Environment Conservation Journal 24 (1):273-280, 2023

Journal homepage:https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)

Phytoremediation potential of macrophytes against heavy metals, nitrates and phosphates: A review

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ARTICLE INFO

Received : 12 April 2022
Revised : 11 June 2022
Accepted : 16 July 2022

Available online: 08.01.2023

Key Words:
Aquatic
Contaminant
Pollutant
Removal
Sequestration

ABSTRACT

Natural waters are degraded either by contaminants or pollutants. Contaminants are synthetic compounds which cause degradation of water quality, even when present in minute residues. They include pesticides, heavy metals, Poly Chlorinated Biphenyl's, Poly Aromatic Hydrocarbons, plastics etc. On the other hand, pollution precisely refers to the increase in nitrates and phosphates in water body. Aquatic macrophytes, besides their role in the food chains, play significant part in mitigating both pollutant and contaminant levels. Their uptake and sequestration of nitrates, phosphates and heavy metals is well documented and published in worldwide. This paper reviews the efficacy of different macrophytes in freshwater ecosystems for uptake of pollutants and contaminants. It will provide an insight for policy makers in efficient mitigation of pollution levels in the water body.

Introduction

Water being employed in many industrial processes, as well as the release of discharges originating from industry and urban growths, exposes aquatic habitats to additional contamination than other environments (Fernandesa *et al*., 2007). Although most aquatic ecosystems have a natural inclination to dilute pollution to some level, significant contamination causes changes in the community's fauna and flora (Mateo-Sagasta *et al*., 2017). Sewage is the most common waste dumped into aquatic habitats. Sewage is made up of industrial, municipal, and domestic wastes, such as waste from baths, washing machines, kitchens, and faeces (Bhutiani *et al.,* 2016). The ideal sinks for the disposal of these contaminants are fresh water sources (Tukura *et al*., 2009; Bhutiani and Ahamad, 2021). Contamination of water bodies by heavy metal ions, which has damaging consequences on the environment and human health, is one of the most serious environmental challenges related to water pollution around the world (Akpor and Muchie, 2010; Bhutiani *et al*., 2022). Chemical elements with a specific gravity greater than five times that of water are known as heavy metals (Charan *et al*., 2014). The build-up of heavy metals in marine ecosystems is a global concern among contaminants. The strong association between metals, metal pollution, and human history was developed due to ancient breakthroughs in mining and metal-working techniques. The burning of fossil fuels, mining and smelting of metalliferous ores, municipal wastes, sewage, pesticides, and fertilisers are the principal causes of metal pollution (Pendias and Pendias, 1989). In terms of metal pollution in the aquatic ecosystem, it is low in open oceans and rises dramatically as it approaches coastal areas and estuaries. Heavy metal pollution is known to cause a variety of ailments around the world, including minamata sickness (organic mercury poisoning), itai-itai disease (cadmium poisoning), arsenic acid poisoning, and asthma caused by air pollution (Matsuo, 2003). Metal pollutants in aquatic systems are normally in soluble or suspension form, and they eventually settle to the bottom or are taken up by organisms. Because of their toxicity, the cumulative and irreversible accumulation of heavy metals in various organs of marine species leads to

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Doi:https://doi.org/10.36953/ECJ.12102318

metal-related disorders in the long run, putting the aquatic biota and other organisms at risk. Heavy metals are hazardous due to their proclivity for bioaccumulation. In comparison to the chemical's concentration in the environment, bioaccumulation refers to an increase in the concentration of a chemical in a biological organism over time.

Phytoremediation is a type of bioremediation in which plants are used to remove, transport, stabilise, and/or eliminate pollutants from the soil and groundwater. As a result, phytoremediation is a plant-based technique that entails using plants to extract and eliminate elemental contaminants from the environment or reduce their bioavailability in soil (Berti and Cunningham, 2000; Bhutiani *et al.,* 2019a&b; Ruhela *et al.,* 2021). Plants extend their root systems into the soil matrix, forming a rhizosphere ecosystem, which accumulates heavy metals and modulates their bioavailability, reclaiming damaged soil and restoring soil fertility (Dal-Corso *et al*., 2019). Phytoremediation has a number of advantages (Yan *et al*., 2020), including:

- Phytoremediation is an autotrophic system fuelled by solar energy, making it easy to run and maintain, and the cost of installation and maintenance is inexpensive.
- It can reduce pollutant exposure to the environment and ecosystem.
- It can be applied over a large-scale field and easily disposed of.
- It prevents erosion and metal leaching by stabilising heavy metals, reducing the risk of contaminants spreading.
- It can also improve soil fertility by releasing various organic matter to the soil.

