to remove, transfer, stabilize or degrade contaminants in soil, sediment and water. Aquatic plants are known for accumulating and concentrating heavy metals from their environment²⁴ and affect metal fluxes through those ecosystems^{25, 26}. Several studies have shown that aquatic plants are very effective in removing heavy metals from polluted water.

Plant assimilation of nutrients and its subsequent harvesting is another mechanism for pollutant removal. Low

cost and easy maintenance make the aquatic plant system attractive for use²⁷. Thus, aquatic plants are increasingly applied as a viable treatment for municipal wastewater. The accumulation of metals in various parts of aquatic plants is often accompanied by an induction of a variety of cellular changes, some of which directly contribute to metal tolerance capacity of the plants²⁸. However, there are some constraints with using aquatic plants such as the requirement for large area of land, the reliability for the pathogen destruction, and the types and end-uses of aquatic plants²⁷. The reason behind the better efficiency of aquatic plants in the removal of heavy metals from water than the terrestrial plants from soil is the soluble form of metals in water. In an aqueous solution, metals are already present in soluble form so accumulation by the aquatic plants can be achieved much easier.

Recently, there has been growing interest in the use of metal-accumulating roots and rhizomes of aquatic and semi-aquatic vascular plants for the removal of heavy metal from contaminated stream²⁹.

6.1. *Pistia stratiotes* (water lettuce) is an aquatic plant that grows rapidly and is also a high biomass crop with an extensive root system that enhances the heavy metals removal. This plant has exhibited different patterns of lead removal and although accumulated at higher concentration of lead mainly in the root system. Mohd Shahrel B Baharadin (2008)³⁰ found that the constructed wetland containing 15-plants recorded the highest removal with 99.28% for lead removal and 65.89% for cadmium removal. Removal at neutral dead *P.stratiotes* appears to be an efficient and low cost alternative to be considered in industrial effluent treatment³¹.

6.2. *Eichhornia crassipes* (water hyacinth) has been listed as most troublesome weed in aquatic system. It is a submerged aquatic plant, found abundantly throughout the year in very large amount and drainage channel system in and around the fields of irrigation. Tiwari *et al.* (2007)³² explained that heavy metals Pb, Zn, Mn show greater affinity towards bioaccumulation in their study. Presence of higher concentration of heavy metals in plants signifies biomagnifications. *Eichhornia crassipes* has a unique property to accumulate heavy metals Cd, Cu, Pb and Zn from the root tissues of the plant^{33, 34}. According to Shao-Wei Liao, (2004)³⁵ water hyacinth is able to absorb and translocate the cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni) in the plant's tissue as a root or shoot. However, it is 3 to 15 times better to locate the elements into the roots than the shoots. Water hyacinth plants had high bioconcentration with low concentrations of the five elements. This shows that water hyacinth can be a promising candidate to remove the heavy metals. This plant also exhibited that Pb accumulated mainly in the roots and the petiole contents comparable at high concentrations than other parts and prolonged immersion⁵. Wolverton [1989]³⁶, Brix (1993)³⁷, and Johnston (1993)³⁸ explained the reason for turbidity reduction i.e. the root hairs have electrical charges that attract opposite charges of colloidal particles such as suspended solids and cause them to adhere on the roots where they are slowly digested and assimilated by the plant and microorganisms. Brix (1993)³⁷ observed that *Eichhornia crassipes* has been used successfully in wastewater treatment system to improve the water quality by reducing the levels of organic and inorganic nutrients. Thus, water hyacinth

would probably have high tolerance and should be capable of removing large amounts of lead³⁹.

6.3. Duckweed is a variety of free-floating aquatic plant at the water surface. It is fast growing and adapts easily to various aquatic conditions. Duckweed commonly refers to a group of floating, flowering plants of the family Lemnaceae. The different species (*Lemna*, *Spirodela*, *Wolffia* and *Wolffiella*) are worldwide distributed in wetlands, ponds and some effluents lagoon. The plants can grow at temperature ranging from 5 to 35°C with optimum growth between 20°C and 31°C^{39, 40}.

The capacity of duckweed (*Lemna* sp.) to remove toxic heavy metals from water are well documented and plays an important role in extraction and accumulation of metals from wastewater. The common aquatic plant *L.minor* can remove up to 90% of soluble Pb from water.

L.minor can grow well in pH from 6 to 9 while the lowest value of pH it can tolerate was in between pH 5-6. The growth rate of *L.minor* was inhibited gradually with increasing concentration of ammonia. However, nitrate had few inhibitory on the growth⁴¹.

Uysal and Taner (2009)⁴² examined the ability of the *L.minor* to remove soluble lead under different pH values (4.5-8.0) and temperature (15-35°C) in presence of different Pb concentrations 0.1-10.0mg/L for 7 days. Their results show Pb accumulation was highest at pH4.5 and then it decreased to pH 6, but it did not change at pH 6-8 range. The maximum lead accumulation was obtained at 30°C. Removal potential is good at pH 5(91%) as compared to pH 8 (87%) for 1 mg/L Pb concentration while at higher concentration of Pb (20 mg/L) removal

potential in acidic medium is good as compared to alkaline pH medium²⁹.

