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A Review of Water Quality Improvement with the Help of Aquatic Macrophytes

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Abstract

Metallic elements in the water have been rapidly increased due to the high population growth, urbanization, and industrialization. Metals which have high density and high atomic weight are non-degradable, they persist in various environs, have the potentiality to enter the food chain or food web. Due to their toxic nature, heavy metallic contamination has become the most hazardous pollutant in the growing world. Therefore, reduce or remove water contamination is the predominant importance. Utilization of plants to refine water quality is a green technology, which is an effective method, environment-friendly and consumes fewer energy inputs, and also carried out less amount of cost. In this review article, we enlighten the potential of various aquatic macrophytes to reduce or remove the heavy metal contaminants from the aquatic eco-system.



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Keywords

Aquatic Macrophytes, Green Technology, Heavy Metals, Water Quality Improvement

Introduction

Environmental degradation is caused because of urbanization, industrialization, and high population growth. Due to the high pollution rates and their effects on various environs, many developed countries decided to modify environmental policies and decrease pollution rates and their effects.¹ "The direct discharge of water from any industrial or domestic source is called Wastewater".² Various environmental difficulties, which related to pollution are created by unstructured inorganic chemicals for instance cyanide, toxic, or non-toxic heavy metals, nitrogen, phenols, phosphorous, hazardous organics, etc. These chemicals are origin from industrial and residential sources which is polluting the wetland at a massive place.³ In water pollution, heavy metal pollution is the most severe predicaments in the developing world. Environs are hazardous and highly toxic for plants, animals, and also humans when the heavy metallic elements are present. Wet and dry waste deposition in the benthic zone of the aquatic bodies can raise the limit of various toxic or non-toxic metals that have high relative density and high relative atomic weight in the aquatic ecosystem,

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which developing the accumulation of different components in the environs.^{4,5} Many sources are liable for the deposition of heavy metals in environs. Sources, such as mining, municipal sewage, smelter, tanneries, textile industry, and chemical industry.4,5 Pollutants, which have high relative density and high relative atomic weight are difficult to isolate from the abiotic components of the environment because it cannot be degraded into harmless small molecules like organic pollution.⁶ The food chain and the food web become highly hazardous for living things when the heavy metal present in it.7 Usually, emitted hazardous metallic elements in aquatic water bodies are Arsenic (As), Cadmium(Cd), Copper (Cu), Chromium (Cr), Mercury (Hg), Nickel (Ni), Lead (Pb), Zinc (Zn), etc. To decrease or isolate heavy metallic elements from the contaminated water and sediment was done with the help of various possible physical mechanisms and chemical applications, but these types of technologies are costly, energyintensive, and metal-specific. Tam & Wong (1994) and also Eger (1994) proposed an effectual method to reduce or remove heavy metallic elements from the aquatic ecosystem.^{8,9} Utilization of green plants to refine water quality is green technology, which is an effective method, environment-friendly and consume fewer energy inputs, and also carried out less amount of cost. Lots of research through several researchers had been carried to amend water quality through biotic components especially microorganisms, terrestrial plants, and aquatic plants, they concluded green plants have great potential to reduce or remove the hazardous metallic element from the contaminated ecosystem.^{10,11,12,13,14}