Plants have faster growth rate, high biomass production and ingest significant amounts of heavy metals. Additionally, they transport metals in above-ground sections and have a mechanism to withstand metal toxicity and thus they are utilised in phytoremediation (Burges *et al*., 2018). In aquatic ecosystems absorbing industrial effluents and municipal wastewater, macrophytes are effective instruments for reducing heavy metal contamination. Because of their inexpensive cost, frequent abundance in aquatic habitats, and ease of handling, they are favoured over other bio-agents. Heavy metal removal requires the extraction and transport of contaminants to aerial parts, or the inactivation of hazardous metals in a system, hence aquatic macrophytes are significant tools. Heavy metals are sequestered by aquatic macrophytes, whether free-floating, submerged, or emergent. The rate of metal absorption, accumulation, and translocation in plants is influenced by plant species and environmental conditions such as the metal's chemical speciation, temperature, pH, redox potential, and salinity (Dhir *et al*., 2009). The availability of metals to macrophytes is regulated by pH, which is critical for metal speciation. Various macrophytes are known for their ability to remove metals from contaminated environments (Burges *et al*., 2018) (Table 1).

Heavy metal removal by water hyacinth (*Eichhornia crassipes*)

Water hyacinth is a prominent freshwater weed in most of the world's frost-free zones, and is widely considered to be the most bothersome aquatic plant. Despite its negative consequences, it is commonly used as water ornamental around the world due to its lovely, stunning blossoms. Aquatic plants such as water hyacinth (*Eichhornia crassipes*) are a sensible and practical technique to absorb toxic substances and enhance water quality. Water hyacinth could effectively phytoremediate contaminated water including metals like cadmium (Cd), arsenic (Ar), and mercury (Hg), reducing the risk of untreated waste water entering the environment (Nazir *et al*., 2020). According to their research, the largest quantity of metal absorbed per dry weight of water hyacinth was 166.25ppm for cadmium and the lowest was 0.032ppm for mercury. The water hyacinth (*Eichhornia crasssipes*) was found to absorb the most cadmium (Cd) metal from sewage water, compared to arsenic and mercury. After 11 days of exposure, water hyacinth accumulated up to 3.542 and 2.412 $mg^{-1}$of Zn and Cr, respectively, at a metal concentration of 10 mg/l (Mishra and Tripathi, 2009). This plant has removed up to 84% of Cr and 94% of Zn from the environment. During the treatment process, the root of the water hyacinth was the most successful portion of all the plant tissues in accumulating Zn. Under field conditions, water hyacinth removed 600 mg arsenic/ha/d, and under laboratory conditions, it recovered 18% of the arsenic (Alvarado *et al*., 2008).

Table 1: Phytoremidiation potential of aquatic macrophytes

SN	Heavy Metal	Phytoremediatormacrophyte	Reference
1	Cr	*Eichhornia crassipes* *Wolffia globosa* *Pistia stratiotes* *Salvinia minima*	Muramoto and Oki, 1983 Upatham *et al*., 2002 Sen *et al*., 1987 Srivastav *et al*., 1994
2	Cu	*Eichhornia crassipes* *Pistia stratiotes* *Lemna minor* *Vallisneria spiralis*	Delgado *et al*., 1993 Miretzky *et al*., 2004 Kara, 2005 Sinha *et al*., 1994
3	Fe	*Pistia stratiotes* *Potamogeton pectinatus* Myriophyllum spicatum	Zayed *et al*., 1998 Tripathi *et al*., 1991 Brankovi´c *et al*., 2012
4	Ni	*Eichhornia crassipes* *Lemna gibba* *Lemna minor*	Fargo and Parsons, 1994 Zayed *et al*., 1998 Axtell *et al*., 2003
5	Zn	*Eichhornia crassipes* *Pistia stratiotes* *Azolla pinnata*	Low *et al*., 1994 Odjegba and Fasidi, 2004 Jain *et al*., 1990
6	Cd	*Wolffia globosa* *Eichhornia crassipes* *Lemna trisulca* *Salvinia minima* Ceratophyllum demersum	Boonyapookana *et al*., 2002 Zhu *et al*., 1999 Huebert and Shay, 1993 Hoffman *et al*., 2004 Bunluesin*et al*., 2004
7	Mn	*Pistia stratiotes* Typha latifolia	Maine *et al*., 2004 Hejna *et al*., 2020
8	Hg	*Eichhornia crassipes* *Spartina alterniflora* *Scirpus robustus*	Vesk *et al*., 1999 Carbonell *et al*., 1998 DeSouza *et al*., 1999
9	Ag	*Eichhornia crassipes*	Olguin *et al*., 2002
10	Pb	*Eichhornia crassipes* *Lemna minor* *Typha latifolia* Myriophyllum spicatum	Molisani *et al*., 2006 Rahmani and Sternberg, 1999 Qian *et al*., 1999 Sivaci *et al*., 2004
11	Pt	*Eichhornia crassipes*	Hu *et al*., 2003

