Heavy Metal Intrusion and Accumulation in Aquatic Ecosystems

Khursheed Ahmad Wani, Javid Manzoor, Ashaq Ahmad Dar, Razia Shuab, and Rafiq Lone

Abstract Most of the heavy metals have deleterious impacts on the growth and productivity of the plants, and also alters the general physiological characteristics of plants. But, some plants cope with the pollution stress and accumulate more and more toxic and heavy metals in their modified tissues. These toxic substances not only affect the plant physiology, but have toxic impacts on soil health. The toxic metals, in context to many organic compounds are not decomposed by the microbiological activity. Toxic levels of Lead (Pb), Cadmium (Cd) and Mercury (Hg) affects plant processes at physiological and biochemical levels some of the heavy metals are accumulated in aquatic environment and most of them get absorbed in the aquatic plants. Theretofore, a miscellaneous positive correlation among selected aquatic plants and specific heavy metals was reported, however mechanism of a particular model species is still vague. The intrusion of heavy metals may also change the nutrient pool of the aquatic ecosystem that may affect the overall productivity of the system. The work will review some of the important heavy metals, the plants that are useful to reduce the concentration of these metals from different ecosystems.

Keywords Heavy metals · Phytoremediation · Tolerance · Growth · Productivity · Toxicity

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K. A. Wani (✉)
Department of Environmental Science, Govt Degree College,
Bijbehara, Jammu and Kashmir, India

J. Manzoor
Department of Environmental Science, Jiwaji University Gwalior, Gwalior, India

A. A. Dar
Department of Ecology and Environmental Science, Pondicherry University,
Puducherry, India

R. Shuab
Department of Botany, University of Kashmir, Srinagar, India

R. Lone
Department of Botany, SBBS University, Jalandhar, Punjab, India

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1 Introduction

Heavy metals are the high density metallic compound components and are among the essential class of contaminants in the earth. The concentration of heavy metals in nature has expanded because of different anthropogenic activities like burning of petroleum derivatives, release of waste, utilization of fertilizers and pesticides and so forth (Mehmood et al. 2019). Heavy metals are characterized as metallic components that have a moderately high thickness contrasted with water. Heavy Metals are characterized as high-density metallic components with atomic no. >20. Heavy metals contaminants that are regularly found in nature are cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn). Presumably some of these are important for plant development and are referred to as micronutrients, for example, Zn, Cu, Mn, Ni and Co, while others (Cd, Pb and Hg) have obscure organic capacities (Gaur and Adholeya 2004). Natural ecosystems are influenced by the metals and don't experience biodegradation yet can be aggregated in living life forms, subsequently causing different sicknesses and disarranges even in moderately bring down concentration (Clark 1993). The mushroom growth of industries, rapid urbanization and ever increasing population is one of the common causes of environmental degradation and pollution (Bhat et al. 2017). Phytoremediation is an environmentally friendly technique that is ecologically sound and economically effective is a smart way to the current cleanup methods that are very expensive. This technology involves proficient use of plants to eliminate, detoxify or immobilize heavy metals in reasonable means. Recently, phytoremediation as a cost effective and environmentally friendly technology has been developed by scientists and engineers in which biomass/microorganisms or live plants are utilized to remediate the contaminated regions. It very well may be sorted into different applications, including phytofiltration, phytostabilization, phytoextraction, and phytodegradation (Ahmadpour et al. 2012). Different macrophyte species *Phragmites australis* (Cav.) Trin., *Typha orientalis Presl*, *Lythrum salicaria Linn., Arundo donax Linn. var. versicolor Stokes, Typha minima Funk, Juncus effusus L., Pontederia cordata L., Cyperus alternifolius Linn.* subsp. *flabelliformis (Rottb.) Kükenth., Acorus calamus Linn.*, and *Iris pseudacorus Linn.* were investigated and compared for their shapes, biomass, roots, and ability to accumulate heavy metals. *Acorus calamus Linn*, *T. orientalis Presl*, *P. australis (Cav.) Trin.*, *T. minima Funk*, and *L. salicaria Linn.* displayed the maximum concentration of metal tolerance, whereas *P. cordata L., I. pseudacorus Linn.*, and *C. alternifolius Linn.* sub sp. *flabelliformis (Rottb.)* Kükenth. had the minimum. The concentration of different metals ranges from minimum to maximum, such as *T. minima Funk, P. australis (Cav.) Trin., L. salicaria Linn., A. donax Linn. var. versicolor Stokes, P. cordata L., and A. calamus Linn.*, whereas T. *orientalis Presl and C. alternifolius Linn.* sub sp. *flabelliformis (Rottb.)* Kükenth had poor capacity to gather heavy metals (Sun et al. 2013).

