CHAPTER-27

AQUATIC MACROPHYTES FOR THEIR PROSPECTIVE USE IN PHYTOREMEDIATION OF HEAVY METAL CONTAMINATION: A MINI REVIEW

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Summary

Phytoremediation, a form of bioremediation involves naturally the direct use of green plants naturally to uptake or absorption of pollutants through roots and their translocation to the upper part of the plant is one of the feasible options among the phytotechnologies applied to remove heavy metals concentration from the contaminated water bodies. Aquatic macrophytes possess certain characteristics and features and can tolerate the influence of environmental conditions. An attempt has been made in this chapter to discuss the potential use of some aquatic macrophytes like *Ipomoea aquatica* Forsk, and *Eichhornia crassipes*, (Mart.) Solms, *Typha angustata* Bory & Chaub, *Hydrilla verticillata* (L.f.) Royle, *Pistia stratiotes* and their prospective use in phytoremediation.

Keyword: Bioremediation, Phytoremediation, Environmental pollution, aquatic macrophytes

Introduction

Bioremediation is defined as a treatment that utilizes naturally occurring organisms to break down hazardous substances into less toxic or non-toxic substances" which includes bioaccumulation, biosorption, and phytoremediation (Vijayaraghavan and Balasubramanian, 2015). Phytoremediation involves the direct use of green plants naturally to uptake or absorption of pollutants

E-Book ISBN: 978-81-981814-9-7, DOI: https://doi.org/10.34256/adbor.25.27.215

through roots and their translocation to the upper part of the plant (Sharma et al. 2015). Several organic and/or inorganic pollutants (metals, persistent organic pollutants, pesticides) can be removed with the help of phytoremediation from contaminated soil, sludge, sediments, and water (Bhatia and Goyal 2014; Bauddh et al., 2015), several plant species have been used in remediation of contaminated soil and water (Sharma et al., 2015).

The plant species to be used in phytoremediation must have certain characteristics and features (Valipour and Ahn, 2016) like -

- High growth rate
- Extensive root system
- Adaptation to the different habitats
- High biomass yield and high tolerance with the ability to accumulate pollutants in the above-ground parts

However, there is influence of some environmental factors on the plant growth rate (Gupta et. al., 2012) like -

- Temperature
- pH
- Solar radiation
- Water salinity

Which can influence its performance in phytoremediation. Therefore, the impact of these environmental factors is associated directly with the growth rate, size and weight of aquatic plants and also the availability of nutrient affects the growth and performance of aquatic plants. The disadvantage of phytoremediation in spite of all these environmental factors is the long removal time (Parmar and Singh, 2015) which can be overcome by a combination of more than one phytoremediation technique.

Phytoremediation of toxic heavy metals by aquatic macrophytes

Nowadays heavy metal pollution in the aquatic environment has become a topic of more concern all over the world. Therefore, the diverse group of aquatic macrophytes having the potential to hyper-accumulate many heavy metals can be exploited in the removal of heavy metals (Rai, 2008) with the help of sustainable, cost-effective, and innovative Phytoremediation technology for the treatment of contaminants (Pilon-Smits and Freeman, 2006). The presence of highly toxic heavy metals in water bodies which are considered to be lethal to the organisms and can contaminate the food chain (He, et al. 2005). The aquatic plants used in the phytoremediation of toxic trace elements by various workers and suggested their uses.

Prasad et. al., (2001, 2005) studied aquatic plants for biomonitoring toxic trace Cd, Cu, Cr, Pb, Hg, Fe, Mn, Zn, Ni, and Co elements in a varied range of toxicity bioassays. Several angiosperm families having aquatic and semiaquatic environments like Ranunculaceae, Cyperaceae, Haloragaceae, Potamogetonaceae, Hydrocharitaceae, Najadaceae, Juncaceae, Pontederiaceae, Lemnaceae, Typhaceae, Zosterophyllaceae, etc. were studied and based on the results they concluded that the macrophytes accumulate metals from water and produce an internal concentration which was supposed to be several-fold larger than their surroundings and play a vital role in the biogeochemical cycling of trace metals. The submerged plants are reported to accumulate trace metals to the tune of 103-104 or reduce the water velocity in polluted lakes with heavy metal concentrations thus increasing sedimentation of the suspended fine particulate trace metals, which otherwise are toxic to the biota when present in the interstitial waters in available form.

