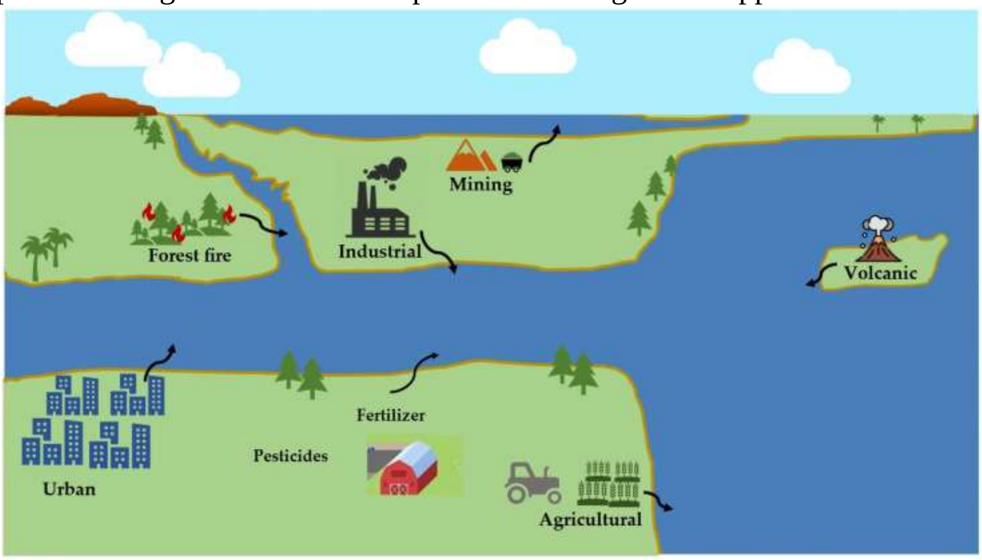
AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 06 Issue: 04 April 2025 Article No: 01

Heavy Metal Pollution of Aquatic Ecosystem and its Phytoremediation Using Algal Biomass

S. Deepan Rajesh[1], R. Arasi[2] and E. Inpent Campal[3]
[1]College of Fisheries, Lembucherra
[2]Fisheries College and Research Institute, Thoothukudi, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam
[3]Central Institute of Fisheries Education, Andheri (West), Mumbai, (M.S.)

SUMMARY
Heavy metal pollution in aquatic ecosystems has emerged as a significant environmental concern due to its persistence, bioaccumulation, and toxicity. Sources of contamination include industrial effluents, mining activities, agricultural runoff, and urban wastewater. These pollutants adversely affect aquatic life by disrupting physiological functions, bioaccumulating in organisms, and propagating through the food chain, posing severe risks to biodiversity and human health. Traditional remediation methods, while effective, are often cost-prohibitive and environmentally invasive. Phytoremediation using algal biomass has gained attention as an eco-friendly and cost-effective alternative. Algae exhibit remarkable biosorption capacities due to their cell wall properties, enabling them to sequester heavy metals efficiently. This review highlights the sources and impacts of heavy metal pollution in aquatic ecosystems and explores the potential of algal biomass for sustainable remediation strategies.

INTRODUCTION
Heavy metal pollution in aquatic ecosystems has become a pressing global issue due to its persistence, toxicity, and bioaccumulative nature. The rapid pace of industrialization, urbanization, and agricultural intensification has significantly increased the release of heavy metals such as cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), and mercury (Hg) into water bodies. These pollutants originate from diverse sources, including industrial effluents, mining activities, agricultural runoff, urban wastewater, and natural processes like volcanic eruptions and rock weathering. Once introduced into aquatic environments, heavy metals pose severe risks to ecological balance and human health. They are non-biodegradable and can accumulate in sediments, aquatic organisms, and the food chain, leading to toxic effects on both flora and fauna. For instance, heavy metals can disrupt physiological functions in aquatic organisms, impair reproduction, and reduce biodiversity. In humans, exposure to contaminated water or seafood can result in neurological damage, organ failure, and increased cancer risks. Traditional remediation methods for heavy metal removal such as chemical precipitation, ion exchange, filtration, and advanced oxidation processes are often effective but come with high costs and environmental drawbacks. These limitations have driven the exploration of eco-friendly and cost-effective alternatives like phytoremediation. Algae-based phytoremediation has emerged as a promising solution due to the high metal-binding capacities of algal biomass and its potential for large-scale application.



