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Review Article

Prospects and Challenges of Heavy Metal Pollution Mitigation in the Bay of Bengal by Phytoremediation

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Abstract

Heavy metal pollution, a grave concern due to its toxicity and longevity, has reached alarming levels in some coastal areas of the Bay of Bengal. Originating from shipbreaking industries, untreated industrial wastages, agricultural residues, and anthropological sources, this pollution has become a major environmental threat. It can enter the food chain and accumulate in the human body, posing a significant risk to human health. Due to the advancement of science, many sophisticated techniques have been developed in recent years to detect heavy metals in the environment. At the same time, some techniques have also been developed to remove heavy metals from the marine environment. However, the efficacy of these techniques has some doubt. Amidst this crisis, Phytoremediation, a plant-based method, offers a beacon of hope. This review delves into the dire consequences of heavy metal pollution in seawater, human health toxicity, and the crucial role of phytoremediation in mitigating this crisis.

Keywords: Heavy metal, Phytoremediation, Bioaccumulation, Bio amplification.

INTRODUCTION

Bangladesh, a small country of 1 47,570 sq. km boasts a nautical area of about 1, 18,813 sq. km [1]. The Bay of Bengal, one of the world's 64 largest marine ecosystems [2], is a treasure trove of aquatic biodiversity. It is settled in the northeast of the Indian Ocean and shares the edges of many countries, including Bangladesh, India, Myanmar, Thailand, and Sri Lanka [2]. The Bay of Bengal, with its vibrant coral reefs, unique species of marine life, and extensive mangrove systems, is a testament to the ecological richness of our planet.

The Bay of Bengal, with its extensive economic and social value, is not just a source of livelihood for many but also a hub of commercial activities and a popular tourist destination. It serves as a crucial trade route, facilitating seaborne trade that has seen a significant boost due to globalization. The sea supports various industries such as fertilizer, pharmaceutical, textile, food processing, shipping, pulp and paper, and cement, all of which are located near coastal areas and discharge their waste into the coastal water.

A study revealed that the shrimp industry near coastal areas uses multiple unprescribed antibiotics and 620 tons of urea per year and produces 15 tons of waste daily, directly coming to the sea and polluting seawater [2]. The Ganges, the Brahmaputra, and the Meghna Rivers are the most extensively popular river systems, which carry lots of sediments, industrial chemicals, agricultural wastage, pollutants, and heavy metals to the estuary, which leads to seawater. This is one of the most vital reasons for increasing pollution in the Bay of Bengal.

Recently, Bangladesh has been dominating the ship building and breaking industry. The shipbreaking industry has emerged in the coastal area of Bangladesh since 1969 because of increased demand for iron, revenue generation, and employment opportunities [3]. Every year, 60-65 ships are broken in Chattogram and Khulna ports (The Daily Star, November 4, 2019). Many studies have focused on the fact that the water of the Bay of Bengal and Karnaphuli River close to Chittagong port channels is highly polluted by heavy metals due to shipbreaking industries [4, 5].

This industry has endangered the adjacent atmosphere, seawater and ecological system by dumping hazardous waste from broken ships without following proper surplus management. Consequently, ship-breaking areas' water, soil and air are getting severely polluted. The biodiversity of terrestrial and marine habitats is in a vulnerable condition. As ship breaking occurs in open beaches, harmful substances such as Polycyclic Aromatic Hydrocarbon (PAHs), Polyvinyl Chloride (PVC), Polychlorinated Biphenyl (PCB), heavy metals (Hg, Cu, Pb, Ni, Fe, As, Cd, and some other harmful substances come in contact to the environment and pollute the seawater directly [6]. According to SDG 14.1, all countries should focus on reducing marine pollution by 2025. Removing heavy metals from water to mitigate their harmful environmental effects is crucial. Various methods and techniques have been developed and implemented to eradicate heavy metals from effluent, including physical, chemical, and biological processes.