This expansion of overwhelming metal fixation is a noteworthy worry to the people and environment (Kabata-Pendias 2011), in light of their non-biodegradable nature. Instant and necessary measures are required to remediate such polluted systems. Of all the remediation advances, phytoremediation has been favored due to its cost-viability, ecofriendly nature (Uqab et al. 2016) and easy maintenance (Kamran et al. 2014).

Phytoremediation is a novel methodology and a coordinated multidisciplinary approach which gives an incredible potential to treat such polluted systems utilizing plants (Uqab et al. 2016: Jadia and Fulekar 2009: Sarma 2011). Numerous regular strategies are extremely costly, relentless and don't give the adequate outcomes. Phytoremediation, serves a biological option, has increased expanding consideration due to its cost-effective nature.

Plants are of special interest, as most of the plants accumulate dangerous metals and supplements in huge amounts in contrast with to terrestrial plants (Pratas et al. 2012). Also, in view of biochemical arrangement, propensity, species, bounty and condition, these macrophytes has been found to assimilate these toxins at various rates and efficiencies. Studies have discovered that amid the metal-binding cysteine-rich peptides (phytochelatins), which detoxify heavy metals by forming complexes with them (Kinnersely 1993). Plants are equipped for expelling the metal pollution from water and additionally from soil. Aquatic plants of different kinds whether free gliding, submerged all are known for evacuating heavy metals. Phytoremediation is an ecofriendly innovation that utilizations characteristic or genetically modified plants, with their related rhizospheric microorganisms which invigorate plant development and purify soil and water in blend with the plants (Uqab et al. 2016). Phytoremediation is an all around arranged cleanup innovation for an assortment of natural and inorganic toxins. Plants extricate metals, hydrocarbon mixes and man-made synthetic compounds, for example, herbicides, fungicides, pesticides and anti-infection agents. Phytoremediation is an environmental friendly, cheap, efficient and most reliable as it helps to remove the contamination. Plants have and utilize an assortment of instruments to manage the contaminations particularly heavy metals, hydrocarbon mixes and manmade synthetic compounds, for example, herbicides, fungicides, pesticides. Plants sequester them in their cell dividers. Plants chelate these contaminants in the soil in inert structures or complex those in their tissues and can store them in vacuoles, far from the delicate cell cytoplasm where most metabolic procedures happen. Organics might be debased in the root zone contingent upon their properties of plants or taken up, trailed by corruption, sequestration, or volatilization. Effectively phytoremediated natural contaminations incorporate natural solvents, for example, TCE (the most widely recognized toxin of groundwater) (Newman and Reynolds 2004), herbicides, for example, atrazine (Burken and Schnoor 1997). Explosives, for example, TNT (Hughes et al. 1997), petroleum hydrocarbons, and the fuel added substance MTBE (Davis et al. 2003) and polychlorinated biphenyls (PCBs). Phytoremediation is a developing innovation that utilizations plants to expel contaminants from soil and water (Bhadra et al. 1999). Phytoremediation technologies which are used for the uptake of heavy metals include mechanisms of phytoextraction, phytostabilisation, rhizofilltration, and phytovolatilization (Fig. 1).