The Role of Wetland Plants to Improve Water Quality

"Wetland is the transitional area between terrestrial and aquatic ecosystem". It means wetland is neither truly aquatic nor terrestrial; it is possible that wetlands can be both at the same time depending on seasonal variation. Wetlands are the natural asset, which is the most productive and adaptive ecosystems on the Earth also provides many important services to the society 15 and cover between 1 to 9 % of the Earth's surface with 56% found in tropical and subtropical regions of the world and also express rich diversity due to their genesis, geographical location, water chemistry, dominant species, and soil or sediment characteristics.¹⁶ Aquatic plants plays a significant role to improve water quality, reduce flood and storm damage and also support high levels of biological diversity, therefore known as "Kidney of Landscape" or "biological supermarket"17 Macrophytes are ordinarily present in aquatic bodies all over the Earth. Natural processes or urban and agricultural runoff increases the nutrient into the water bodies, which supports the luxurious growth of macrophytes, algae, etc.¹⁷ For the few decades, Macrophytes were extensively utilized to improve water quality as well as to reduce or remove the heavy metals and other contaminants from wastewater.¹⁸ At the global stage, broad research is being conducted by multiple researchers to study the efficiency of various aquatic macrophyte species to reduce or remove the contaminant from the various aquatic environments. Researchers scientifically proved that green macrophytes are significant to remove the organic components from the aquatic ecosystem.^{19, 20, 21, 22} Macrophytes play a promising and substantial role to decrease trace metallic elements from the aquatic ecosystem.²³ Hazardous contamination can isolate or decrease from the aquatic environment with the services of microorganisms and various aquatic plant species. Macrophytes both live and dead, are suitable for the uptake and absorption or detoxifying heavy metals and various contaminants from the water bodies²⁴ because they have a rapid growth rate, excess amount of biomass production, high adaptive nature to various habitats, and adventitious root system which increases the absorption capacity of macrophytes.²⁵ Macrophytes are practically applied to remove multi pollutants from the single water bodies and some hyper accumulator species are applied as sources of valuable heavy metals.²³ A comprehensive review on "Water quality improvement through macrophytes" given by Dhote and Dixit (2009), they discuss the potential of various aquatic plants to purify wastewater and concluded that wetland plants are suitable for wastewater treatment because macrophytes have an enormous potentiality to uptake nutrients and other contamination from the wastewater and decrease the water pollution level.26 Mohammed et al., (2005) presented a review paper on the utilization of aquatic macrophytes and they noted that the macrophytes offered multiple benefits such as food, biofertilizer, and sources of medicine. They also remarked about the perception belief that most aquatic macrophytes are an extremely unpleasant threat to the aquatic ecosystem; still, they can be utilized in various ways to make them environmentally friendly.²⁷ Free-floating macrophytes and submerged macrophytes are the chief sources to reduce the concentration of toxic metal and other contamination from the wastewater, which improves the water quality.²⁸ Despite many advantages, there are disadvantages too, such as limited to the depths where roots can reach, the ratio of macrophytes cover to Lake Surface is a limiting factor and the removal rate depends on the tolerance capacity of macrophytes.²⁹

Review of the Various Macrophytes Species with their Water Improvement Quality

Typically, three types of aquatic macrophytes are used to refine wastewater.^{25, 28}

Floating Macrophytes

Except for the roots the whole plant body is over the water in the Floating macrophytes. These macrophytes are dominant in the wetland. Floating macrophytes are the main source to exchange the oxygen between the atmosphere and the water zone. Due to their rich productivity, rich nutritive value and easy harvesting process floating macrophytes are suitable to remove or reduce the contamination from the aquatic ecosystem.²⁸

Metal Removal by Floating Macrophytes

(Azolla pinnata, Eichhornia crassipes, Lemna sp., Pistia stratiotes, Potamogeton pectinatus, Salvinia sp.)

Floating macrophytes, Eichhornia crassipes, Lemna minor, and Pistia stratiotes are dominant to refine effluent from the various contaminants.30, 31 Freefloating macrophytes, Water hyacinth (Eichhornia crassipes) is a widely distributed weed across the Earth and a notable name to refining wastewater with green technology. Eichhornia crassipes examined with multiple heavy metals (Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Nickle, and Zinc) by Soltan and Rashed (2003) and they demonstrated that Eichhornia crassipes can accumulate multiple heavy metals without showed any hazardous symptoms for long period and also demonstrated that in the macrophytes roots can accumulate a large amount of heavy metallic element than the shoots.³² The chemical research on Eichhornia