Kumar et. al., (2008) studied macrophytes for phytoremediation carried out at Pariyej reservoir, in Gujarat State, India, for assessing the heavy metal contamination and accumulation in certain aquatic macrophytes, species: *Ipomoea aquatica* Forsk, *Eichhornia crassipes*, (Mart.) Solms, *Echinochloa colonum* (L.) Link, *Typha angustata* Bory & Chaub, *Nelumbo nucifera* Gaerth. *Hydrilla verticillata* (L.f.) Royle, and *Vallisneria spiralis* L. were analyzed for Co, Cd, Ni, Cu, Pb, and Zn contamination. *Nelumbo nucifera* among used aquatic plants was reported with a larger accumulation of heavy metals and the *Echinochloa colonum* with a poor accumulation of heavy metals. The arrangement of six heavy metals in the lakes was in the following descending order: Zn > Cu > Pb >Ni > Co > Cd, compared with the standard, normal, and critical toxicity range in plants. The normal range metals were Cd and Pb whereas Co and Ni were within the critical range. Zn and Cu showed alarming toxicity levels in the Pariyej reservoir. They reported two most useful plant species *Typha angustata* and *Ipomoea aquatica* as bioremediants in phytoremediation study due to their ability to accumulate heavy metals.

Agunbiade et. al., (2009) examined the potential of *Eichhornia crassipes* for its phytoremediation potential from contaminated coastal areas in Ondo State, Nigeria by assessing plant to the ten metals, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, V and Zn to evaluate the enrichment factor (EF) and translocation factor (TF) in the plant. The results of EF and TF revealed accumulation of toxic metals Cr, Cd, Pb, and As at the root and the shoot to a high degree, creating large biomass on the water surface and can serve as a plant for both rhizofiltration and phytoextraction in phytoremediation technology.

Srivastava et. al. (2009). studied *Hydrilla verticillata* (L.f.) Royle plants for the accumulation of Zn. The plant was supplemented with Zn (0 - 5 000 μM) for 2 and 7 d. At 5000 μM and after 2 and 7 days Zn accumulation was reported at about 7.60 and 18.07 mg(Zn) g-1(d.m.). Based on this high capacity of accumulation of Zn by *Hydrilla verticillata* proved to be the best phytoremediater. Narang et. al., (2011) studied phytoremediation of mercury using *Eichhornia crassipes* and reported a maximum accumulation of mercury (92.21 μg g–1 dry wt) in the roots of plants treated with 1000 μg l^{-1} concentration of mercuric acetate on 14^{th} day of treatment. The bioconcentration factor (BCF) was found to be highest for the lowest mercury concentrations (1 μg l–1) in the medium.

Singh et. al. (2012) reviewed the phytoremediation of Lead from wastewater using aquatic plants and concluded that the phytoremediation technology is eco-friendly economically sound and viable technology than the current methods which were very expensive. Jaikumar (2012) reviewed *Eichhornia crassipes* for its phytoremediation potential with the wastewater sewage discharge to the Velachery Lake near southern Chennai and proposed to control the pollution through water hyacinth (*Eichhornia crassipes)* by Phytoremediation technology to solve the sewage pollution in the lake for eco-friendly Aquaculture and Tourism.

Vesely, et. al. (2012) examined the influence of different chelates applied in the soil primary on Al and secondary on Fe and Mn mobilization and their removal from solution by comparing the efficiency of 10 μM tartaric acid and 3 μM EDTA in the soil washing process and accumulation potential of *Pistia stratiotes* in rhizofiltration process. The plant response to the toxic element Al and other elements Fe and Mn was determined by the nitrogen and free amino acids content in plants. The results showed a decrease in the efficiency of chelates in order 10 μM tartaric acid > deionized water > 3 μM EDTA for all studied elements and *P. stratiotes* was able to remove up to 90% of elements during the 15 days. Roots were reported with higher content of toxic elements Al, Fe, and Mn than in the leaves with the increased time. The trend of accumulation of Al with Fe ($R^2=0.89$) was established and the toxicity impact of high levels of Al was observed by increased free amino acids (AA) level.