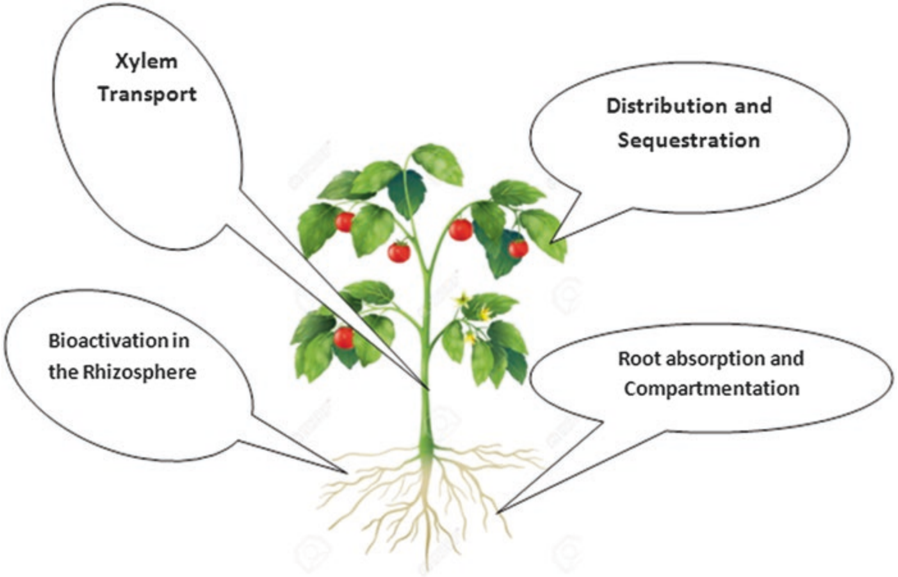

Fig. 1 Heavy metal hyperaccumulation by plants

The fundamental focal point of this chapter is to examine the capability of phytoremediation procedure to treat substantial metal polluted destinations, to give data about the components embraced by plants for overwhelming metal take-up and furthermore to give a concise rundown of sea-going plants productive for remediation of different metals.

2 Methodology

The search for relevant literature was approached with a rather broad perspective. Keywords were heavy metals, aquatic plants, phytoremediation, cadmium, phytotoxicity, metal stress, Hyperaccumulator, hyperaccumulation, contamination, toxicity, metal stress, nutrient pool, nutrient dynamics (Bhat et al. 2017), photosynthetic rate, growth, yield, multiple pollution, soil enzyme, biomass accumulation, sodium chloride, nitrate reductase activity, fast growing plant, phytoextractor, antioxidant enzyme, oxidative stress, hydrogen peroxide, NADP oxidase, phytochelation and their synonyms.

International data base was searched; resulting in a total of 1000 references, out of these more than 600 came from Elsevier and Science direct. ISI web base of knowledge was also used to select the most of the references. The rest came from smaller databases. The references were sorted in two rounds, in the first round irrelevant references were excluded. The quality of reference was assessed by using the criteria such as contribution of new knowledge, originality of empirical findings, use of theory in design and analysis and finally, whether, the reference took the special characteristics of environment toxicant such as lead, mercury, cadmium into consideration.

3 Heavy Metals and Metal Accumulation

3.1 Lead (Pb)

The orderly investigation on physiological impacts of lead on plant kingdom and other living ecosystems, work began at the end of 1960’s, although the dangerous impacts of the metals were known for long time. Moreover, in contrast to dicots, monocot response to heavy metals was reported in detail (Broyer et al. 1972). In spite of the fact that lead is thought to be lethal to the plants, metal sensitivity and reaction of various responses depend upon physiology and genetic make-up of plant. The pattern of impacts and capability of imperative product plants to tolerate the metal toxicity need a careful examination. Effect of lead on physiology and biochemistry on fauna (Rashid et al. 2019) and flora (higher plants) was studies (Thapa et al. 1988; Pahlsson 1989).

3.1.1 Major Sources of Lead

The major sources of lead contamination incorporate metal purifying, toxic paints, lead arsenate, pesticides, vehicular emissions (Singh et al. 2018) and fertilizers containing phosphate (Lagerwerff and Armiger 1973; Goldsmith et al. 1976). Furthermore, use of antiknocking agents particularly lead alkyl in fuel makes the automobiles a major source of lead (Smith 1971) which gets accumulated on roads and near roadsides, and later on may be transported to far areas by different means. The soil and lushness occupying the wayside are regularly accumulating lead substance (Cannon and Bowlers 1962; Chow 1970; Motto et al. 1970; Page and Ganje 1970).