Heavy metal removal by *Lemna*

The Lemnaceae family includes duckweed, which is a tiny, free-floating aquatic plant. Duckweed species have been recommended for wastewater treatment and have been used in water quality studies for monitoring heavy metals (Radic *et al*., 2010). They are regarded a better option and have been used in water quality studies for monitoring heavy metals. All metals (cadmium, copper, lead and nickel) were removed with higher than 80% efficiency by *Lemna*, with nickel (Ni) removing the most (99%) from sewage mixed industrial effluent. Lead accumulation and absorption were substantially higher in dry biomass than for other metals (Bokhari *et al*., 2016). The plant's bioconcentration factors were less than 1000, with the highest values for copper (558) and lead (523.1), indicating that it is a moderate accumulator of both metals.

Heavy metal removal by *Azolla*

Azolla has a great potential for heavy metal removal from water resources and can be employed in heavy metal phytoremediation. *Azolla filiculoides* has the ability to absorb Cr, Pb, Zn, Hg, Cu, Cd, Ag, and Ti, making it a valuable plant for bioremediation and heavy metal removal from wetlands (Hassanzadeh *et al*., 2021).

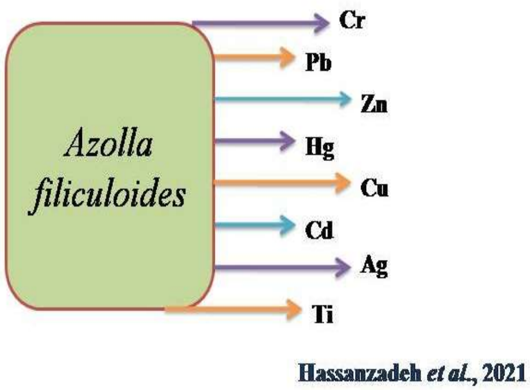

Figure1: Phytoremediation efficiency of *Azolla filiculoides*

Another study (Shafi *et al*., 2015) found that *A. filiculoides* can accumulate the most Zn in its tissues when compared to Cu, Pb, and Cd, which could be related to Zn's importance in the fern's vital functions. Metal accumulation in the roots of *A. filiculoides* is higher than in the leaf tissue, indicating inadequate ion transport in this water fern. In another study, *Azolla caroliniana* was revealed to show phytoremediation against metals (Bennicelli *et al*., 2004). More lead than cadmium has been taken up by *A. caroliniana*. Lead levels were 53-416 mg/kgd.m., while cadmium levels were 23-259 mg/kgd.m. According to these findings, *A. caroliniana* is more tolerant of lead than cadmium. The presence of lead and cadmium ions inhibited the growth of *A. caroliniana* by 30–37% and 24–47%, respectively (Stepniewska *et al*., 2005). *Azolla pinnata* is a promising candidate for the removal of Cd^{+2} from wastewater. As a result, *A. pinnata* could play a key role in the rehabilitation of anthropogenic-stressed aquatic ecosystems and wastewater treatment (Tantawy *et al*., 2017).

Heavy metal removal by *Potamogeton*

Potamogeton spp, a globally distributed submerged macrophyte, produces vast amounts of biomass and may remove hazardous metals like Cd and Hg from effluent (Demirezen and Aksoyo, 2007). Heavy metals (Cr, Fe, Mn, Zn, Cd, and Pb) are accumulated by *Potamogeton pectinatus* at concentrations of 300.86, 1782.31, 1777, 146.79, 0.38, and 6.85 ppm, respectively. *Potamogeton pectinatus* gathered heavy metals of Cr, Zn, Cd, Pb in its roots (lower portions), Cr, Mn, Zn in its stem, Cr, Zn, Cd in its leaves, and all tends to accumulate considerable amounts of Cu, Cr, Pb, As, and Cd (Ibrahim *et al*., 2016). *Potamogeton pectinatus* accumulates large amounts of metals in its tissues, resulting in a reduction in heavy metals (Fe, Cu, Zn, and Pb) in waste water. The plants were able to remove 70-85% of Fe, Cu, Zn, and Pb from waste water, demonstrating their metal phytoremediation capability (Singh *et al*., 2014).

Heavy metal removal by *Salvinia*

Salvinia molesta is a free-floating perennial weed that can be utilised to remediate blackwater effluent in environmentally friendly sewage systems. The study clearly shows that *Salvinia molesta* consumes heavy elements like as chromium, cadmium, copper, and lead (Table 2), yet the growth regulation process remains unchanged (Donatus, 2016). *Salvinia biloba* was shown to be highly successful in the removal of Cu and Pb (>95%) from water samples, but less so in the removal of Zn (77–70%) and Cd (79–54%). The buildup of Cd, Cu, Pb, and Zn in plant tissue caused visible visual changes in leaves, indicating that this aquatic fern can be used as an ecological indicator of heavy metal contamination in contaminated waters (Emiliani *et al*., 2020).

