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A Review on Phytoremediation Potential of Aquatic Macrophytes of North Bihar, India

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ABSTRACT

North Bihar is occupied by large number of various types of wetlands like chaurs, swamps, dhar, man, ditches, lakes, ponds and pools which support the luxuriant growth of diverse types of macrophytes and also sustain the occurrence of several macro-invertebrate therein. There are more than 120 species of macrophytes reported from this region. These plants acts as valuable natural resources for the livelihood of the region in the form of food, vegetables, fodder and medicine. Moreover, there are increasing evidences suggesting increase of heavy metal pollution in the area due to both municipal and domestic waste. The accumulation of heavy metals like As, Cd, Cr, Pb and Cu has also threatened the habitat of various macrophytes. Consequently, the plants have also evolved the mechanism of phytoremediation of these elements mainly by bioaccumulation. There are several reports which proved that compared to edible crops, aquatic macrophytes show better tolerance to heavy metal stress owing to their higher growth rate and higher biomass under unfavorable environment. Present review focused on exploring the major aquatic macrophytes commonly occurring in wetlands of North Bihar and their utilization for phytoremediation of heavy metals and metalloid.

Keywords Aquatic macrophytes, Heavy metals, Hyperaccumulation, Phytoremediation.

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INTRODUCTION

In addition to natural processes, anthropogenic activities like urbanization and industrialization, mine tailings, disposal of high metal wastes, gasoline and paints, increasing use of chemical fertilizers and pesticides, animal manures, sewage sludge, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition have caused the water bodies to become increasingly polluted by heavy metals and metalloids (Kumar *et al.* 2019). Heavy metal contaminated water pose a continuous problem to human and animal health. Therefore, decontamination of heavy metals and metalloid contaminated water bodies is highly desired to reduce the associated human risks and for maintenance of environmental health and ecological restoration (Beniah and Enyoh 2019). Many different extraction methods have been developed empirically for *in situ* or *ex situ* treatment/removal of contaminated soils, sediments and water. Conventional techniques for reclamation of such water are not only expensive but environmental non-friendly also (Sood *et al.* 2012). One of the most effective and affordable technological solutions is application of a process commonly known as phytoremediation. Phytoremediation is an emerging environmental friendly, cost-effective, non-invasive, and aesthetically pleasing 'green' technology that uses the remarkable ability of plants and their associated micro biota, water amendments and agronometric techniques to concentrate metals and hence can be potentially used to remediate and reclaim metal-contaminated sites (An *et al.* 2020). Plants utilize several methods to remediate the polluted sites. Plants are used for phytoremediation of terrestrial environment to remove organic or inorganic pollutants such as: toxic metals, chlorinated solvents, petroleum hydrocarbons, polychlorinated biphenyls and even radionuclides (Bhat *et al.* 2022). Till date, more than 400 plant species belonging to 45 different plant families have been reported from temperate and tropical regions with the potential to tolerate and hyperaccumulate heavy elements (Babu *et al.* 2021). Among various plant species which have the exceptional ability to reclaim aquatic properties, macrophytes are considered to be highly desired due to their unique physiological advantages like competitiveness and aggressiveness, short life cycle, prolific seed production, vegetative means of propagation to enhance its prolific growth, evasiveness and adaptability at wide variety of conditions.

Present review is focused on applications of wild macrophytes for environmentally sustainable phytoremediation technique for heavy metal polluted water bodies and hence offer widespread applicability of this green technology. Different biotechnological approaches to enhance the bioavailability of heavy metals in the water are also discussed shortly. It can be therefore concluded that phytoremediation of heavy metal contaminated wetlands by selected native plant species is a reliable approach and necessary for making the waste land resource accessible for crop production.

Heavy metal contamination of wetlands with special reference to North Bihar

Wetlands are considered to be the main sink for heavy metals which are being continuously released by natural erosion of minerals and anthropogenic activities. Unlike organic contaminants which are oxidized to oxides of carbon (IV) by microbial action, most metals don't undergo microbial or chemical degradation, and persists in water bodies for a long time after their introduction into the environment (Mohammed *et al.* 2022). Moreover, the presence of toxic metals in water can severely inhibit the biodegradation of organic contaminants. Heavy metal contamination may pose serious risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated water or through the complex food chain. Therefore, the characterization and remediation of aquatic ecosystems contaminated by heavy metals is essential for their adequate protection and restoration (Mukherjee *et al.* 2018). In developing countries like India, with great population density and scarce funds available for environmental restoration program, cost effective and ecologically sustainable remedial options are required to revive contaminated water resources to scale back the associated risks, make the water available for agricultural production, enhance food security, and scale down tenure problems.