3.1.2 Concentration of Lead in the Earth

The lead concentration in the earth is dynamic and is expanding quickly because of the industrialization and urbanization amid the most recent couple of decades. Hussanin et al. (1993) announced in sandy soils an expanded aggregate and accessible lead in Egypt which had been flooded with water of household origin for up to 67 years. Moreover, during half a decade of irrigation metal concentration decrease with depth and, the total and available lead respectively, amplified from 0.01 gL^{-1}–0.04 gL^{-1} and 0.0007 gL^{-1}–0.003 gL^{-1}. Not with standing, Akhter and Madany (1993) reported 697.2 mgg^{-1} and 360.0 mgg^{-1} of lead and metals (lead, zinc, nickel, chromium) respectively, in road dust and house hold residue of Bahrain. A 0.003 mgL^{-1} lead concentration was reported in uncontaminated fresh water (Forstner and Wittman 1979), however as per, the worldwide scope of lead focus in aquifers differed from 0.001–0.06 mgL^{-1}. The amount of lead in water was observed to be as high as 0.0014 gL^{-1} that was utilized for cattle's and cleansing by countryside population (Chandra et al. 1993). An estimation by researchers of Chaudhary Charan Singh Agricultural University, Hissar (India) the amount of lead in Haryana was observed to vary from 0.01–0.02 g kg^{-1} and 0.007 to 0.022 g kg^{-1} in agriculture soils and in soils inundated with household water (Kuhad and Malik, 1989). Moreover, a lead concentration of 0.010–0.015 g kg^{-1} was also reported in soil (Kuhad and Malik 1989). Singh et al. (1997) while investigating the lead accumulation capability *Panicum maximum* reported 0.006 mg g^{-1} and 0.0008 mg g^{-1} lead in shoots when it was developed on the sewage and uncontaminated site, respectively.

Different water courses have additionally became polluted with abnormal state of lead. Amount of lead in representative water samples of Hussain Sagar Lake (Hyderabad, India) was accounted between 38,000 and 62,000 ngL^{-1}. Furthermore, it was also discovered that ground water gathered lead levels to a range of 200–1000 m, having 0.007–0.028 mg/l which diminished up to 0.001–0.009 mg/l water in the ground water from span of 1000–2000 meter of the water body (Srikanth et al. 1973). Waste deposition in the lake may be the possible reason. In India soils and water have turned out to be contaminated upto unsafe limits as there is greater lead collection in vegetation with no secondary lead sources in these belts (Kumar et al. 1993; Dabas 1992; Bharti and Singh 1993).

The metal persists to a great extent as a shallow store or topical airborne covering on flora surfaces (Schuck and Locke 1970). Also a 5–200 times more lead was reported in unwashed foliage surfaces (Smith 1971). Leaves with hairs accumulate more lead as compared to glabrous leaves perhaps because of the general wash-off of metal by precipitation (Zimdahl and Koeppe 1977).

3.1.3 Lead Uptake by Plants

Soil contains dissolvable and insoluble salts of lead that are steadfastly bound to particles of size 1–1000 nm (colloidal). Different life-forms may assimilate lead both from air as well as soil. The airborne part of lead, which comes out in the form of residue exhaust, and damp vapor, accumulate on the aboveground plant parts (Zimdahl and Koeppe 1977). Different vegetation types developing on the side of road are particularly enhanced with lead due to arrival of lead from vehicles which diminishes with distance from roadside (Wallace et al. 1974; Goldsmith et al. 1976; Wheeler and Rolfe 1979). The root biomass can remove a portion of this metal, however its movement to aboveground biomass is generally constrained. Different conditions of soil, for example, cation trade limit (Miller et al. 1975; Zimdahl and Faster 1976; John and Laerhoven 1976) and different particles (Rolfe and Reinbold 1977; Singh et al. 1994) change lead take-up from the soil arrangement. Welsh and Denny (1980) reported the accumulation of lead in aquatic plant cells was connected with tissue uronic acid. In maturing macrophyte tissue, an increased surface territory and hence lead binding sites which increment the take-up limit with respect to lead was reported (Odum and Drifmeyer 1978). Lead apparently progresses toward becoming complexed to anionic sites related with pectic substances with cell wall (Sharpe and Denny 1976; Guilizzoni 1991). It was discovered that in *Zea mays* lead may decrease cadmium take-up (Miller et al. 1977) and in *Sesame indicum* root and leaf biomass, it meddled with Cd (II), Cu (II) and Na (I) take-up (Singh et al. 1994). The presence of abundant measure of phosphate, insoluble accelerates of lead orthophosphate and lead pyrophosphate lessen lead assimilation, yet the presence of chelating agents, for example, Diethylenetriaminepentaacetic acid enhances lead take-up (Martin and Hammand 1966; Tandon and Crowdy 1971; Wallace et al. 1976). Diethylenetriaminepentaacetic corrosive likewise builds the take-up and movement of lead in *Hordeum vulgare* (Patel et al. 1977).

3.1.4 Accumulation and Localization of Lead in Aquatic Plant Parts

Pistia stratoites (water lettuce) is an aquatic plant that develops quickly and a high biomass crop with a broad root framework that has potential to improve the substantial metals evacuation. This plant displayed diverse pattern to lead removal, albeit, accumulated high concentrations mostly in the root framework. The sorption of weakened substantial metal particles, specifically Pb and Cd by dead *P. stratiotes* has appeared to be a proficient and easy choice to be considered in mechanical profluent treatment (Miretzky et al. 2005). *Eichhornia crassipes* (water hyacinth) has been recorded as most troublesome weed in aquatic system. It is a submerged aquatic plant, found bounteously throughout the year in very large amount and drainage channel system in and around the fields of irrigation.