Origin of heavy metals in aquatic ecosystems

Many aquatic ecosystems have been subjected to industrial waste discharge. Domestic and agricultural pollution generating both organic and inorganic contamination, such as pesticides and heavy metals, are leading to widespread contamination of both surface and groundwater by runoff. Metals are introduced into the aquatic ecosystems as a result of weathering of soil and rocks, from volcanic eruptions and from a variety of human activities involving mining, processing and use of metals and/or substances containing metal contaminants. These heavy metals may also be derived from remobilization from natural soils due to the changes in local redox conditions and the corrosion of subsurface engineering structures due to prolonged submergence under acidic groundwater. Industrial activity has led to very high heavy metal concentrations on the environment, which are in general 100–1000 fold higher than those in the Earth's crust, and locally, living organisms can be exposed to even higher levels. In a river polluted by base-metal mining, cadmium was the most mobile and potentially bioavailable metal and was primarily scavenged by non-detrital carbonate minerals, organic matter, and iron-manganese oxide minerals. Although mercury is a naturally occurring element and it was always present in the environment, global human activity has led to a significant increase of mercury released into the atmosphere, aquatic environment and land. The most common treatment processes used include chemical precipitation, oxidation/reduction, ion exchange, membrane technologies, especially reverse osmosis, and solvent extraction. Each process presents advantages, disadvantages and ranges of applications depending on the metal ion, initial concentration, flow rate or raw water quality.

Phytoremediation of heavy metals by algae

Heavy metal removal mechanisms include sedimentation, flocculation, absorption and cations and anion exchange, complexation, precipitation, oxidation/reduction, microbiological activity and uptake. Microalgae remove heavy metals directly from polluted water by two major mechanisms; the first is a metabolism dependent uptake into their cells at low concentrations, the second is biosorption which is a non-active adsorption process. Phytoremediation is defined as a process of decontaminating soil and aquatic systems by using plants, fungi or algae to absorb heavy metals. Recently, the use of aquatic plants especially micro and macro algae has received much attention due to their ability to absorption of metals and taking up toxic elements from the environment or rendering them less harmful. The algae have many features that make them ideal candidates for the selective removal and concentration of heavy metals (Table 1), which include high tolerance to heavy metals, ability to grow both autotrophically and heterotrophically, large surface area/volume ratios, phototaxy, phytochelatin expression and potential for genetic manipulation. Macroalgae have been used extensively to measure heavy metal pollution and marine environments throughout the world. In recent years, several species of the green algae Enteromorpha and/or Cladophora have been utilized to measure heavy metal levels in many parts of the world.

Table 1: Uptake and accumulation of metals by some algal species

Species	Metal	References
Laminaria japonica	Zinc (Zn)	Fourest and Volesky
Tetraselmis chui	Arsenic (As)	Irgolic et al.
Spirogyra hyalina	Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As) and Cobalt (Co)	Kumar and Oommen
Sargassum vulgare	Lead (Pb)	Holan and Volesky
Sargassum fluitans	Copper (Cu)	Davis et al.
	Iron (Fe)	Figueira et al.
	Zinc (Zn)	Fourest and Volesky
	Nickel (Ni)	Holan and Volesky
Sargassum natans	Lead (Pb)	Holan and Volesky