6.4. *Hydrilla verticillata* (Hydrilla) is a submerged aquatic weed that can grow up to the surface and form dense mats in all bodies of water. For removal of contaminants whole plant plays important role. Denny (1980)⁶ observed that the reliance upon roots for heavy metal uptake was in rooted floating-leaved taxa with lesser reliance in submerged taxa. He also observed that tendency to use shoots as sites of heavy metal uptake instead of roots increases with progression towards submergence and simplicity of shoot structure.

Ghosh (2010)⁴³ explained that *Hydrilla verticillata* has strong appetite for both arsenic and cadmium but its appetite for lead is not so strong. Therefore, it is understood that this macrophyte is effective accumulator of arsenic and cadmium but less effective to extract lead from contaminated water.

7. CONCLUSION

Phytoremediation is one new cleanup concept that involves the use of plants to clean contaminated water. Despite all of today's present technology, it seems that foliage plants and trees may be the best means of improving water quality. An interdisciplinary technology can benefit from many different approaches that used aquatic plants are suitable for wastewater treatment because they have tremendous capacity of absorbing nutrients and removes heavy metals from wastewater and hence bring the pollution load down. Boyd (1970a)⁴⁴ observed that aquatic plants are suitable for wastewater treatment because they have tremendous capacity of absorbing nutrients and

removes heavy metals from wastewater and hence bring the pollution load down.

This review shows that aquatic plants such as pistia, duckweed, water hyacinth and hydrilla can have remediatry effects on lead removal from wastewater. Therefore, aquatic plants uptakes on heavy metals are varied based on their species to species as well as metal to metal.

Ghose (2010)⁴³ reported that *Hydrilla verticillata* has strong appetite for both arsenic and cadmium but its appetite for lead is not so strong .So, it is understood that this aquatic plant is effective accumulator for arsenic and cadmium but less effective to extract lead from contaminated water.

On the other hand Duckweed (*L.minor*) biomass presented the highest mean removal percentage and *Pistia stratiotses* the lowest for all metals tested Pb^{2+} , Ni^{2+} , Cd^{2+} , Cu^{2+} and Zn^{2+} ³¹. Water hyacinth (*Eichhornia crassipes*) may serve the purpose for phytoremediation⁴⁵ although its use may sometimes cause serious ecological problem.

Duckweed appear to be better alternative and have been recommended for wastewater treatment as they are

- (1) Duckweed cold tolerance allows it to be used for year-round wastewater treatment in areas where tropical aquatic plants, such as water hyacinth, can only grow in summer⁴⁶.
- (2) More easily harvested than algae.
- (3) Capable of rapid growth and wide range of pH⁴⁷.

This review revealed that duckweed is effective in removal of lead from the polluted water by simply harvesting the plant. More research is needed to better understand the potential use of aquatic plants for lead removal from lead contaminated water.

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Table 1:- Conventional method for removal of Lead ²

Methods	Mechanism	Advantages	Disadvantages
Reverse Osmosis	Separated by a semi-permeable membrane at a pressure greater than osmotic pressure caused by the dissolved solids in wastewater.	The ability to reduce the concentration of other ionic contaminants, as well as dissolved organic compounds.	Clogging of membrane and expensive.
Ion Exchange	Metal ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin. Ion exchange uses mainly hydrocarbon derived polymeric resins.	Effective removal of dissolved lead and cadmium in the acidic pH range.	High cost and partial removal of certain ions.
Chemical Precipitation	Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers.	It is cost effective technique and can be performed by a simple pH adjustment.	Large amount of sludge containing toxic compounds produced.
Electrodialysis	The ionic components (heavy metals) are separated through the use of semi-permeable ion selective membranes. Application of an electrical potential between the two electrodes causes a migration of cations and anions towards respective electrodes.	Osmotic pressure is not a factor in ED system, so the pressure can be used for concentrating salt solutions to 20% or higher .	Formation of metal hydroxides clogs the membrane.

Table 2:- Advantages and Disadvantages of different forms of Phytoremediation.

Methods	Advantages	Disadvantages
Phytoextraction	<ul style="list-style-type: none"> - Cost of phytoextraction is fairly inexpensive. -The contaminant is permanently removed from the soil¹⁶. 	<ul style="list-style-type: none"> -Metal hyperaccumulators are generally slow- growing with a small biomass and shallow root systems. -Plant biomass must be harvested and removed, followed by metal reclamation or proper disposal of the biomass¹⁷.
Rhizofiltration	<ul style="list-style-type: none"> -The ability to use both terrestrial and aquatic plants for either <i>in situ</i> or <i>ex situ</i> applications. -The contaminants do not have to be translocated to the shoots¹⁶. 	<ul style="list-style-type: none"> -The constant need to adjust pH. -Plants may first need to be grown in a greenhouse or nursery¹⁶.
Phytostabilization	<ul style="list-style-type: none"> - The disposal of hazardous biomass is not required. -The presence of plants also reduces soil erosion and decreases the amount of water available in the system¹⁶. 	<ul style="list-style-type: none"> -Contaminant remaining in soil. -Application of extensive fertilization or soil amendments, mandatory monitoring is required¹⁷.
Phytovolatilization	<ul style="list-style-type: none"> -Contaminants could be transformed to less-toxic forms, such as elemental mercury and dimethyl selenite gas. -Contaminants or metabolites released to the atmosphere might be subject to more effective or rapid natural degradation processes such as photodegradation¹⁴. 	<ul style="list-style-type: none"> -The contaminants or a hazardous metabolite might accumulate in vegetation such as fruit or lumber. - Low levels of metabolites have been found in plant tissue¹⁷.