Tiwari et al. (2007) clarified that overwhelming metals Pb, Zn, Mn demonstrate more noteworthy partiality towards bioaccumulation in their investigation. Nearness of higher grouping of substantial metals in plants implies the biomagnifications. *Eichhornia crassipes* has the extraordinary property to aggregate substantial metals Cd, Cu, Pb and Zn from the root tissues of the plant (Muramoto and Oki 1983).

A few investigations have been accounted on the utilization of dried plant material as a potential biosorbent in to remove Lead (II) in the wastewater., Liao and Chang (2004) argued that water hyacinth can retain and translocate the cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni) in the plant's tissue as a root or shoot. Water hyacinth plants had high bioconcentration with low convergences of the five components. This demonstrates water hyacinth can be a promising contender to eliminate the substantial metals. The generally low leaf substance, until the point when uncommon conditions are utilized, demonstrated the nearness of an anticipation instrument to repress Pb take-up (David et al. 2003). Wolverton (1988) and Brix (1993) clarified that explanation behind turbidity decrease i.e. the root hairs have electrical charges that draw in inverse charges of colloidal particles, for example, suspended solids and cause them to follow on the roots where they are gradually processed and acclimatized by the plant and microorganisms. Brix (1993) seen that *Eichhornia crassipes* has been utilized effectively in wastewater treatment framework to enhance the water quality by lessening the dimensions of natural and inorganic supplements. Consequently, the water hyacinth would most likely have high resilience and ought to be fit for removal of huge measures of lead (Sutcliffe 1962).

Duckweed is an assortment of aquatic plant free-gliding at the water surface. It is quickly developing and adjusts effectively to different amphibian conditions. Duckweed usually alludes to a gathering of gliding, blossoming plants of the family Lemnaceae. The distinctive species (*Lemna*, *Spirodela*, *Wolffia* and *Wolfiella*) are worldwide conveyed in wetlands, lakes and a few effluents tidal pond. The plants can develop at temperature running from 5 to 35 °C with ideal development between 20 °C and 31 °C and over an extensive variety of pH (3.5–10.5) (Cayuela et al. 2007). Wetlands and lakes are the most widely recognized destinations to discover duckweed.

The limit of aquatic plant, for example, duckweed (*Lemna* sp.) to expel lethal overwhelming metals from water are all around recorded and assumes an imperative job in extraction and aggregation of metals from wastewater. The normal seagoing plant *L. minor* can expel up to 90% of dissolvable Pb from water. *L. minor* can develop well in pH from 6 to 9 while the most reduced estimation of pH it can endure in between pH 5–6. Nonetheless, nitrate had couple of inhibitory on the development (Chong et al. 2003). Uysal and Taner (2009) inspected the capacity of the *L. minor* to expel dissolvable lead under various pH esteems (4.5–8.0) and temperature (15–35 °C) in nearness of various Pb concentrations 0.1–10.0 mgL^{-1} for 7 days. Their outcomes indicate Pb amassing was most noteworthy at pH 4.5 and after that it diminished to pH 6, yet it didn't change at pH 6–8 territory (Gallardo et al. 1999). *Hydrila verticillata* (Hydrilla) is a submerged aquatic weed that can develop up to the surface and frame thick tangles in all waterways. For expulsion of contaminants entire plant assumes imperative job. Showed that the dependence upon roots for substantial metal take-up was in rooted floating-leaved taxa with lesser dependence in submerged taxa. He likewise observed that inclination to utilize shoots as locales of overwhelming metal take-up rather than roots increments with movement towards submergence and effortlessness of shoot structure. Gallardo et al. (1999) discovered that following multi week of presentation to concentrated lead arrangement demonstrated greatest take-up (98%) of Pb by *Hydrilla*.