Heavy metal contamination in wetlands of Bihar is a concerning environmental issue (Laura *et al.* 2020). Wetlands, which include marshes, swamps, and other water-saturated areas, can be vulnerable to heavy metal pollution due to various human activities and natural processes (Beniah and Enyoh 2019). Key reasons for heavy metal contamination in the wetlands of Bihar include Industrial Discharges, Agricultural Runoff, Urbanization and Municipal Waste and Natural Weathering and Geological Factors. Heavy metal contamination in wetlands can have detrimental effects on the ecosystem. Accumulation of heavy metals in sediments and water can impact the growth and reproduction of aquatic plants, algae, and other organisms. It can also bioaccumulate in the food chain, leading to toxic effects on higher trophic levels, including fish and birds. Efforts to mitigate heavy metal contamination in wetlands involve both remediation and conservation approaches. Remediation techniques may include sediment dredging, constructed wetlands for phytoremediation, and water treatment technologies. Conservation measures focus on reducing pollutant inputs, promoting sustainable agriculture practices, and managing industrial discharges through strict regulations and monitoring. It is crucial for the government, local communities, and relevant authorities to collaborate in identifying contaminated wetlands, implementing remedial measures, and raising awareness on the importance of wetland conservation and sustainable practices to prevent further heavy metal contamination.

Mechanisms of phytoremediation of heavy metals by macrophytes

Phytoremediation is a method of environmental remediation that utilizes plants to remove, degrade, or stabilize contaminants in soil, water, or air. It is an eco-friendly and cost-effective approach that harnesses the natural abilities of plants to clean up polluted sites. Phytoremediation can be classified into several different types based on the specific mechanisms employed by plants to address different types of contaminants (Fig. 1). Macrophytes, such as aquatic plants or micro/macro algae, can play a significant role in the phytoremediation of heavy metals from aquatic sources. Heavy metals can contaminate water bodies through natural sources or human activities like mining and industrial processes (Mukherjee *et al.* 2018, Bhat *et al.* 2022). Aquatic macrophytes can help remediate heavy metals by Phytoaccumulation, Rhizofiltration, Phytostabilization, Phytovolatilization. It's important to note that the efficiency of heavy metals remediation by aquatic macrophytes can vary depending on factors such as the plant species, growth conditions, heavy metals concentration, and the duration of treatment. Additionally, proper management and disposal of harvested plants are necessary to prevent the reintroduction of heavy metals into the environment. Regular monitoring and evaluation of the remediation process are essential to ensure its effectiveness and environmental safety. Floating aquatic plants have roots that extend into the water, allowing them to absorb or accumulate contaminants primarily through their root systems. They are often referred to as hyperaccumulating plants because they have the ability to absorb and accumulate high levels of contaminants, such as heavy metals, from the water. Examples of floating aquatic hyperaccumulators include water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemna* spp.). On the other hand, submerged aquatic plants are fully submerged in the water. These plants accumulate contaminants, particularly heavy metals, through their entire bodies, including leaves, stems, and roots. Submerged plants are also effective in nutrient and heavy metal cycling within aquatic ecosystems. They can uptake and store nutrients and metals, helping to maintain a healthy balance in the water. Common submerged aquatic plants used in phytoremediation systems include various species of waterweed (*Elodea* spp.) and pondweed (*Potamogeton* spp.). Both floating and submerged aquatic plants play crucial roles in nutrient and heavy metal recycling within aquatic ecosystems. They help in removing contaminants from the water, enhancing water quality, and creating a healthier environment for aquatic organisms. These plants can be an effective and sustainable approach for the remediation of polluted water bodies.

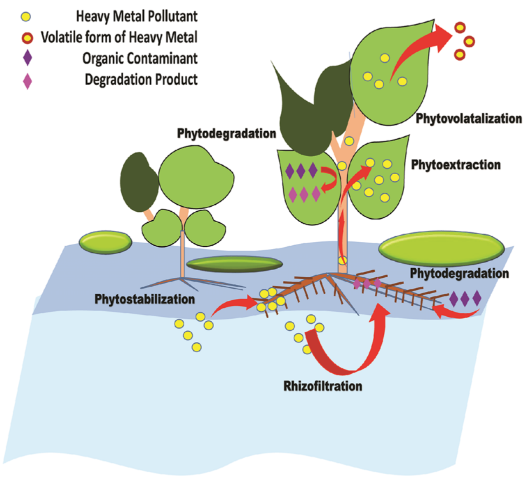

Fig. 1. Means of phytoremediation.