Table 2: Uptake of heavy metals by *Salvinia molesta*

SN	Heavy metal	Concentration (ppm)	
		Before treatment	After treatment
1	Copper	1.092	2.035
2	Chromium	2.021	1.052
3	Lead	2.974	1.924
4	Cadmium	0.251	0.018

(Donatus, 2016)

Heavy metal removal by *Pistia*

Cu, Zn, Fe, Cr, and Cd uptake have no negative effects on the plant, making *Pistia stratiotes* a viable candidate for use as a hyper-accumulator plant for the broad-scale mitigation of organic pollutants and heavy metals from wastewater (Eloy *et al*., 2019). During the experiment, the biomass of *P. stratiotes* removed more than 70% of the zinc and cadmium from the contaminated fluid.

Eutrophication of water bodies:

Eutrophication is the process of an overabundance of nutrients in a water body, resulting in abundant growth of basic plant life. This process is indicated by the excessive development (or bloom) of algae and plankton in a water body. Plant development in an ecosystem is limited by the availability of nutrients such as nitrogen and phosphorus. The growth of algae, plankton, and other simple plant life is favoured over the growth of more sophisticated plant life when water bodies are too loaded with these nutrients. All water bodies are vulnerable to a slow and natural eutrophication process, which has accelerated in recent decades due to cultural eutrophication. The structural changes in the water body are triggered by the constant increase in the input of nutrients, mostly nitrogen and phosphorus (organic load), until it surpasses the capacity of the water body.

Phytoremediation potential of aquatic macrophytes against nitrates:

The contamination of water caused by high amounts of nitrates present in various bodies of water is referred to as nitrate water pollution. Nitrate pollution occurs in surface and groundwater as a result of numerous sources of nitrate leaking into the soil and then into the water supply. The roots of aquatic plants create a range of micro-environments surrounding them that can support the growth of nitrifying or denitrifying bacteria (Wu *et al*., 2003). The elimination of nitrate by aquatic plants was found to entail both plant absorption and the impact of microbes (Chong *et al*., 2003). In terms of nitrate removal, some emergent macrophytes produce significant purification effects (with nitrate removal percentages surpassing 50%). In terms of nitrate removal percentage, there was a highly significant difference between the three species of aquatic plants (Table 3, $P < 0.01$). The nitrate removal percentage of *Acoruscalamus* was the highest, at 86.16 percent, and the nitrate removal percentage of *Phragmitesaustralis* was much lower, at only 62.34 percent, than the other two species (Li *et al*., 2016).

Phytoremediation potential of aquatic macrophytes against phosphates:

The ability of *Eichhornia crassipes* and *Pistia stratiotes* to sequester phosphorus was calculated. After 48 hours of equilibrium time, the phosphate removal efficiencies of *P. stratiote s*and *E crassipes* were 71.6% and 76.8%, respectively. At pH 7, *P. stratiotes*and *E. crassipes* had maximum removal efficiencies of 77.7% and 83.7 percent, respectively. *Pistia stratiotes* had the greatest uptake of 47 mg/l at 250 mg/l, despite having the highest removal efficiency of 89.5 percent at 25 mg/l. *E. crassipes* had the highest uptake of 47 mg/l at 250 mg/l, despite having the highest removal efficiency of 89.5 percent at 25 mg/l. After five days, *P. stratiotes*and *E. crassipes* had 35.4 percent and 41.6 percent phosphorus sequestration potential from a eutrophied water body, respectively, showing higher phytoremediation efficacy (Dayarathne *et al*., 2020). The sequestration of phosphates is exhibited in table 4.

Table 3: The nitrate removal percentages of plants

SN	Final nitrate removal	Plant	Final nitrate removal
1	0.6473	*Scirpus validus*	0.6234
2	0.7118	*Phragmites australis*	0.6874
3	0.8162	*Acorus calamus*	0.8616

(Li *et al*., 2016)

Table 4: Sequestration percentage of phosphates

SN	Plant	Days	Sequestration percentage
1	***Eichhornia crassipes***	5	41.6
		10	23.5
		15	29.3
2	***Pistia stratiotes***	5	35.4
		10	10.9
		15	16.2

(Dayarathne *et al*., 2020)

Conclusion

Phytoremediation is an efficient technique by which we can eliminate the contaminants from the water body. Macrophytes such as *Eicchornia, Lemna, Azolla, Potamogeton, Salvinia and Pistia* can effectively remove the heavy metals. Besides, they can be helpful in the removal of nitrates and phosphates enabling lake reclamation. Therefore, they can be used for the control of eutrophication in the lakes.

Conflict of interest

The authors declare that they have no conflict of interest.

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