3.2 Cadmium (Cd)

Pollution of biosphere particularly the hydrosphere had been increased significantly, since the onset of industries (Nriagu 1990). The wastewater from industries containing hazardous pollutants particularly heavy metals, directly discharged into water bodies is one of the most important cause of contamination to living beings as they biomagnifies along the food chain due to their persistency and toxicity. In particular, Cadmium (Cd) is one of the common trace pollutants which are very harmful to organisms. Cadmium being non-essential heavy metal, is one of the "black list" substance in the Dangerous Substance Directory (Herrero et al. 2008). Apart from geochemical weathering of rocks, it is also dissipated into the ecosystems from power stations, metal working industries, Nickel-Cadmium batteries, fertilizers of phosphate origin and heating systems (Wagner 1993; Toppi and Gabbrielli 1999). The different methods that are employed to remove Cd from water are chemical precipitation, solvent extraction, adsorption, ion exchange, and electrophoresis and membrane separation. In addition to incomplete metal removal and generation of toxic sludge, expensiveness of these technologies had led to the exploration for low cost, low impact, visually benign and environmental friendly methods. Removal of heavy metals by plants generally called phytoremediation is a new cleanup method, that is environmental friendly and aesthetically pleasant (Chaney et al. 2005; Huang et al. 2004; Susarla et al. 2002). A number of laboratory experiments performed for Cd removal from aqueous media indicate that phytoremediation is a promising technique for metal removal. The most common species that are reported to have heavy metal removal properties are *Eichhornia crassipes, Alternanthera sessilis, Ceratophyllum demersum, Azolla pinnata, Chara coralline, Hygrorrhiza aristata, Hydrodictyon reticulatum, Hydrocotyle umbellate, Lemna minor, Salvinia, Pistia, Spirodela polyrhiza, Vallisneria spiralis* (Rai 2009).

Lu et al. (2004) investigated the phytoremediation potential of *Eichhornia crassipes* from tap water contaminated with different concentrations of Cd and Zn. They observed that metal removal was rapid in the first 4 days. The high values of bioconcentration factor for Cd and Zn suggested the heavy metal removal potential of water hyacinth and can be used for remediation purposes. Liao and Chang (2004) reported the removal of Cd and other heavy metals with *Eichhornia crassipes* Mart. Solms from the constructed wetlands of Taiwan. Similarly, *E. crassipes* can accumulate a substantial amount of Cd in shoot biomass (371 mg kg^{-1}) as well as root biomass (6103 mg kg^{-1}) (Zhu et al. 1999). They also observed that Cd along with other heavy metals results in the lesser accumulation of Cd in the aerial parts as compared to the shoots (Soltan and Rashed 2003). This property of heavy metal accumulation of *E. crassipes* makes it a favourable specie for Cd removal from water. Phytoremediation potential of *Eichhornia*, for the removal of cadmium (Cd), lead (Pb) and zinc (Zn) was also reported by Aisien et al. (2010). They observed that initially the metal removal from solution was rapid for first 2 weeks till saturation point was reached. Abhilash et al. (2009) reported 98% Cd removal with *Limnocharis flava* (L.) after 30 days from hydroponics experiment. Further, high bioconcentration factor (BCF) and translocation factor (TF), demonstrating that *L. flava* would be a suitable candidate for the phytofiltration. The translocation factor is calculated as the Cd concentration in shoots divided by the Cd concentration in roots, evaluates the capacity of plant to translocate heavy metals from root to shoot. Kashem et al. (2008) while investigating the Cd accumulation ability of *Colocasia antiquorum, Raphanus sativus* L. and *Ipomoea aquatica* reported that Cd accumulation intensified with rise in concentration. The Cd concentration in *Colocasia antiquorum* and *Ipomoea aquatica* was highest in roots in contrast to *Raphanus sativus* L. in which the concentration was maximum in aerial plant parts. The Cd concentration in dead leaves, normal leaves, stems, bulbs and roots increases from 158 to 1060, 37 to 280, 108 to 715, 42 to 290 and 1195 to 3840 mg kg^{-1}, respectively. These results demonstrated that *Colocasia antiquorum* had µgood Cd removal potential. An interesting absorption pattern was observed in H. verticillate. It was observed that maximum Cd absorption occurs during the daytime at the growth temperature (15–25 °C) (Dulay et al. 2010). *Azolla pinnata* which was considered to be more effective in comparison to *E. crassipes* has the BCF for Cd in roots as 24,000 which were quite high (Noraho and Gaur 1996). Similarly, Valderrama et al. (2013) evaluated the phytoremediation potential of *Azolla filiculoides* for Cd and Cu removal from the medium contaminated with 0.5–1.0 mg L^{-1} of Cd and 0.1–25 mg L^{-1} Cu. The results indicate that the concentration of Cd and Cu reached upto 1623.20 and 6013.1 µg/g, respectively. Wang et al. (2008) investigated that Cd phytoextraction of *Ipomoea aquatica* was correlated with the aqueous Cd ions in the free and complex form. It was also observed that high BCF of Cd in *Ipomoea aquatica* indicates its high potential to remediate Cd contaminated waste water.