RESULTS AND DISCUSSION

The wetlands of North Bihar are diverse in their types, including chaurs, swamps, dhar, man, ditches, lakes, ponds, and pools. These wetlands provide a favorable environment for the growth of various types of macrophytes (aquatic plants) and support a rich diversity of macro-invertebrates. Over 120 species of macrophytes have been reported in this region (Singh 2011). These plants are not only valuable natural resources but also crucial for the livelihood of the local communities, providing food, vegetables, fodder, and medicinal resources. However, the increasing evidence of heavy metal pollution in the area, resulting from both municipal and domestic waste, poses a threat to the wetland ecosystem. Heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and copper (Cu) have been found to accumulate in the wetlands, endangering the habitat of various macrophytes (Rai *et al.* 2002). During the present study review, survey of macrophytes were done and recent literature available on the diversity of macrophytes in the North Bihar region was studied. Phytoremediation potential of these plants were surveyed through literature search based on published

Table 1. Macrophytes in the wetlands of North Bihar with phytoremediation potential.

Botanical name of the plant	Phytoremediation potential	References
	Algae	
Chara vulgaris	Cd, As	Mahajan *et al*. (2019), Taleei *et al.* (2019)
Nitella sp.	Cr, Cd	Pattiyage *et al.* (2013)
	Ferns	
Azolla pinnata	Hg, Cr, Cd, As, Pb	Bennicelli *et al.* (2004), Upadhyay *et al.* (2007), Rai (2008), Mashkani and Ghazvini (2009), Sood *et. al.* (2012)
Marsilea minuta	Cd, As, Pb	Das *et al.* (2013), Hassi *et al.* (2017), Rachmadiarti *et al.* 2019
Salvinia natans	Zn, Cd, Co, Cr, Fe, Cu, Pb, Ni	Dhir. (2009), Rápó *et al.* (2020)
	Angiosperms	
A. Dicots		
Aeschynomene indica	Cd, Pb	Lee *et al.* (2007),Golda *et al.* (2014), Bandara and Vitharage (2016)
Alternanthera philoxeroides	Cd, Cr, Fe, Cu, Pb,	Ansari and Sharma (2017).
Alternanthera sessilis	Cd, Cr, Fe, Mg, Cu, Pb, As	Mazumdar *et al.* 2015, 2021, Singh *et al*. 2022
Amaranthus spinosus	Zn, Cu, Pb, Cr, Cd	Chinmayee *et al*. (2012), Kelechi *et al*. (2022)
Ammannia baccifera	Cu	Kadam *et al.* (2018)
Celosia argentea	Pb, Cu, Cd, Hg	Fu *et al*. (2017), Yang *et al*. (2021)
Centella asiatica	Zn, Cu, Pb, Cr, Cd, Ni,	Li *et al.* (2018), Mazumdar *et al.* (2021)
Ceratophyllum demersum	Zn, Cu, Pb, Cd,	Abdallah *et al*. (2012), Ostroumov *et al.* (2019)
Eclipta prostrata	Fe, Zn, Cu, Ni, Si, Al, Pb, Cr, Cd	Kumari *et al* (2016) Sharma (*et al.)* (2021)
Enhydra fluctuans	Pb, Cd , Cr	Jha *et al.* (2016), Parven *et al.* (2022), Demarco *et al.* (2023)
Euryale ferox	Cr, Cd, Pb , Cu	Rai *et al.* (2002)
Ipomoea aquatica	Fe, Zn, Cu, Al, Pb, Cr, Cd	Chanu and Gupta (2016), Hanafiah *et al.* (2020), Hisam *et al.* (2022)
Jussiaea repens al.	Hg and Cd	Rachma *et al.* (2014) Mukhopadhyay *et* (2016) ,
Lindernia crustacea	Hg	Muddarisna *et al.* (2013)
Lippia javanica	Ni	Maria *et al.* (2002), Bett *et al.* (2022)
Ludwigia adscendens	Pb, Cd and Cr	Hosam *et al* (2018). Fida and Marátus (2020)

Table 1. Continued.