1. Heavy Metal:

The definition of heavy metal is complex, and specialists have discussed it. They are defined as heavy metals due to their high atomic weight or high density [7]. But now the term 'heavy metal' has been used to describe metallic chemical elements and metalloids that are toxic to the environment, humans, and animals, such as chromium, iron, manganese, cobalt, nickel, copper, zinc, cadmium, led, mercury, zinc, etc. [7]. Some lighter metalloids and metals, such as selenium, arsenic, and aluminum, are also toxic. They are also called heavy metals; however, some heavy metals are harmless, such as gold. These heavy metals are non-degradable and bio-accumulating. These heavy metals come in the environment from different sources. When they come in contact with seawater, it causes pollution.

2. Sources of Heavy Metal in Sea Water:

Heavy metals persist in the environment from different resources and pollute environmental elements such as water, soil, etc. They are naturally found on the Earth's crust and emerge into the environment due to anthropological activities [8], industrial wastages, agricultural residues, and pollution from metal-based industries such as shipbreaking and building [9]. Pesticides, insecticides, and fertilizers used in agricultural fields are good sources of heavy metals that run off to the sea [10]. The sea has become a linchpin in the global trademark. Different industries have been built based on the sea. However, heavy metal contamination in seawater has become a significant threat to the environment and ecosystem. Even a trace amount of these toxic metals (Cr, Pb, Hg, Cd, Ni, etc.) can cause harm to humans, plants, and animals. Heavy metals in seawater can accumulate in the muscles of different marine fish and plants (Figure 1).

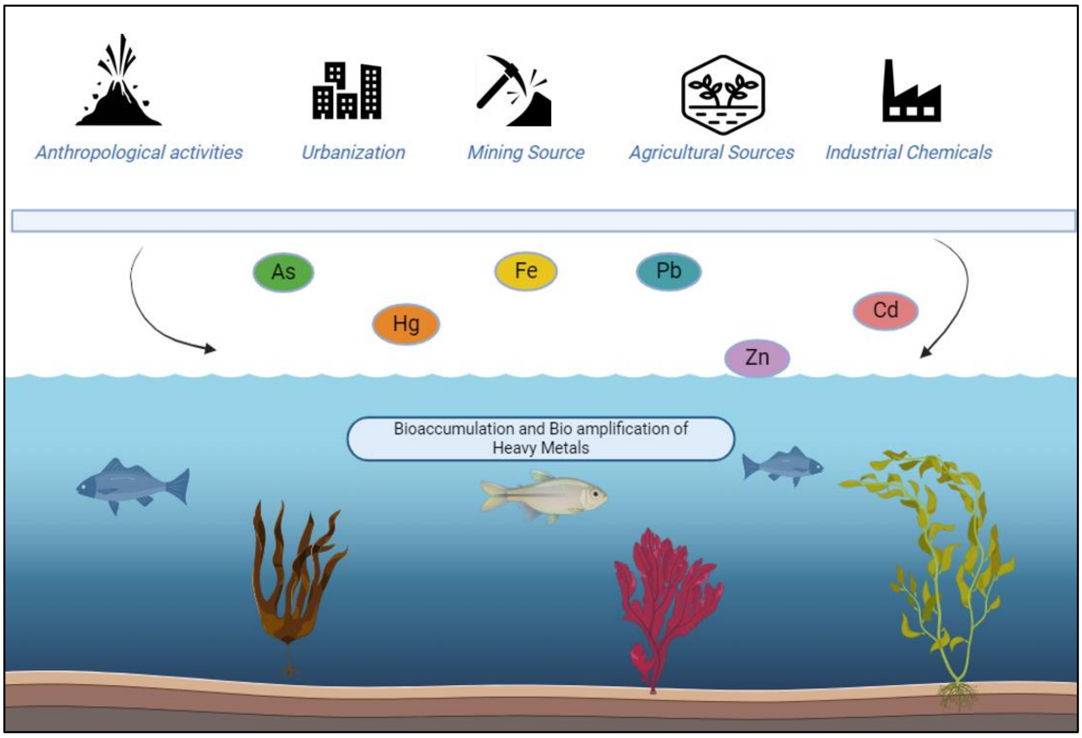

Figure 1: Heavy metals come from different sources in the sea and enter the food chain of aquatic animals

3. Impact of Heavy Metal Pollution:

Heavy metal pollution has become a global concern, and the increasing quantity of heavy metals has become a threat to aquatic and marine ecology, leading to human.

