Journal of Agricultural Technology 2012 Vol. 8(1): 1-11
Available online http://www.ijat-aatsea.com
ISSN 1686-9141

Phytoremediation of lead from wastewater using aquatic plants

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Divya Singh, Archana Tiwari and Richa Gupta (2012) Phytoremediation of lead from wastewater using aquatic plants. Journal of Agricultural Technology 8(1): 1-11.

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 one of the most toxic pollutants which show hazardous effects on all living livings. Lead is one such pollutants which disrupts the food chain and is lethal even at low concentrations. The prevailing purification technologies used for removal of contaminants from wastewater 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 was 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.

Introduction

An excess level of heavy metals are exposed into environment, for example by industrial waste and fertilizers causes serious concern in nature as they are non- biodegradable and accumulate at high levels. 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 health (Akpor and Muchie, 2010). The common heavy metals like Cd, Pb, Co, Zn and Cr etc. are phytotoxic at both low concentration as well as very high concentration are detected in waste water. If these metals are presented in sediments then these 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).

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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 phytoplanktons. Hence, proper treatment of lead from soil and industrial wastewaters is very important. Several conventional methods are used for the removal of lead from wastewater includes chemical precipitation, ion exchange and reverse osmosis etc. but major drawbacks with such treatments are produces large amount of sludge and may be ineffective or expensive processes. So, the search for a new, simple, effective and ecofriendly technology involving the removal of toxic heavy metal from wastewater has directed attention towards phytoremediaton. Some of the aquatic plants have been 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.

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 lead (Oram). As other source is lead paint, batteries, lead piping used in water distribution system.

Effects of lead

Lead is one of the most abundant toxic metals that pose a serious threat to human beings, animals and phytoplanktons. In human, it is absorbed directly into the blood stream and is stored in soft tissues, bones and teeth (95% in bones and teeth) (David *et al.,* 2003). It can also affect the kidney and most importantly the nervous system and brain. Thus, lead can accumulate over a lifetime and it causes diseases such as anemia, encephalopathy, hepatitis and nephritic syndrome. It exceeds the WHO (2004) allowable standard 0.15 mg/L 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 (US EPA, 2005).

Lead also influencing 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 like spinal desformity and blackening in the tail region (European commission, 2000).

Conventional methods for treatment of lead

Heavy metals such as lead, mercury, arsenic, copper, zinc and cadmium are highly toxic when adsorbed into the body (Garty, 2001). Lead, one of the earliest metals recognized and used by humans, has a long history of beneficial use to humankinds, but recognized as toxic and as posing a widespread threat to humans and aquatic life (Rashed, 2003). 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 exist for the removal of lead from polluted water that methods were as follows:-

Table 1. Conventional method for removal of Lead

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 can be justified by their low costs and can be performed by a simple pH adjustment.	The 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.	The formation of metal hydroxides, which clog the membrane.

Source:- Akpor and Muchie (2010)

Phytoremediation

Phytotechnologies an emerging technique during the last two decades and plant based bioremediation technologies that 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 has actually implemented for the last 300 years (Henry, 2000). The generic term "Phytoremediation" consists of the Greek prefix phyto (plant), attached to the Latin word remedian (to correct or remove an evil) (Prasad, 2004). Phytormediation 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 intensive (Cunningham *et al.,* 1996). Phytoremediation has also been called green remediation, botano-remediation, agro remediation and vegetative remediation (Erakhrumen, 2007). It is a less destructive to the environment, cost effective, aesthetically environmental pollutants removal approach most suitable for developing countries (Pivertz, 2001). The plant used in the phytoremediation technique must have a considerable capacity of metal absorption, its accumulation and strength to decrease the treatment time (Mudgal *et al.,* 2010). There are several ways by which plants cleanup or remediate contaminated sites.

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 sludge (Raskin and Ensley, 2000).

Rhizofiltration

It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate and contaminants from polluted aqueous sources in their roots (Jadia and Fulekar, 2009). Terrestrial plants are more preferred because they have a fibrous and much longer root system, increasing amount of root area that effectively removed the potentially toxic metals (Nandakumar *et al.,* 1995).

Phytostabilization

In this phenomenon use of plants to reduce the mobility bioavailability of pollutants in the environment, thus preventing their migration to groundwater or their entry into food chain (Cunningham *et al.,* 1996).

Phytovolatilization

The use of plants to uptake of contaminants from soil and waste water, transforming them into volatilized compound and then transpiring into the atmosphere is known as phytovolatilization (Pivertz, 2001). When using different forms of phytoremediation there are many positive and negative aspects to consider. The advantages and disadvantages are listed below in table 2.

