

Heavy Metal Uptake Potential of Aquatic Plants through Phytoremediation Technique - A Review

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Abstract

Bioremediation means using biological agents to clean environment. Heavy metal pollution being the core all over the world needs immediate attention so that our degrading environments will be remediated. Phytoremediation is an ecofriendly that has shown promising results for the contaminants like heavy metals. The basic fundamental elements in phytoremediation are plants whether terrestrial or aquatic which play key role for remediation of heavy metal affected environments. Phytoremediation has also been a solution for various emerging problems.

Keywords: Bioremediation; Phytoremediation; Environment; Pollution

Introduction

Water and land- the important natural resources are required for the sustainability of mankind in nature. However due to increased industrialization and urbanization these resources are facing severe pollution. Heavy metal pollution is a worldwide concern [1] especially in water and soil and all the countries throughout the world are severely affected by the above said problem. Heavy metals are the high density metallic chemical elements and are among the important class of contaminants in the environment. The concentration of heavy metals in the environment has increased as a result of various anthropogenic activities like burning of fossil fuels, discharge of municipal wastes, use of fertilizers and pesticides etc. This increase of heavy metal concentration is a major concern to both humans and ecosystem [2], because of their non-biodegradable nature. Instant and necessary measures are required to remediate such polluted systems. Of all the remediation technologies, phytoremediation has been preferred because of its cost-effectiveness, ecofriendly nature [3] and simple maintenance [4].

Phytoremediation is a novel strategy and an integrated multidisciplinary approach which provides a great potential to treat such polluted systems using plants [3,5,6]. Many conventional methods are very expensive, laborious and don't provide the acceptable results. Phytoremediation, serves an ecological alternative, has gained increasing attention since last decade as an emerging cheaper technology.

Aquatic plants are of special interest, because they are capable of bio-accumulating toxic metals and nutrients in large quantities in comparison to terrestrial plants [7]. In addition, based on biochemical composition, habit, species, abundance and environment, these macrophytes has been found to absorb these pollutants at different rates and efficiencies. Studies have found that during the pollutant stress these plants produce metal-binding cysteine-rich peptides (phytochelatins), which detoxify heavy metals by forming complexes with them [8]. Plants are capable of removing the metal contamination from water as well as from soil. Aquatic plants of all types whether free floating, submerged or emergent's all are known for removing heavy metals.

The main focus of this paper is to discuss the potential of phytoremediation technique to treat heavy metal contaminated sites, to provide information about the mechanisms adopted by plants for heavy metal uptake and also to give a brief list of aquatic plants efficient for remediation of various metals.

Heavy Metals

Heavy metals are defined as metallic elements that have a relatively high density compared to water. Heavy Metals are defined as high density metallic elements with atomic no. >20. Heavy metal contaminants that are commonly found in the environment are cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn). No doubt Some of these are necessary for plant growth and are known as micronutrients such as Zn, Cu, Mn, Ni and Co, while others (Cd, Pb and Hg) have unknown biological functions [9]. Biological systems are affected by the metals and do not undergo biodegradation but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations [10].

Chromium (Cr)

Chromium abbreviated as (Cr)- is the Most abundant element in the Earth's mantle that are widely used in industry as alloying, tanning of animal hides, plating, inhibition of water corrosion, textile dyes, ceramic glazes, refractory bricks, and pressure-treated lumber [11]. Environmental contamination increased due to wide anthropogenic use of Cr and has become an increasing concern in the last 10 years [12]. Chromium exists in several oxidation states, but the most stable and common forms are Cr (0), the trivalent Cr (III) and the hexavalent Cr (VI) species. As Cr (VI) and Cr (III) present different chemical, toxicological, and epidemiological characteristics, they are regulated by EPA differently, gives Cr a unique characteristic among the toxic metals [13]. Cr (VI) which is considered a human carcinogen [10] and is also toxic to many plants [14], aquatic animals [15], and microorganisms [16] While as on other hand Cr (III) is considered a micronutrient in humans, being necessary for sugar and lipid metabolism and is generally not harmful.