3.1 Risk to Ocean Health:

The solubility of heavy metal pollutants in seawater is controlled by several factors such as pH, temperature, salinity, nature of different anions, etc. Heavy metal pollutants (either in soluble or particulate form) introduced to the marine environment ultimately settle onto the seabed. Primary productivity is the basis of the marine food chain. Pollution through the shipping industry severely hampers primary productivity. Phytoplankton are the best index of biological productivity. However heavy metal pollution can affect the abundance and photosynthesis activity of phytoplankton. A study revealed that the occurrence and distribution of *Anabaena, Clostratum, Coscinodiscus, Euglena* and *Zygnema* in the shipbreaking area was very unsatisfactory [11]. The study also showed that the abundance of zooplankton was also quite low [11, 12].

3.2 Threat to Biodiversity:

Aquatic life is comprised of phytoplankton, zooplankton, macrophytes, benthos, benthic invertebrates, and fish. Heavy metal emergence in rivers and oceans has been a major threat to the existence of aquatic life. Much research has been conducted to demonstrate the fate of heavy metal contaminants along with the associated effects on the aquatic environment. Aquatic organisms uptake heavy metals through food and sediment particle ingestion. Heavy metal-contaminated water enters via the epidermis and gills of fish and is then transported inside the cells crossing biological membranes and ionic channels.

Heavy metals enter the aquatic body through consumption, damage DNA, initiate genotoxicity, create abnormal gene expression, break DNA strands, and disturb DNA-protein interaction. Due to heavy metal exposure to the ocean, the existence of aquatic life is at risk [13]. It generates reactive oxygen species (ROS) which results in oxidative modifications of DNA. Hydroxyl radicals change nitrogenous bases and break DNA. That's why the existence of aquatic life is at risk. Analysis of DNA damage in aquatic animals is the most dependable biomarker to study the level of genotoxicity caused by exposure to heavy metals in aquatic reservoirs. The most reliable biomarker is to analysis DNA damage to investigate the genotoxicity prevalence through comet assay or single cell-gel electrophoresis. Consumption of heavy metal containing aquatic animals can cause Minamata (organic mercury poisoning) and Itai Itai diseases (cadmium poisoning) [14]. The synergy of heavy metals with biochemical inducements in fish may prevent the communication of fish with their surroundings.

3.3 Impacts on Fish Existence:

The Bay of Bengal is a reservoir of different species of fish. But they are endangered and will become extinct soon if proper steps are not taken. Aquatic fishes uptake heavy metals through the ingestion of food and sediment particles. Heavy metal can also enter through the epidermis and gills of fish and then be transported inside the cells crossing biological membranes and ionic channels. Different species accumulate different heavy metals in their body. Pb accumulates in bivalve shells and Cd, Zn, and Mn accumulate in the tissue. Even amphibians accumulate Cd, Mn, and Zn in their early stages of life. Some species of fish are missing in the shipbreaking area of Bangladesh such as Koiputi (*Anodonotostoma chacunda*), Chapti mach (*Bahaba chaptis*), Kata mach (*Arius thalassinus*), Nandi bailla (*Gobius sadanandio*), Dora bailla (*Elotris fusca*), Khika mach (*Sphyraena forstegi*) [15]. Some endangered fish species are: Lakha (*Polynemus indicus*), Dora mach (*Apocryptes serperaster*), Foli chanda (*Stromateus chinensis*), Bhetki (*Lates calcarifer*) etc [16].