crassipes has shown that roots and shoots can accumulate metallic elements like Cr, Cu, Pb, Mn, and Zn in a large amount from sewer water.33 The excessive growth of Eichhornia crassipes causes the diminution of metallic pollutants, as well as certain physicochemical parameters like Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) in wastewater.³⁴ Dhote and Dixit (2007) also supported these results and concluded in Mansarovar Lake accumulation of nutrient in the aquatic ecosystem leads the considerable growth of Eichhornia crassipes, Hydrilla verticillata, and Phragmities sp.35 Hadiyanto et al., (2013) worked on Phytoremediations of Palm Oil Mill Sewer water by using Macrophytes and Microalgae for Biomass Production. The study aimed to make the utilization of two floating macrophytes, Eichhornia crassipes, Nymphaea sp., and cyanophycean algae, Spirulina sp. to decrease the amount of COD (Chemical Oxygen Demand) and the Nutrient content from the present effluent and the result indicated Eichhornia crassipes is more effective to reducing contaminants and nutrients in palm oil mill sewer water because it has a complex root system and a lot of stomata leading to needs of more carbon sources.36 Burull us lake, Mediterranean coast study was conducted by Nafea and Mohamed (2015) to investigate the accumulation capacities of six heavy metals namely Cd, Cu, Fe, Pb, Ni, and Zn through six native macrophytes such as Ceratophyllum demersum, Eichhornia crassipes, Lemna gibba, Najas armata, Phragmites australis and Potamogeton pectinatus and proved selected macrophytes can accumulate heavy metallic elements inside the plant body and they also reported Potamogeton pectinatus showed the mickle accumulation capacity for toxic metal such as Lead (Pb), Cadmium (Cd) and Zinc (Zn) respectively and Eichhornia crassipes showed good accumulation capacity of Copper (Cu).37 Macrophytes like Azolla pinnata var. imbricata can phytoremedify various metallic elements, which have high relative density and relative atomic weight such as Chromium (Cr), Copper (Cu), and Lead (Pb) from the multi-metal solution as well as monitoring the pollution of selected heavy metals and fluorides.38 Aquatic fern, Lemna polyrrhiza can be used as phytoremediators to remove more than one heavy metallic element from contaminated wastewater.39 The study of Rizwana et al., (2014) demonstrated that aquatic fern Lemna minor (Duckweed) has a great capacity to adapt the environmental factors and it plays a sustainable role to reduce contaminants from the aquatic ecosystem. They also proved that aquatic fern Lemna minor have good potential to remediate highly toxic elements Mercury (Hg), Cadmium (Cd), and Lead (Pb) from contaminated wastewater.40 Another aquatic fern with metal accumulating potentialities also reported by several researchers: Salvinia natas for Copper (Cu),⁴¹ Azolla pinnata, Salvinia minima, and Salvinia molesta for Chromium (Cr).42 Pistia stratiotes and Persicaria glabra have great capability to absorb heavy metals, Copper (Cu), and Lead (Pb) respectively.43 Trapa natans is the best evidence to indicate that inorganic contaminants are rich in the aquatic ecosystem.44 Duckweed (Lemna minor) is a highly sensitive macrophyte to different pollutants.45 Guimaraes et al., (2012) suggested various species of Lemna, for example, Lemna genus, Lemna gibba, and Lemna minor to decrease heavy metals from the wastewater and they also demonstrated Lemna gibba was great efficient than Azolla caroliniana and Salvinia minima to improve wastewater quality.46 Sekomo et al., (2012) technically proved that it can remove 94 % Cr, 36 % Pb, 33% Cd, 29% Cu, and 51-82 % Zn from the textile wastewater.47 Pistia stratiotes is an effective aquatic macrophyte to amend water quality because of the rich growth rate, the broad coverage area of surface water, and easy harvestable characters, and this macrophyte can take out 80% of Mercury (Hg) (in a concentration of 2 µg/L to 10 µg/L) from the coal mining effluent in 21 days.48,49

Submerged Macrophytes

In the submerged macrophytes the entire plant body is under the water, which plays a central role in the aquatic ecosystem. The whole submerged macrophyte plays a substantial and promising role to remove the contamination from the water bodies.

Metal Removal by Submerged Macrophytes

(Cabomba sp., Ceratophyllum sp., Egeria sp., Hydrilla sp.)

Abu Bakar *et al.*, (2013) studied heavy metal removal [Aluminium (Al), Arsenic (As), and Zinc (Zn),] from the effluents of the gold mine and the accumulation capacity of three submerged macrophytes, *Cabomba*