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Received June 29, 2017; **Accepted** July 24, 2017; **Published** July 26, 2017

Citation: Wani RA, Ganai BA, Shah MA, Uqab B (2017) Heavy Metal Uptake Potential of Aquatic Plants through Phytoremediation Technique - A Review. J Bioremediat Biodegrad 8: 404. doi: [10.4172/2155-6199.1000404](https://doi.org/10.4172/2155-6199.1000404)

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Cadmium (Cd)

The most dangerous metal that is cadmium and is characterized by high stability and toxicity is non-degradable and this property allows it to stay in circulation when it is released to the environment. Cadmium finds its fate in water bodies when its released from industrial waste water treatment plants [17,18]. The main characteristics of cadmium are that it is an odorless, silver-white, blue -tinged or grayish- white powder, having an atomic weight of 112.4. Other characteristic feature of cadmium is that all cadmium compounds have an oxidation state of +2. Cadmium cause cancers [19] and oxidative stress when it binds with essential respiratory enzymes [20].

Nickel (Ni)

Nickel – a metal that belongs to transition series is a silvery white metal that is hard and ductile and mostly used in metallurgical processes such as electroplating and alloy production as well as in nickel-cadmium batteries. When it comes to occurrence of this transition metal it is primarily found in combination with oxygen as oxides or sulphur as sulphides that occur naturally in the earth's crust. When it comes to the toxicity of nickel, it follows the same trend as other metals i.e., its toxicity is dependent on the route of exposure and the solubility of nickel compound also plays an important role [21]. The main characteristic feature of nickel is that it is not destroyed in the body but its chemical form may be altered. The metabolic activity of nickel is reflected by its binding ability to form ligands and its transport throughout the body.

Zinc (Zn)

The most common element that is found in the earth's crust is zinc and is found in all three spheres of earth that is atmosphere, hydrosphere and lithosphere and we can say that zinc has shown its presence in the biosphere and is present in all foods. The main use of zinc is that it is used as anti-rusting agent that helps to prevent rust and corrosion which otherwise cause damage to steel and iron. For the proper functioning of metalloenzymes viz alcohol dehydrogenase, alkaline phosphatase, carbonic anhydrase, superoxide dismutase, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) polymerase, zinc is an essential nutrient needed by humans and animals. For normal protein, nucleic acid and membrane metabolism, zinc plays an important role. Zinc also plays an important role in growth and division of cells. Zinc deficiency may have an impact on carcinogenesis, though the direction of the influence seems to vary with the agent [22,23]. Therefore, certain levels of zinc intake are recommended.

Arsenic (As)

Arsenic is a silver-grey brittle crystalline solid with atomic number "33" and atomic weight of "74.9". Arsenic is odorless, tasteless and exists in the -3, 0, +3, and +5 valence oxidation states [24] and in various chemical forms in natural waters and sediments [25]. Two most common forms in natural waters are arsenite (AsO_3^{3-}) and inorganic arsenate (AsO_4^{4-}), referred as As^{3+} and As^{5+} .

Arsenic that is found in the environment is one of the contaminants which is highly toxic to man and other living organisms [26]. It is generally found that the inorganic species, arsenite and arsenate are the predominant species in most environments than organic ones which might also be present [27]. In general, inorganic compounds of arsenic are regarded as more toxic than most organic forms [28,29].

Heavy Metal Uptake Mechanisms Adopted by Plants

Phytoremediation is an ecofriendly technology that uses natural

or genetically modified plants, with their associated rhizospheric microorganisms which stimulate plant growth and decontaminate soil and water in combination with the plants [3]. Phytoremediation is a well-planned cleanup technology for a variety of organic and inorganic pollutants. Plants extract metals, hydrocarbon compounds and man-made chemicals such as herbicides, fungicides, pesticides and antibiotics. Phytoremediation is an environmental friendly, cheap, efficient and most reliable as it helps to remove the contamination. Plants possess and use a variety of mechanisms to deal with the contaminations especially heavy metals, hydrocarbon compounds and man-made chemicals such as herbicides, fungicides, pesticides. Plants sequester them in their cell walls. Plants chelate these contaminations in the soil in inactive forms or complex those in their tissues and can store them in vacuoles, away from the sensitive cell cytoplasm where most metabolic processes occur. Organics may be degraded in the root zone depending on their properties of plants or taken up, followed by degradation, sequestration, or volatilization. Successfully phytoremediated organic pollutants include organic solvents such as TCE (the most common pollutant of groundwater) [30], herbicides such as atrazine [31]. Explosives such as TNT [32], petroleum hydrocarbons, and the fuel additive MTBE [33] and polychlorinated biphenyls (PCBs). Phytoremediation is an emerging technology that uses plants to remove contaminants from soil and water [34].