Borker et. al. (2013) investigated the effect of cadmium chloride on some biochemical parameters and the potential of cadmium uptake of *Eichhornia crassipes* and observed that the species is more favorable to tolerate higher concentrations of heavy metals and showed higher accumulation capacities concerning cadmium through phytoremediation. Sukumaran (2013) studied a comparative assessment of the efficiency of aquatic weeds like *Typha latifolia, Eichhornia crassipes, Salvinia molesta* and *Pistia stratiotes* to treat the effluents under laboratory conditions and observed the bioconcentration factor (BCF) of lead, copper, arsenic and cadmium by the floating and emergent plants *Eichhornia crassipes* and *Typha latifolia* based constructed wetlands and concluded that Lead from Titanium sponge industry effluent was removed prominently by *Eichhornia crassipes* than the emergent plant *Typha latifolia* and the prominent removal of other metals only by *Typha latifolia*.

Gandhi et. al. (2013) studied the phytoremediation of chromium and fluoride in industrial wastewaters by using an aquatic plant species *Ipomoea aquatica* and reported that the percent removal of Fluoride and Chromium as examined every 24-hour time interval with a high percentage removal of chromium (VI) than the percent removal of Fluoride. Based on the findings it was concluded that the plant *Ipomoea aquatica* followed the phytoextraction mechanism in the removal of chromium and it followed the phytovolatization mechanism in case of fluoride removal.

Das et. al. (2013) examine the extent of cadmium (Cd) accumulation with its probable impact on the physiological and biochemical basis of heavy metal tolerance in *Marsilea minuta* Linn. with hydroponic culture method and a substantial deterioration of the plant biomass was recorded after Cd salt (0 μM, 50 μM, and 100 μM) was allowed to absorb by the plants for prolong days. Roots were reported with more absorbed metals than the leaves also the significant rise of antioxidative enzymes was found to be the regulator and responsible for metal tolerance to Cd-induced oxidative stress in *Marsilea minuta* Linn.

Li et. al. (2013) investigated the absorption capability of the aquatic plant *Pistia stratiotes* L. (water lettuce) towards contaminants in water and its subsequent use in wetlands constructed for wastewater treatment. They studied the effects of Cd on root growth, accumulation of Cd, antioxidant enzymes, and malondialdehyde (MDA) content in *P. stratiotes*. The results specified that *P. stratiotes* have a substantial capability to accumulate Cd and superoxide dismutase (SOD) and peroxidase (POD) activities were induced by Cadmium than catalase activity suggesting an improved defense mechanism against Cd-induced oxidative damage provided by SOD and POD and the accumulation of Cd promoted MDA production. Yuanqing et. al. (2013) investigated *Pistia stratiotes* L. (water lettuce) for the removal of heavy metals lead (Pb) and chromium (Cr from a metal solution. *Pistia stratiotes* was grown at four concentrations of Cr and Pb, i.e. 5.0, 10.0, 15.0, and 20.0 mg/L, respectively in a single metal solution and the removal of up to 80% of Cr and 93% of Pb after 10 days was reported with the bioconcentration factor (BCF) value in the range between 299 and 1026 for Cr and between 1672 and 1852 for Pb, respectively. The amount of BCF in *Pistia stratiotes* showed that the removal of Pb was higher than the removal of Cr with more accumulation of heavy metals in roots than leaves suggesting the capability of aquatic macrophytes to lead and chromium removal from moderately contaminated waters.