Botanical name of the plant	Phytoremediation potential	References
Mazus pumilus	Cd, Cu and Hg	Huang and Deng (2020)
Melochia corchorifolia	As and Pb	Idris *et al.* (2016)
Nelumbo nucifera	Cu, Cr, Pb, As and Cd	Hamidian *et al.* (2016)
Neptunia oleracea	Pb, Cd , Zn , As, Hg and Cr	Syuhaida *et al*. (2014), Atabaki *et al.* (2020)
Nymphaea nouchali	Cu, Cr, Pb, As and Cd	Mokhtar *et al.* (2020)
Nymphoides cristatum	Cr and Cd	Riyazuddin *et al*. (2022)
Phyla nodiflora	Pb, Cu and Zn	Yoon *et al*. (2006)
Polygonum barbatum	Mn, Cu and Cd	Li *et al.* (2020)
P. hydropiper	Cd	Zhang *et al* . (2023)
P. glabrum	Cu, Ni, Fe, Mn & Cd	Bhatti *et al.* (2022)
Ranunculus sceleratus	Al, Pb, Cd , Zn , As, Hg and Cr	Sharma *et al*. (2021)
Rotala indica	Cd, Pb	Marbaniang *et al.* (2014), Dogan *et al.* (2015)
Rumex dentatus	Al, Pb, Cd , Zn , As, Hg and Cr	Sharma *et al*. (2021)
Trapa bispinosa	Cu, Cd, Fe, Mn and Zn	Sweta *et al.* (2015), Kumar *et al*. (2018)
Utricularia aurea	Cr	Augustynowicz *et al*. (2015)
Veronica anagallis-aquatica	Cd, Pb and Zn	Ahmad *et al.* (2016), Karzan *et al.* (202)1
B. Monocots		
Aponogeton natans	Cr, Pb, Zn, Hg, Ni, and Cd	Rai *et al.* (2009)
Commelina benghalensis	Pb, Cd and Zn	Sekabira *et al* (2011)
Cyperus esculentus	Cd, Cr, Cu, Mn, Fe, Ni, Pb and Zn	Chandra and Yadav (2011)
C. rotundus	As, Cd, Pb, Rb, Sn, and Zn	Ariyachandra *et al.* (2023)
C. articulatus	Ni, As and Cd	Hussein (2012)
Echinochloa colona	Cd, Cu and Pb	Kim *et al.* (2010)
Eichhornia crassipes	Ag, Cd, Cr, Cu, Hg, Ni, Pb, and Zn	Odjegba *et al.* (2007)
Eleocharis atropurpurea	Cu and Cd	Sa'ad *et al.* 2011
Eragrostis nutans	Cd	Abad and Khara (2007)
Fimbristylis dichotoma	Cu, Pb and Cd	Wang *et al.* (2020)
Hydrilla verticillata	Cr, Pb, Zn, Hg, Ni, As and Cd	Zhan *et al.* (2020)
Hygroryza aristata	Fe, Zn, Cu, Cr, Pb, Cd, Hg, and As	Ahmad *et al.* (2011)
Juncus bufonius	Cd ,Cr, Ni, Zn and Cd	Najeeb *et al.* (2011)
Kyllinga brevifolia	Cd	Hao *et al.* (2014)
Leersia hexandra	Cu, Cd ,Cr and Pb	Lin *et al.* (2019)
Lemna minor	Cd, Cr, Cu, Hg, Ni, Pb, and Zn	Bokhari *et al.* (2016)
Monochoria hastata	Cd, Cr and Cu	Talukdar *et al.* (2015), Hazra *et al*. (2015)
Ottelia alismoides	Fe ,Mn, Zn, Cu	Shinde *et al.* (2020)
Panicum paludosum	Pb and Cd	Hidayati and Rini (2020)
Paspalum scrobiculatum	Cd, As, Pb and Cr	Vishal *et al.* (2018), Chandanshive *et al.* (2017)
Phragmites karka	Pb, Mg , Pb and Cr	Badejo *et al.* (2015), Rai (2021)
Pistia stratiotes	Cu, Co, Cr, Pb, Cd, Hg, and As	Odjegba *et al.* (2014)
Potamogeton crispus	Cu, Cr, Pb, As and Cd	Norouznia *et al.* (2014)
Saccharum spontaneum	Zn, Pb, Cu, Ni, Cd and As	Mukherjee *et al.* (2017), Banerjee *et al.* (2020)
Sagittaria guayanensis	Cd, As and Pb	Tanvir (2021)
S. sagittifolia	Cd, Cr, Cu, Hg, As, Ni, Pb, and Zn	Demarco *et al.* (2019)
Schoenoplectus articulatus	Cd, Cr, Cu, Pb, and Zn	Duman *et al.* (2007)
Spirodela polyrhiza	Cd, As, Ni, Cu and Hg	Chaudhuri *et al.* (2014), Singh *et al.* (2020)
Typha angustata	Cd, Cr, Cu, Mn, Fe, Ni, Pb and Zn	Chandra and Yadav (2011)
Vallisneria spiralis	Cd, Co, Cu, Ni, Pb and Zn	Kumar *et al.* (20080
Wolfia arrhiza	Cd and Pb	Xie *et al.* (2013)

results. As summarized in Table 1. There are at least 68 species of plants which have phytoremdiation potential. Since, some of the plants like *Euryale ferox* are edible therefore they cannot be used for phytoremediation but in experimental conditions they have shown to possess the bioaccumulation potential.

CONCLUSION

In response to heavy metal pollution, the aquatic macrophytes in the region have also evolved mechanisms of phytoremediation. The present review focuses on exploring the major aquatic macrophytes commonly found in the wetlands of North Bihar and their potential utilization for phytoremediation. These plants have the ability to accumulate and detoxify heavy metals, thus providing a natural means of reducing metal concentrations in the wetland ecosystem. By studying and harnessing the phytoremediation potential of these macrophytes, it is possible to mitigate the impact of heavy metal pollution and preserve the ecological balance of the wetland habitats in North Bihar.

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