3.4 Detrimental Effect of Heavy Metal on Human Life:

Heavy metals can bioaccumulate and amplify by entering into the food web. Among all heavy metals, Hg, Cu, Zn, and Cd can quickly accumulate in organisms and harm the liver, lungs, kidneys, stomach, skin, and reproductive systems, even in trace amounts. These heavy, harmful and inorganic metals can be transferred to humans or any other animal through consumption, resulting in life-threatening diseases. Table 1 shows the detrimental effects of heavy metals.

Table 1: Harmful Impact of Heavy Metals on Human Health

Heavy metals	Diseases	Reference
Arsenic	○ Diabetes ○ Hypertension ○ Central nervous system impairment ○ Skin disorders ○ Gingitivitis	[17, 18, 19]
Lead	○ Disturbance in the central nervous system ○ Blood disorders ○ Neurological disorders ○ Oxidative stress	[20]
Cadmium	○ Carcinogenic	[18, 21]

Heavy metals	Diseases	Reference
	○ Organ toxicity ○ Induces apoptosis	
Nikel	○ Carcinogenic ○ Allergic reactions ○ Epigenetic effects	[21]
Zinc	○ Zinc poisoning ○ Liver failure, bloody urine, ○ Kidney failure	[22]
Iron	○ Lung cancer ○ Affects the central nervous system	[21]
Mercury	○ Damage to heart and brain ○ Respiratory diseases ○ Delayed mental development	[23]
Copper	○ Liver toxicity ○ Gastrointestinal disorder	[24]
Chromium	○ Lung disorder ○ Acidogenesis ○ Mutagenic	[25]

4. Worldwide Heavy Metal Sea Pollution:

Heavy metal pollution has been identified in the coastal regions of oceans and seas worldwide. Undoubtedly, it is a significant problem that directly affects marine life and indirectly affects human health and resources. Heavy metals are introduced to coastal regions and seawater through various sources and activities, including sewage and industrial waste gushing, atmospheric deposition, shipbreaking and shipwrecks, coastal modifications, mining activities, and oil pollution [26]. Worldwide, specialists fear heavy metal pollution in the ocean and its impact.

One of the world's most anthropogenically impacted locations is the Arabian Gulf. The Red Sea Gulf of Saudi Arabia was investigated to identify seawater pollution. The sea was highly polluted with heavy metals such as Zn, Ni, As, Cu, Mn, Fe, Pb, Sb, Co, Cr, Cd, and Hg [27].

Jinzhou Bay is northwest of the Liaodong Gulf and east of the Bohai Sea, severely contaminated by Cu, Pb, Zn, Cd, Hg, and As [28].

Untreated or partially treated industrial and domestic wastewater is discharged directly or carried by different streams into the Karachi coastal water, which results in heavy metal pollution [29].

The surface seawater of Dalian Bay, People's Republic of China, was investigated and found to be highly heavy metal (Cu, Zn, Pb, As, Hg, Cd) contaminated [30].

The Ennore estuary situated on the southeast Coast of India is one of the most significant marine ecosystems, which receives effluent discharges from industry and is an extremely occupied area. The highest concentration of heavy metal observed in Cu was $47.27\pm1.78 \mu gL^{-1}$, and the lowest concentration observed in Hg was $1.78\pm0.20 \mu gL^{-1}$ [31].

5. Heavy Metal Pollution in the Bay of Bengal:

The Bay of Bengal is also getting polluted with heavy metals. Rivers carry many sediments, industrial hazardous elements, agricultural waste pollutants, and heavy metals to the estuary, leading to seawater. This is one of the most vital reasons for increasing pollution in the Bay of Bengal. Chittagong is the country's largest port and coastal city. Approximately 200 ships and 200000 LDT of different categories of ships are recycled annually in different yards in Bangladesh [32]. A recent study has been conducted on heavy metal concentration in seawater collected from the coastal region of Chittagong City. It was highly polluted with toxic heavy metals Fe (23.68 mg/L), Mn (1.136 mg/L), Pb (0.452 mg/L), Cu (0.164 mg/L), Cd (0.012 mg/L), Ni (0.0066 mg/L) which is quite alarming [33].