Bakar et al. (2013) tested three aquatic plants *(Cabomba piauhyensis, Egeria densa*, and *Hydrilla verticillata*) for heavy metal As, Al, and Zn phytoremediation. They reported higher accumulation by plants *E.densa* and *H. verticillata* (95.2%) arsenic and (93.7%) Zinc whereas *C.piauhyensis* showed (83.8%) aluminium accumulation and concluded that *H.verticillata* was found to the most suitable plant for phytoremediation among three aquatic plants studied. Putra et. al. (2014) examined a combination of an electro-assisted (EAPR) system and hydroponic phytoremediation for the speedy removal of Pb^{2+} and Cu^{2+} from contaminated water at a laboratory scale experiment. To assess the possible rapid removal and uptake of lead and copper concentration by water lettuce (*Pistia stratiotes* Linn.) a hydroponic setting was used. The efficiency of two–dimensional (2*D*) of cathode–pot electrode was introduced in the study and the comparisons of the results of the hydroponic EAPR system with the plants exposed to the lead and copper contaminated water by using phytoremediation for the 7 d process. They found that high concentrations of lead and copper were accumulated by roots and also the chlorophyll content in treated plants with high lead concentrations for EAPR system revealed that the water lettuce could be the better plant to cope with lead and copper stress. The general metal uptake in the plant system was higher under EAPR system than one compared with the phytoremediation process.

Srivastava et. al. (2014) applied a combinational approach and conducted a field experiment to evaluate the performance of the five plants singly and in all possible combinations of two plants, for As removal from 4 L of 2500 mg L^{-1} As in 30 days. Experimental results showed an increase in growth rate (19%) in *Hydrilla* as compared to control, while there was a decline in growth rate by other plants under As stress. Between different combinations, *Ceratophyllum* + *Lemna*, *Hydrilla* + *Ceratophyllum,* and *Hydrilla* + *Wolffia* showed higher growth in As (92%, 43%, and 33%, respectively) than under control conditions. Total As removal (mg) in 30 days was reported maximum for *Ceratophyllum* + *Lemna* (4365) followed by *Hydrilla* + *Ceratophyllum* (3326) and *Hydrilla* + *Wolffia* (1896). *Hydrilla* always contributed more than 50% in all combinations of plants. The study revealed the use of *Hydrilla*/*Ceratophyllum* in combination and also proposes screening of different such combinations of two or more plants for improved application of phytoremediation technology in the field. Brahaiţa et. al. (2015) studied the capacity of *Lemna minor* and *Pistia stratiotes* macrophytes to decontaminate waters polluted with heavy metals, with the help of a process of phytoextraction and phytoaccumulation as *in-situ* bioremediation technology for the waters of the decantation ponds originated from the mining industry.

Reddy et. al. (2015) carried out phytoremediation studies on sugar industrial effluents by using various hydrophytes plant species *Eichhornia crassipes*, *Pistia stratiotes*, *Nelumbo lutea,* and *Marsilea quadrifolia* for the removal from the contaminated aqueous environment. Based on the results it was concluded that phytoremediation is a very effective and eco-friendly technology for the treatment of industrial effluents and all the test plants studied efficiently reduced almost all the physical, chemical, and biological factors of the sugar industry effluent water to a substantial level. Putra et. al. (2016) evaluated lead (Pb) and copper (Cu) absorption using water hyacinth (*Eichhornia crassipes* (Mart.) Solms) by using EAPR (electro-assisted phytoremediation) method and found remediation of copper (Cu) and Lead (Pb) for 7 d of wastewater treatment. Their results showed that the absorption of Pb by water hyacinth based on the EAPR process was much lower than that in the phytoremediation whereas absorption of Cu was very high in the plant root.

Rai and Singh (2016) reviewed on multifaceted utility of *Eichhornia crassipes* from the Asia Pacific region and discussed the cost-effective and eco-friendly utilization of plants for the development of the technology used in the accumulation and absorption of the heavy metals and other nutrients under phytoremediation. Sarangam et al.(2016) studied phytoremediation of chromium by using *Ipomea cornea, Jatropha gasifolia,* and *Heliotropium curassavicum* L. plants for Chromium accumulation study with hydroponic culture method. Phytoaccumulation of Cr was studied on the initial day and after the 30th day of growth. The results obtained on bioaccumulation showed a linear relationship between increased concentration of Chromium accumulation and Cr treatment concentration. *Heliotropium curassavicum* was found to have with maximum Cr^{+6}

concentration than in *Ipomoea carnea* and *Jatropha gasifolia*. Based on the results it was concluded that *Ipomoea cornea* and *Heliotropium curassavicum* have enhanced accumulation ability for Cr remediation.