sp., Egeria sp., and Hydrilla sp. and concluded that Hydrilla verticillata is the highly appropriate aquatic macrophyte species to remediate AI, As and Zn from wastewater.⁵⁰ The highest accumulation capacity of iron (Fe) through Ceratophyllum demersum was recorded by Nafea and Zyada (2015) during the case study of Burull us lake, Mediterranean coast.37 A corresponding study was conducted by Elankumaran et al., (2003) between submerged macrophytes (Hydrilla verticillata Casp.) and floating macrophytes (Salvinia) and they demonstrated that the reduction efficiency of submerged macrophyte, Hydrilla verticillata Casp. was high in lower concentrations (approximately at 5 ppm) compared with floating macrophyte species Salvinia they also concluded in a high concentration (approximately at 25 ppm) reduction efficiency of floating macrophyte species, Salvinia is more compared with submerged macrophyte species Hydrilla verticillata Casp.51 Bunluesin et al., (2007) checked the reduction potential of various metallic elements (which have high relative density and high atomic weight) from the non-living biomass of aquatic macrophytes. They suggested that submerged species Hydrilla verticillata is an impressive bio absorbent for contaminated effluent treatment and also concluded that Hydrilla verticillata can absorb Cd (Cadmium) contamination from low concentration.52 The rootless submerged plant Ceratophyllum demersum was found capable of removing comparatively higher amounts of Cu, Cr, Fe, Mn, and Pb from waste pond water due to more surface area coverage and biomass ratio.51 Wang et al., (2014) studied the potential of submerged pond macrophytes and recorded the maximal concentrations of Iron (Fe-16,429 mg/kg), Chromium (Cr-4,242 mg/kg), and Nickle (Ni-2,662 mg/kg) in Ceratophyllum demersum and the result also suggested that submerged species Ceratophyllum demersum is a strong prospect species to decrease the metallic pollutants from the aquatic environments.53

Emergent Macrophytes

In the emergent macrophytes, roots grow inside the lake bottom merely their leaves and stems are spread outside the water. These types of macrophytes are normally found at the bank of the water bodies and attached to the sediments with the help of the root system, which plays a notable role in the uptake of heavy metallic elements from the sediments. Emergent macrophytes have an effective capacity to store the nutrients over a long period than floating macrophytes.²⁸ (*Phragmites sp., Typha sp.*)

Metal Removal by Emergent Macrophytes

Laing et al., (2003) proved that Phragmities australis can remove Zinc (Zn) and Iron (Fe) from wastewater. They also concluded that leaves and stem of Phragmities australis plays a substantial role in Zinc (Zn) removal.⁵⁴ Phytoremediation study of heavy metals from domestic runoff through emergent macrophyte, Typha was conducted by Mojiri et al., (2013) and they clarified that the emergent macrophyte Typha domingensis is an efficient accumulator macrophyte species to remediate Lead (Pb), Cadmium (Cd), and Nickle (Ni).55 Most toxic metallic elements for instance Cd (Cadmium), Iron (Fe), Chromium (Cr), Lead (Pb), Copper (Cu), and Nickel (Ni) can isolate from water effluent through emergent macrophyte species, Typha angustifolia.56 Due to the less amount of translocation and mobility of heavy metals within the tissue of emergent macrophytes, these type of macrophyte was rarely utilized to refine the contaminated wastewater or sediment. For example, Phragmities and Typha can remove fewer amounts of hazardous metals from contaminated wastewater or sediment.57 Miranda et al., (2014) found Marsilea guadrifolia to amend Selenium (Se) rich mining water and remarked that Marsilea quadrifolia can also remove other metals in less amount such as Cd (Cadmium), Manganese (Mn), Chromium (Cr), Cobalt (Co), Copper (Cu), Molibladum (Mo), Iron (Fe), Nickel (Ni) and Zinc (Zn) from the contaminated wastewater but a fewer amount.58

Conclusion

Researchers scientifically demonstrated that macrophytes are appropriate to refining the effluent

due to the abounded potential to absorb nutrients and other contaminants from the aquatic ecosystems which decrease the pollution level. This review article highlighted the potential of macrophytes to refine wastewater and concluded that submerged and emergent macrophytes also have the potential to refine the water quality from the various wastewater resources and decrease the pollution level but the free-floating macrophytes were more effective. In the case of the emergent macrophytes and surface floating macrophytes, only the root system takes part in the uptake and expansion of the metallic elements in tissues, whereas in submerged macrophytes root system, as well as shoot system such as leaves take part in refining effluent. Submerged rooted macrophytes have the great potentiality to decrease or isolate metallic elements that have high atomic weight and high relative density from effluent as well as sediments. Alive and dead macrophytes are appropriate for the uptake and absorption or detoxifying the heavy metallic elements and other several contaminants from the water bodies because they have more or less special characters: expeditious growth rate, rich biomass production, great adaptive abilities to various habitat, and adventitious root system which increases the absorption capacity of macrophytes. The reduceable or removable efficiency is majorly related to the plant growth rate, metal tolerance to the tissue, and adaptability to the various environs. So, it is an important task to select the correct macrophyte species before the treatment equipment design to reduce or remove the heavy metallic elements from the contaminated wastewater or sediments.

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