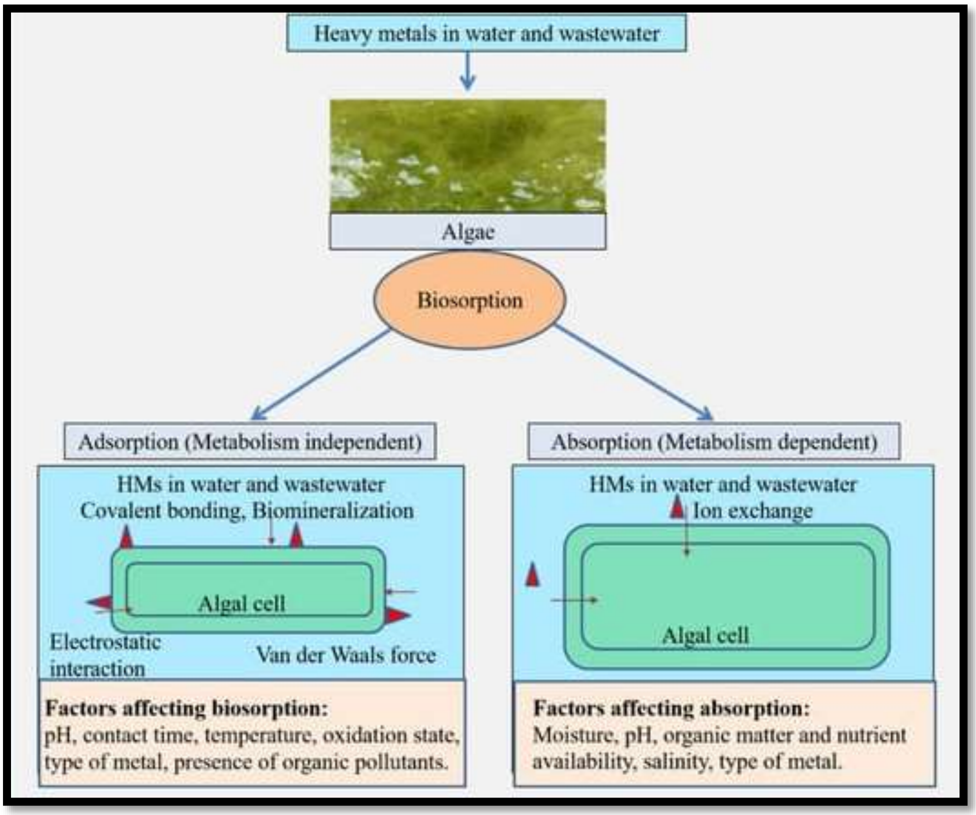
The brown algae (Phaeophyta) are particularly efficient accumulators of metals due to high levels of sulfated polysaccharides and alginates within their cell walls for which metals show a strong affinity. Some algal species may convert mercuric or phenylmercuric ions into metallic mercury which is then volatilized out of the cell and from the solution. The blue green alga Phormidium successfully can hyperaccumulate heavy metals like Cd, Zn, Pb, Ni and Cu. *Dunaliella salina*, a green microalgae, have high tendency for zinc accumulation followed by copper and cobalt, the lowest tendency was for cadmium, this may be due to the importance of zinc as hydrogen transferring in photosynthesis.

Mechanisms of Heavy Metal Uptake by Algal Biomass

Bioaccumulation: This process involves the uptake of heavy metals from the environment into the algal cells. Metals can be transported across cell membranes and sequestered in intracellular compartments, such as vacuoles. This helps in reducing the bioavailability of metals in the environment.

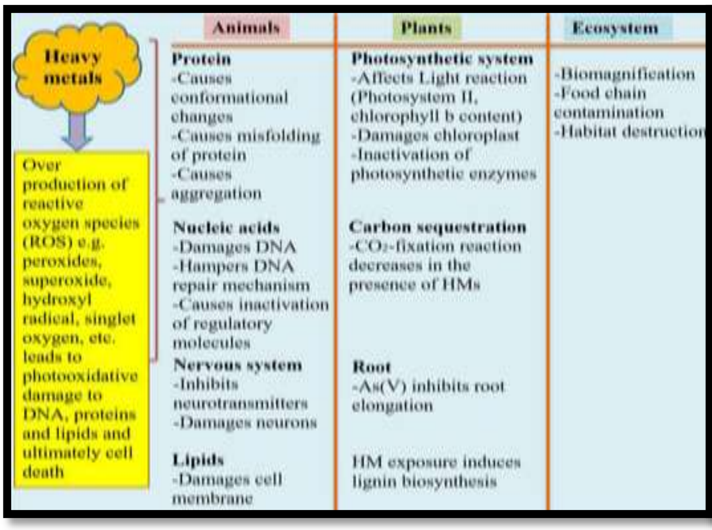
Biosorption: Algae have cell walls rich in polysaccharides, proteins, and lipids that can passively bind heavy metals. This binding can occur through various mechanisms, including ion exchange, complexation, and chelation, effectively removing metals from the aqueous phase.

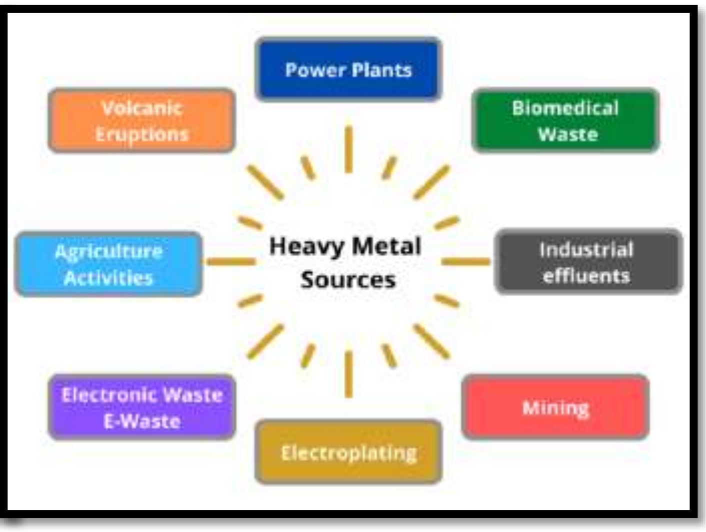
Biotransformation: Algae can alter the chemical state of heavy metals, converting them into less toxic or more stable forms. Processes like reduction, methylation, and complexation are part of this transformation, contributing to the detoxification of contaminated sites.