Salvinia herzegoii in contrast to *Pistia stratiotes* accumulates a high level of Cd (Maine et al. 2001). Similarly, another species of *Salvinia*, *S. minima* was considered as Cd hyperaccumulator due to large surface area of roots with hydroxyl and carboxyl groups (Olguin et al. 2002). Phytoremediation capability was also reported other plants also such as, *Potamogeton natans, Myriophyllum aquaticum, Wolffia globosa*, and *Typha* (Cardwell et al. 2002; Fritioff and Greger 2006; Boonyapookana et al. 2002). Thus, Cd removal ability of macrophytes was studied very extensively and can be used to remediate Cd from contaminated water.

The primary target of Cd toxicity is unknown however, it was found to cause various phytotoxic indications *viz,* loss of chlorophyll, inhibition of growth, H_2O imbalance, phosphorus and nitrogen deficit etc. (Toppi and Gabbrielli 1999; Benavides et al. 2005). Cd can replace Zn, Ca and Fe from its compounds such as proteins, due to its chemical similarity. It can also react with the sulphur containing proteins and peptides and can cause oxidative stress (Benavides et al. 2005; Sandalio et al. 2001; Romero-Peurtas et al. 2004). Cd also interferes with mitochondrial electron transfer chain of plant cells, stimulates reactive oxygen species production which intern induces lipid peroxidation. The inhibition of water transport which causes proline accumulation was also reported due to Cd accumulation (Schat et al. 1997).

3.2.1 Cadmium Take-Up in Plants and Transportation

Cadmium is a one of the most dangerous heavy metals because of its high portability and the little fixation at which its impacts on plants start to appear (Barcelo and Poschenrieder 1992). Jarvis et al. (1976) found that the underlying foundations of lettuce discharged substantially more of their consumed Cd for translocation to the shoots than different products (ryegrass and orchard grass). The more prominent translocation is because of dynamic transport or to active transport or lack of metal absorption to fixed or soluble chelators in the root or perhaps due to exchange with the Ca, Mn and Zn traveling through the roots (John 1976). Moral et al. (1994) announced that Cd was effectively transported to ethereal parts of tomato and was not distinguished in natural products. Hinesly et al. (1984) detailed that the pH of the soils had extraordinary effect on cadmium transportation in corn (*Zea mays* L.). The highest grain Cd concentrations happened at soil pH at around 6.0. The take-up of cadmium by corn was less from the most acidic soil that additionally had the highest organic matter content (Street et al. 1977). Miragaya and Page (1976) found that the proportions of complexed to uncomplexed Cd were autonomous of Cd focus and somewhat influenced by pH over a scope of 6.0–8.5. Numerous components in the soils have been appeared to impact the take-up of substantial metals by plants. The cadmium take-up expanded with diminishing soil pH (Lagerwerff 1971; Miller et al. 1977) and diminished with expanding soil cation trade limit (Haghiri 1974). The cadmium seems, by all accounts, to be assimilated latently (Cutler and Rains 1974) and translocated openly (Jarvis et al. 1976). The chelators in supplement arrangements can help in cadmium take-up (Francis and Rush 1974). The articulated cooperation's amongst Zn and Cd happened in cadmium uptake and translocation. Evidently, some portion of Cd danger was an aftereffect of Cd obstruction in a Zn-dependent process (Falchuk et al. 1975).

The distinctions in the capacity of plants to collect overwhelming metals have been identified with contrasts in their root morphology (Hemphill 1972; Schierup and Larsen 1981). Plant with different thin roots would collect a bigger number of metals than one with couple of thick roots. Wahbeh (1984) contrasted with the ingestion and accumulation of Cd, Mn, Zn, Mg and Fe in three types of aquatic grasses. The two species *Halophila ovalis* and *Halophila uninervis* had higher photosynthetic and respiratory rates than *Halophila stipulacea* (Wahbeh 1984). Chukwuma (1993) reported the accumulation of cadmium, lead and zinc in developed and wild plant species in the abandoned lead-zinc mine. McKenna et al. (1993) reported that the associations between Zn and Cd in nutrient solution and their consequences for the aggregation of the two metals in plant roots and leaves. They detailed higher Cd focus is more in young leaves of lettuce and spinach. The potential accumulation of Cd in old leaves couldn't be exclusively because of the transpiration rate. The metal binding peptides are present in older leaves in higher amounts than in younger leaves in tobacco and cadmium was transported into the vacuoles as methods for detoxification (Lange and Wagner 1990). Cadmium concentrations were accounted higher in roots than in shoots (Cataldo et al. 1981; Rauser 1986). The suggestion set by for forage yields, this much of concentration is supposed to be less toxic for the animals feeding in these crops.