This is caused by stress from industrial effluents. Ship industries discharge wastewater directly into the sea without treatment, causing long-term harm to marine ecosystems, aquatic life, and seawater. So, we need a convenient treatment method to remove heavy metals from seawater.

6. Conventional Heavy Metal Treatment Methods:

Heavy metal removal techniques from wastewater have received considerable attention recently and worldwide concerns are developing efficient and eco-friendly removal methods. Different studies have been conducted to treat water containing heavy metals and organic pollutants. It is important to evaluate and select an appropriate treatment method that is economical, environmentally friendly, and easy to apply. Physical, chemical, and biological methods are used to treat wastewater [34]. Photocatalysis, chemical precipitation, flotation, membrane filtration, etc. are common treatment methods with some limitations. Physio-chemical methods are uneconomical and produce large volumes of chemical waste. Bioremediation is a technique where all the limitations can be recovered. Table 2 shows the comparison of bioremediation over other heavy metal treatment methods.

Table 2: Comparison of Bioremediation over Heavy Metal Treatment Methods

Process	Mechanism	Advantages	Limitations	References
Photocatalysis	Mineralization or breakdown for complex contaminants, Heavy metal ions in water can be removed by reducing toxic high valence ions into low valence ions or zero valence metals.	Highly effective, Non-selective Reusable for multiple times.	Costly Complicated to handle, transport and storage of effluents	[35]
Chemical precipitation	Precipitates filths through altering pH, electro-oxidizing potential or coprecipitation using precipitating agents	Easy technology Economic Efficient for removing heavy metals Non-selective	Complicated and non-eco-friendly Ineffective to remove metal ions at low concentration Requires an additional oxidation step for complex metals High sludge production	[36]
Coagulation / flocculation	charge neutralizing of fine particles and then promoting the clumping of these particles together by flocculating agents	Simple process Inexpensive Significant reduction of heavy metals, chemical oxygen demand, organic carbon and adsorbable organic halogen	Require non-reusable coagulants, flocculants etc. Difficult to manage and treat increased sludge volume Inefficient to remove arsenic	[37]
Flotation process	Works by introducing air bubbles into contaminated water to rise the suspended contaminants to the outward.	Removes small and low-density particles, low retention time	Metal selective, Selectivity depends on pH High maintenance and operation cost	[36, 38]
Electrochemical treatment	Electrolysis	Efficient technology for recovering valuable metals More effective and rapid organic matter separation pH control is not mandatory	High cost of equipment High maintenance cost for anodes Requires additional chemicals such as salts, coagulants etc. Sludge deposition on electrodes can stops the continuous process Requires post treatment to remove ions	[39]
Reverse osmosis	Semi-permeable membrane is used to remove larger particles and a pressure is applied to overcome osmotic pressure.	No chemicals are required Efficient elimination of particles Suspended solids, volatile and non-volatile matter	High maintenance and operation cost Membrane clogging, poor water permeability The choice of membrane depends of membrane filtration Pretreatment required	[40]
Ion -Exchange	Ions of water are exchanged for other ions fixed to beads	Easy to use with other techniques Produce high quality effluent	Beads and reactors get clogged matrix gets degrade	[41]

Process	Mechanism	Advantages	Limitations	References
		Comparatively inexpensive Efficient for metal removal Can be applied as continuous or batch system	pH sensitive	
Bioremediation	Bacterial bioremediation Fungal bioremediation Algal bioremediation Plant bioremediation or Phytoremediation	Easy to apply Inexpensive, low capital investment Fast High growth rate	Need to monitor continuously Sometimes detrimental at high concentrations of heavy metal	[42]

7. Bioremediation:

Bioremediation is one of the most effective methods which is cost-effective, environmentally friendly, and overcomes the limitations. Bioremediation is a process of reducing, detoxifying, degrading, mineralizing, or transforming more toxic pollutants to less toxic ones through living organisms such as plants, bacteria, fungi, etc. Bioremediation came into extensive usage as it is an eco-friendly and cost-effective method. In recent years, researchers have advanced different bioremediation techniques that remove pollutants from the environment. Bioremediation can be bacterial, fungal, algal, or plant based.