Heavy Metal Accumulation and tolerance Mechanism's in algae

Organisms respond to heavy metal stress using different defense systems , such as exclusion, compartmentalization, making complexes and the synthesis of binding proteins such as metallothioneins (MTs) or phytochelatins (PCs) and translocate them into vacuoles. Carboxylic and amino acids, such as citrate, malate, and oxalate, histidine (His) and nicotianamine (NA), and phosphate derivatives (phytate) are potential ligands for heavy metals and are found to play a role in tolerance and detoxification. Studying the absorption of heavy metals in higher plants, we found the greater accumulation of Al and B in our experiment may be related to the





high concentrations of pectins in the cell wall. This would provide the plants a strong tolerance to heavy metals and, therefore, greater phytoextraction. The adsorption, phytosorption and affinity of algae for heavy metal cations in wastewater treatment because of its high negatively charged surface (cell wall components) have been acknowledged for a long time. Two marine algae, *Thalassiosira weissflogii* and *Thalassiosira pseudonana*, produce phytochelatins in great amounts due to the higher activity of phytochelatin synthase, which has greater affinity for the glutathione substrate or metal ions.

CONCLUSIONS

Heavy metal pollution in aquatic ecosystems poses a significant threat to environmental health and human well-being. The persistence and toxicity of heavy metals necessitate the development of effective and sustainable remediation strategies. Algal-based phytoremediation has emerged as a promising solution due to the unique properties of algae, such as their high metal-binding capacity, rapid growth, and adaptability to diverse environments. Algae can efficiently remove heavy metals through biosorption and bioaccumulation, making them an eco-friendly alternative to conventional remediation methods. However, challenges such as the disposal of metal-laden biomass, the presence of multiple contaminants, and the scalability of the process need to be addressed to fully realize the potential of algal phytoremediation. Advances in biotechnology, including genetic engineering and the use of algal consortia, offer opportunities to enhance the efficiency and applicability of this approach. The accumulation of heavy metals by micro and macroalgae provides an advantage for phytoremediation over other methods which are more costly and not environmental friendly. Therefore, there is a need to improve the possibilities of accumulation of heavy metals in algae, using the genetic engineering to develop transgenic species overexpressing phytochelatins and metallothioneins that can form complexes with heavy metals and translocate them into vacuoles to maximize phytoaccumulation and the removal of toxic elements from the aquatic ecosystems.

REFERENCES

Al-Homaidan A. A., Al-Ghanayem A. A., Areej A. H., International Journal of Water Resources and Arid Environments 1 (2011) 10.

Cai, X. H., Logan, T., Gustafson, T., Traina, S., Sayre, R. T., Molecular Marine Biology and Biotechnology. 4 (1995) 338.

González, I., Águila E., Galán, E., Environ. Geol. 52 (2007) 1581.

Holan, Z. R., Volesky, B., Biotech Bioeng. 43 (1994) 1001.

Jain, C. K., Water Research. 38 (2004) 569.

Le Cloirec, P., Andrès Y., In Bioremediation of aquatic and terresterial ecosystems. 2005. ISBN 1-57808- 364-8.

Leung, C. M., Jiao, J. J., Water Research. 40 (2006) 753.

Mitra, N., Rezvan, Z., Seyed Ahmad, M., Gharaie, M., Hosein, M., International Journal of Ecosystem. 2 (2012) 32.

Payne, R. 2000. Spirulina as bioremediation agent: Interaction with metals and involvement of carbonic anhydrase. M.Sc. Thesis, Rhodes University

Payne, R. 2000. Spirulina as bioremediation agent: Interaction with metals and involvement of carbonic anhydrase. M.Sc. Thesis, Rhodes University

Mei, L., Xitao, X., Renhao, X., Zhili, L., Chinese Journal of Oceanology and Limnology. 24 (2006) 154.