Table 2. Advantages and Disadvantages of different forms of Phytoremediation

Methods	Advantages	Disadvantages
Phytoextraction	1. Cost of phytoextraction is fairly inexpensive. 2. The contaminant is permanently removed from the soil (Henry, 2000).	1. Metal hyperaccumulators are generally slow- growing with a small biomass and shallow root systems. 2. Plant biomass must be harvested and removed, followed by metal reclamation or proper disposal of the biomass (Prasad, 2004).
Rhizofiltration	1. The ability to use both terrestrial and aquatic plants for either *in situ* or *ex situ* applications. 2. The contaminants do not have to be translocated to the shoots (Henry, 2000).	1. The constant need to adjust pH. 2. Plants may first need to be grown in a greenhouse or nursery (Henry, 2000).
Phytostabilization	1. The disposal of hazardous biomass is not required. 2. The presence of plants also reduces soil erosion and decreases the amount of water available in the system (Henry, 2000).	1. Contaminant remaining in soil. 2. Application of extensive fertilization or soil amendments, mandatory monitoring is required (Henry, 2000).
Phytovolatilization	1. Contaminants could be transformed to less-toxic forms, such as elemental mercury and dimethyl selenite gas. 2. Contaminants or metabolites released to the atmosphere might be subject to more effective or rapid natural degradation processes such as photodegradation (Prasad, 2004).	1. The contaminants or a hazardous metabolite might accumulate in vegetation such as fruit or lumber. 2. Low levels of metabolites have been found in plant tissue (Prasad, 2004).

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 (Outridge and Noller, 1991) and metal fluxes rough those ecosystems (Jackson *et al.,* 1994 and St-Cyr, 1994). 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 are another mechanism for pollutant removal. Low cost and easy maintenance make the aquatic plant system attractive to use (Kanabkaew and Puetpaiboon, 2004). 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 plants (Prasad *et al.,* 2001). 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 plants (Kanabkaew and Puetpaiboon, 2004). One reason that the aquatic plants are able to remove of the heavy metals from the water than terrestrial plants from soil is the soluble form the metals in water. Metals present in a soluble form in soils before plants can absorb them. In an aqueous solution, metals are ready in soluble form so accumulation by the 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 stream (Gallardo *et al.,* 1999).

Pistia stratoites (water lettuce) is an aquatic plant that grows rapidly and a high biomass crop with an extensive root system that able to enhance the heavy metals removal. This plant exhibited different patterns to lead removal and although accumulated at high concentrations mainly in the root system. Mohd. Shahrel B Bahradin (2008) found that the constructed wetland containing 15-plants recorded the highest removal with 99.28% for lead removal and 65.89% for cadmium removal at neutral condition (pH 7) showed better removal compared to the base and acidic conditions.

The sorption of diluted heavy metal ions, in particular Pb and Cd by dead *P.stratiotes* appear to be an efficient and low cost alternative to be considered in industrial effluent treatment (Miretzky *et al.,* 2005). *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) 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 the biomagnifications. *Eichhornia crassipes* is the unique property to accumulate heavy metals Cd, Cu, Pb and Zn from the root tissues of the plant (Muramoto and Oki, 1983 and Nor, 1990).

Some studies have been reported on the use of dried plant material as a potential biosorbent in industrial to remove Lead (II) in the wastewater. Liao and Cheng (2004) 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 immersion. The relatively low leaf contents, until drastic conditions are used, indicated the presence of a prevention mechanism to inhibit Pb uptake (David *et al.,* 2003). Wolverton (1989), Brix (1993) and Johnston (1993) explained that 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) 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, the water hyacinth would probably have high tolerance and should be capable of removing large amounts of lead (Sutcliffe, 1962).

Duckweed is a variety of aquatic plant free-floating 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 *Wolfiella*) 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 and across a wide range of pH (3.5-10.5) (Sutcliffe, 1962 and Cayuela *et al.,* 2007). Wetlands and ponds are the most common sites to find duckweed.

The capacity of aquatic plant such as 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 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 growth (Chong *et al.,* 2003).

Uysal and Taner (2009) 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 0.1-10.0 mg/L for 7 days. Their results show Pb accumulation was highest at pH 4.5 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 medium (Gallardo *et al.,* 1999).

Hydrila 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 and Wilkins (1987) 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. Maria T. Gallardo (1999) found that after one week of exposure to concentrated lead solution shown maximum uptake (98%) of Pb by hydrilla.

Conclusion

Phytoremediation is one new cleanup concept that involves the use of plants to clean contaminated environments. 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. This review showed 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. Duckweed appear to be better alternative and have been recommended for wastewater treatment because it has capability of rapid growth on wide range of pH and cold tolerable to grow throughout the year but aquatic plants, such as water hyacinth, can only grow in summer. Duckweed produces biomass faster than any other aquatic plant and has clear potential as an alternative for accumulation of heavy metals. This study revealed that the duckweed (*L.minor*) showed a better lead removal than others from polluted water and may be helpful in research studies and phytoremedial approaches.

Acknowledgement

The authors are grateful acknowledge to the School of Biotechnology, University of Bhopal for providing help and assistance.

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(Published in January 2012)