Plants also make chelating cysteine-rich peptides and small proteins such as metallothioneins and phytochelators that are stored safely in vacuoles. Finally, plants can volatilize certain metals like highly toxic mercury (Hg^{2+}) and methyl mercury. Plants have evolved highly specific and more efficient mechanisms to obtain essential micronutrients from the environment, even when present at low ppm levels. Plants that are used in phytoextraction strategies are termed "hyperaccumulators." They are the plants that achieve a shoot-to-root metal concentration ratio greater than one. To be an ideal hyper-accumulator, a plant should thrive in toxic environments, require little maintenance and produce high biomass, although few plants perfectly fulfill these requirements [35]. Metal accumulating plant species can accumulate heavy metals like Cd, Zn, Co, Mn, Ni, and Pb up to 100 or 1000 times than those taken up by nonaccumulator (excluder) plants (Eddie et al.). Thus, a hyperaccumulator will concentrate more than: 10 ppm Hg; 100 ppm Cd; 1,000 ppm Co, Cr, Cu, and Pb; 10,000 ppm Ni and Zn. Approximately 400 plant species from at least 45 plant families have been reported to hyperaccumulate metals. Most hyperaccumulators bioconcentrate Ni, about 30 absorb Co, Cu, and/or Zn, and even fewer species accumulate Mn and Cd.

Phytoremediation technologies which are used for the uptake of heavy metals include mechanisms of phytoextraction, phytostabilisation, rhizofiltration, and phytovolatilization.

Phytoextraction

Phytoextraction method involves plants to uptake the contaminants through roots and translocate them within the plants, which are then removed by harvesting the corresponding plant. Phytoextraction method is most suitable to remove contaminants from soil, sediment and sludge [36]. Plants possess the ability to extract large concentrations of heavy metals through roots and accumulate them into the above ground parts of plants and produce a large quantity of plant biomass [37].

Phyto stabilization

Phyto stabilization is used for the remediation of soil, sediment, and

Process	Function	Pollution	Medium	Plants
Phytoextraction	Removes metal pollutants that accumulate in plants. Removes organics from soil by concentrating them in plant parts	Cd, Pb, Zn, petroleum, hydrocarbons and radionuclides	Soil and ground water	<i>Viola baoshanensis</i> , <i>Sedum alfredii</i> , <i>Rumex crispus</i>
Phytotransformation	Plants uptake and degrade organic compounds	Xenobiotic substances	Soil	<i>Cannas</i>
Phytodegradation	Plants and associated microorganisms degrade organic pollutants	DDT, Explosives and nitrates	Ground water	<i>Elodea Canadensis</i> , <i>Pueraria</i>
Rhizofiltration	Absorbs mainly metals from water and waste streams	Cd, As, Pb, Zn	Ground water	<i>Brassica juncea</i>
Phytostabilization	Uses plants to reduce the bioavailability of pollutants in the environment	Cu, Cd, Cr, Ni, Pb, Zn	Soil	<i>Anthyllis vulneraria</i> , <i>Festuca arvensis</i>

Table 1: Showing types of phytoremediation, functions, plant species which remove the pollutants [3].