Victor et al. (2016) evaluated the capacity of zinc (Zn), lead (Pb), copper (Cu), cadmium (Cd) and chromium (Cr) uptake and bioaccumulation factor of *Eichhornia crassipes* and *Pistia stratiotes* from wastewaters and reported metals accumulation in water hyacinth and water lettuce in the order of Zn> Pb> Cr > Cu> Cd. The roots of *Eichhornia crassipes* proved better accumulators of the metals than leaves. The metals Pb, Zn, and Cu were reported with a Bioconcentration factor (BCF) of more than 1000 in two species whereas the translocation factor (TF) of Pb, Cr, Zn, and Cu in water hyacinth was found to be low (0.07 – 0.46) except for Cd (3.35). *Eichhornia crassipes* and *Pistia stratiotes* were found to be more effective in the removal of heavy metals from wastewater. Hassan et. al. (2016) studied the phytoremediation capacity of *H.verticellata* for different concentrations of lead 10, 20, and 30 ppm and were used in three replications for each concentration for 30 days. The results showed that the plant can remove 30 ppm of Pb. Significant removing ability by a plant for Pb, in all concentrations 10, 20, and 30 ppm during the experiment period, in the root more than the stem and leaf. It was root > leaf > stem respectively. Metal Pb accumulation in the root was 10.25ppm, in the leaf 9.18ppm and the lowest removal ratio was 8.01ppm in the concentration 30ppm for 30 days.

Rachmadiarti and Trimulyono (2018) studied the phytoremediation capability of Water Clover (*Marsilea crenata* (L). Presl. in synthetic Pb solution and resistance of water clover was determined by the Pb distribution and the percentage of free amino acids in plant tissues. Hydroponically grown Water clover plants of equal size were exposed to 0, 1, 5, and 10 mgL^{-1} of Pb concentration for 10, 20, and 30 days. The Pb concentration was measured by inductively coupled plasma (ICP) and the free amino acid was analyzed by HPLC (High-Pressure Liquid Chromatography). The concentration of Pb in plants and its free amino acid content indicated resistance to Pb accumulation and affected their growth required for phytoremediation. Root tissues reported with highest Pb concentration followed by stem and leaves. Moubark et. al. (2018) investigated the macrophyte *Hydrilla* as a phytoremediator and reported that the purity of water increases by augmenting the reduction of nitrite and ammonia in static river water samples without affecting the concentration of nitrate and phosphate due to the presence of *Hydrilla*. The results showed the capability of *Hydrilla* as a phytoremediator as it improves the nitrogen condition of river water.

Conclusion

With the increasing global population, the challenge of providing clean water for communities will be greater in the future. The demand for human needs generates huge pressure on limited natural freshwater resources globally. Increased population and rapid industrialization resulted in to generation of wastewater discharge into water environments like lakes, rivers, reservoirs, etc.

which contain mainly non-biodegradable heavy metal concentrations including many other toxic pollutants producing serious hazards to human populations. Efforts to educate, and communicate the population globally on the concerns of water pollution by amendments in the law, policies, and regulations have been prepared and implemented by developed countries to reduce the environmental pollution. Also, the development of eco-friendly technologies for the remediation of pollutants started as a need of the future. Ion exchange, reverse osmosis, electrolysis, precipitation, and adsorption are the conventional technologies used so far for wastewater treatment which are inefficient, expensive, and generate large amounts of waste thus there is a need for an alternative cost-effective technology.

To overcome the issues related to water pollution, bioremediation seems to good option in which treatment involves naturally occurring organisms to break down hazardous substances into less toxic or non-toxic substances. It includes phytoremediation, bioaccumulation, and biosorption. Phytoremediation is mainly concerned with the natural and direct use of green plants to uptake/ adsorption of pollutants. Aquatic macrophytes discussed in this chapter could be of great potential in removing heavy metal concentration from different types of water bodies concerning phytoremediation.

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