7.1 Bacterial Bioremediation:

Bacterial Bioremediation is a process where bacteria are applied to transform heavy toxic metals into less harmful state [43] Bacteria have some unique features such as large exterior area, quick growth, high resistance to toxic heavy metals [44], catabolic potentiality, and production of enzymes and biosurfactant which enhance their remediation capacity [45]. Biofilm-mediated remediation techniques have been anticipated for cleaning up heavy metal-contaminated area. It has been reported that *Bacillus thuringiensis* removes 62 % Hg [46], *Klebsiella* spp. removes approximately 97% Pb [47], *Pseudomonas azotoformans* JAW1 removes 98.5 % Cd [48]. Bacterial bioremediation has some limitations such as high concentrations of heavy metal can be inhibitory to bacterial growth, it becomes difficult to monitor temperature, pH, nutrient availability.

7.2 Fungal Bioremediation/ Mycoremediation:

Mycoremediation or fungal bioremediation is the application of fungus (dead or alive) to eradicate environmental contaminants [49]. Fungi and Yeast can accumulate heavy metals for micronutrients and non-nutrient metals in higher amounts than the nutritional requirements [50]. Fungal biomass has the potential to work as a biosorbent for removing heavy metals and radionuclides from polluted waters [51]. Fungi are robust, abundant, and easy to grow. Mycoremediation can be a low-cost method with no hazardous waste. However heavy metals may cause cell lysis of fungi. The selection and use of an appropriate fungal species for the target heavy metal is crucial to the efficiency of mycoremediation.

7.3 Algal Bioremediation/ Phycoremediation:

Heavy metals like Molybdenum, copper, zinc, nickel, manganese, iron, and cobalt are trace elements in algae that benefit algal growth [52]. Even Microalgae are outstanding bioremediators of silver, gold, aluminum, mercury, titanium, cadmium, lead, and arsenic which are not necessary for algal growth. Algal species are resistant to heavy metal stress. Microalgae can form complexes with heavy metals with reactive and active binding sites. Though it is a cost-effective remediation method, algal biomass separation from water is quite expensive. This treatment is limited to specific geographical locations [53]. Temperature creates an impact on the growth. It is a time-consuming procedure. Accumulation of heavy metals in algae can result in entering food chain.

7.4 Phytoremediation:

Many developed countries have developed different approaches to mitigate heavy metals from seawater, but all of them are highly expensive and complex. Phytoremediation can be an alternative way to clean up contaminants from the environment. The word 'Phyto', which means 'Plant' is derived from the Greek word and the Latin word 'remedium', which means 'cure' [54]. Phytoremediation is the application of plants to remove contaminants from polluted environments. This method is better than any other conventional and bioremediation methods. This in situ method is eco-friendly, cost-effective, and reduces soil erosion, removes hazardous, non-biodegradable, inorganic heavy metal contaminants from the environment. The resulting biomass can be a good source of electricity and heat by burning [55]. It is a carbon-dioxide-neutral technology.

Many studies have revealed that plants are suitable for remediation as they harbor different detoxifying pathways to mitigate harmful toxic heavy metals. Other plant parts such as -roots, stems, and leaves work as reservoirs of heavy metals and decrease the content of heavy metals in seawater. However, the ability to accumulate heavy metals varies significantly between species. There are different categories of phytoremediation, such as – phytoextraction, phytostabilization, phytovolatilization, phytoaccumulation, and phytodegradation [56]. Other species of plants use other mechanisms to remove heavy metals. Many studies have been conducted worldwide to illustrate the status of plants and their mechanism to remove heavy metals. Phytoremediation overcomes all other limitations. Table 3 shows the plant species have the potentiality to remove heavy metals.