S. No.	Researcher	Research scale	Contaminant/contaminants	Plant/plants	Results
1.	[43]	Water (25, 50, 75 mg/l) for 1-7 days	Pb	<i>Ceratophyllum demersum</i> and <i>Myriophyllum spicatum</i>	Plants accumulated high amount of Pb and thus showed potential to be used as phytoremediator species in aquatic bodies having moderate Pb pollution
2.	[44]	Water (3.714, 4.952 mg/l)	Cd	<i>Ceratophyllum demersum</i>	<i>C. demersum</i> has strong ability to eradicate the cadmium in ecosystem
3.	[45]	Water 50 µM Cr(VI) solution in laboratory conditions	Cr	<i>Utricularia gibba</i>	<i>U. gibba</i> may be efficient in the removal of chromate over a short time scale
4.	[46]	Water under laboratory conditions	Cd, Pb, Zn, and Cu	<i>Lemna minor</i> , <i>Elodea canadensis</i> , and <i>Leptodictyum riparium</i>	The three species examined can be considered good bioaccumulators for all the metals tested, with the exception of <i>E. canadensis</i> that showed BCF for Pb < 1000
5.	[47]	Water of Iset' river, Ural region, Russia	Cu, Fe, Ni, Zn, and Mn	<i>Ceratophyllum demersum</i> L. and <i>Potamogeton alpinus</i> Balb	The elucidated features allowed <i>C. demersum</i> to accumulate high concentrations of heavy metals than <i>P. alpinus</i>
6.	[48]	Water and soil (1.0, 2.0, 4.0, 8.0 and 16.0 mg/ L)	Ni	<i>Scirpus mucronatus</i> , <i>Rotala rotundifolia</i> and <i>Myriophyllum intermedium</i>	<i>M. intermedium</i> accumulates considerable amount of Ni compared to <i>S. mucronatus</i> and <i>R. rotundifolia</i>
7.	[49]	Water of El-Temsah Lake	Cd, Co, Cu, Ni, Pb and Zn	<i>Ceratophyllum demersum</i> , <i>Myriophyllum spicatum</i> , <i>Eichhornia crassipes</i> , <i>Lemna gibba</i> , <i>Phragmites australis</i> and <i>Typha domingensis</i> .	The inspected native aquatic plant species showed higher levels of heavy metal accumulation which has the potential to be used in the phytoremediation.

Table 2: Plants investigated for phytoremediation potential on water medium (hydroponics).

sludge. The basic operation of this method involves that plants produce certain chemicals which immobilize the contaminants rather than degrading them and thus preventing their relocation to groundwater or their access into food chain [38]. The mechanism of Phyto stabilization is simple and it occur through the sorption, precipitation, complexation, or metal valence reduction and because of these properties this method is commonly used to treat the metals like arsenic, cadmium, chromium, copper and zinc contaminants [39].

Rhizofiltration

Rhizofiltration is the intentional use of the plants belonging to both ecosystems whether terrestrial or aquatic, to absorb, concentrate and accumulate contaminants from polluted aqueous sources in their roots [5]. But in order of preference terrestrial plants are more preferred over aquatic plants because they have a fibrous and much longer root system which increases the amount of root area and effectively removed the potentially toxic metals [40]. It is also known as Hydroponic Systems for Treating Water Streams. Rhizofiltration is mainly used to remediate surface water, extracted groundwater and waste water with low concentrations of contaminant. It can also be used for Pb, Cd, Cu, Ni, Zn, and Cr which are chiefly retained within the roots.

Phytovolatilization

Phytovolatilization involves the use of plants to uptake the contaminants from soil and waste water and transforming them into volatilized compound and then transpiring them into the atmosphere

is known as phytovolatilization [41]. It is primarily used for mercury contaminated soil. In this method the growing trees and other plants may uptake the contaminants with water and pass them through the xylem vessels towards the leaves, converted into nontoxic forms and may finally volatilize them into the atmosphere [42].

Aquatic Plant Species Studied for Phytoremediation

Various plant species studied for phytoremediation includes *Azolla pinnata*, *Lemna minor* accumulates Cu and Cr, *Pistia stratiotes* accumulates Ag, Cd, Cr, Cu, Hg, Pb and Zn, *Lemna gibba* biosorbs as, *Myriophyllum heterophyllum* and *Potamogeton crispus* accumulates Cd. Some aquatic plants investigated for phytoremediation potential on water medium (hydroponics) are shown in Tables 1 and 2.

Conclusion

Heavy metals are the high density metallic chemical elements and are among the important class of contaminants in the environment. Heavy metal pollution has emerged as a very serious problem worldwide. Immediate measures are required to remediate such problem and of all measures phytoremediation technique is preferred because of its cost effectiveness, efficiency and environment friendly nature. Plants used in this technique adopted a variety of mechanisms to deal with heavy metals. Heavy metals form one of largest category of contaminants that are efficiently removed by aquatic plants. Various plant species studied for phytoremediation accumulated considerable amounts of metals and

thus proved to be highly potential for being used as phytoremediator species in aquatic bodies contaminated with heavy metal pollution.

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