Table 3: Plant Species used for removing heavy metals

Species	Family	Country	Contaminants	Phytoremediation process	References
Azolla filiculoides	Salvi-niaceae	Chile	Cd, Cu, Pb	Phytoextraction	[57]
Azolla caroliniana	Salvi-niaceae	India	Cu, Ni, Cr	Phytoaccumulation	[58]
Cyperus alternifolius	Cyperaceae	India	F	Phytoaccumulation	[59]
Eichhornia crassipes	Pontederiaceae	India, Nigeria	As, Hg, Ni, Pb, Zn, Cu, Ag	Phytoaccumulation	[60, 61]
Lemna gibba	Araceae	Germany	U, As	Phyto extraction	[62]
Juncus effusus	Juncaese	China	Pb	Phytodegradation	[62]
Ipomoea Aquatica	Convolvulaceae	Iran, Sri-Lanka	Pb, Cr	Rhizofiltration	[63, 64]

7.4.1 Advantages of Phytoremediation:

Phytoremediation is regarded as a green remediation technology with enormous possibilities. This remediation has multiple advantages with some limitations. This method is time-consuming. But this method is more beneficial than other methods. The advantages of phytoremediation are described below in detail:

- It is a bioremediation method with an autotropic system powered by solar energy and low-budget investment. It is an eco-friendly method as it reduces pollutants [65].
- This green technology can be used for both in-situ and ex-situ applications.
- Through this procedure, bioaccumulation and bioamplification can be avoided. Edible crops are avoided. Fiber crops can be used, such as Kenaf (Hibiscus cannabinus L.) and flax (Linum usitatissimum). Harvested fiber can be further used to manufacture biomaterials such as paper, textiles, etc. [66].
- Plants have several unique cellular structures and use different physiological processes to maintain homeostasis and combat heavy metal contamination.
- Some metals can be recovered from plant tissue (such as potash) which can be economically valuable.
- Plants can tolerate large concentrations of heavy metal, but some hyperaccumulating or metal-tolerant species have been investigated. Plants can accumulate and subsequently metabolize organic and inorganic toxic materials.
- The ability of bast fiber plants can be increased by using chemical amendments in the soil such as 1,2-cyclohexane-diaminetetraacetic acid (CDTA), ethylene glycol tetraacetic acid (EGTA), diethylene-triaminepentaacetic acid (EDTA). these chemicals can increase the solubility, absorption and complexation of metals [67].
- Plants have undergone some treatments (foliar spray of humic acid and gibberellin) to enhance their absorbance capability [68, 69].
- In phytoremediation technology, there is no need for excess nutrients. The addition of an excessive amount of nutrients can result in a significant reduction of plant growth as well as the uptake of heavy metals [70].
- The microbes inhabiting different plant parts directly improve the efficiency of the phytoremediation process. Those microbes help to generate different phytohormones, siderophores, etc. A study conducted on maize revealed that siderophore-producing bacteria can increase the accumulation of heavy metals [71].

8. CONCLUSION

Heavy metal contaminants come to seawater from both man-made and natural resources. Heavy metals from untreated industrial waste are split into seawater, which results in bioaccumulation and bioamplification. The heavy metal concentration in the Bay of Bengal coast is remarkably high. Different techniques have been evolved to mitigate heavy metal pollution from seawater. Phytoremediation is a technique that is quite cheap, convenient, and easier to apply than any other technique. Plants that have the capacity to remove heavy metals can be treated with specific chemicals to increase their adsorptivity. Such an increase in adsorptivity will greatly increase their capacity to remove heavy metals from the environment. Besides, formulations can be developed using different combinations of heavy metal-removing herbs. Such formulations will be relatively cheap compared to other heavy metal-removing techniques. However, the regulatory committee should give the most attention to controlling industrial discharge from shipbreaking yards. Proper management practices and the Government must be employed to regulate heavy metal contamination.

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