Rascio et al. (1993) contemplated development of the entire plant and the chlorophyll content, oxygen advancement, and chloroplast ultrastructure of leaf tissues in maize plants developed on a culture medium either without cadmium (Cd) or provided with expanding groupings of the metal. The plants treated with high Cd focuses demonstrated side effects of overwhelming metal danger, for example, length decrease of the two roots and shoots, leaf blanching, ultrastructural changes of chloroplasts and bringing down of photosynthetic action. A few manifestations showed up at 100 μM Cd, however, the lethal impacts of the metal were discovered just at 250 μM Cd. Quzounidou et al. (1997) contemplated the impacts of a 7-day exposure of 3-day-old wheat plants to expanding Cd concentration with exceptional consideration being given to chloroplast ultrastructural changes, chlorophyll fluorescence reactions, chlorophyll and supplement focus changes and development changes of the entire plant. Cadmium treatment was appeared to harm the structure of chloroplasts, as showed by exasperates shape and the expansion of the thylakoid films. These ultra structural changes recommend that Cd likely prompted untimely senescence.

Gratao et al. (2008) advocated that continuous increment in $CdCl_2$ concentration over some stretch of time seemed to adjust the plants to the harmful impacts of Cd, yet it additionally prompted a noteworthy higher accumulation of Cd in the organic products. Plants subjected to expanding convergences of Cd and different metals ought to give a superior comprehension of the instruments of detoxification, which may incorporate biochemical hereditary qualities with plant rearing to deliver pressure tolerant plants for detoxification or phytoremediation projects of polluted environments by heavy metals. Hsu and Kao (2007) obtained the detached rice leaves and intact leaves attached to rice seedlings, and found that Cd lethality in leaves of rice seedlings is because of H_2O_2 accumulation, which is fundamentally predictable with the aftereffects of Cho and Seo (2005) who detailed that a lower H_2O_2 collection gives Cd-resilience in *Arabidopsis* seedlings.

3.3 Mercury (Hg)

Lenka et al. (1990) investigated the bioconcentration and genotoxicity of aquatic mercury using *Eichhornia crassipes* by treating the plant to water supplemented with different concentrations of methyl mercury or phenyl mercuric acetate or mercury contaminated effluent for 4–96 h. The root samples collected at different exposure time intervals reveal that bioconcentration of mercury depends on concentration as well as duration of exposure. The results also indicate the potential of water hyacinth for mercury removal and hence, can be used for remediation. Dependence of rate of absorption on initial concentration was also reported by Gonzalez et al. (1994). Further, it was observed that mercury removal was rapid initially which decreases thereafter. Bioaccumulation (living plants) and bioabsorption (dry biomass) increases significantly as concentration of mercury ions increases in the solution in contrast to exposure time and pH values which show variations in bioaccumulation with different concentrations (Casagrande et al. 2018). Long before, similar type of results was reported in case of *Pistia stratiotes* L. (De et al. 1984). The absorption enhances as concentration of mercury (II) increases in the solution. It was also found that efficiency of as high as 90% can be achieved below 20 ppm mercury (II). Mercury removal capabilities of *Eichornia crassipes, Pistia stratiotes, Scirpus tabernaemontani* and *Colocasia esculenta* was also reported by Skinner et al. (2007). After exposing plants to different concentrations of mercury (0 mgL^{-1}, 0.5 mgL^{-1} or 2 mgL^{-1}) for 1 month, it was concluded that all these plant species can accumulate mercury. However, among all four species efficiency for metal removal of *Pistia stratiotes* and *Eichornia crassipes* was higher. Jana (1988), while studying the mercury and chromium accumulation in *Eichhornia crassipes* (Mart.) Solms., *HydriIla verticillata* (L.f.) Royle and *Oedogonium areolatum* Lagarh, reported that mercury accumulation was highest in *Hydrilla* followed by *Oedogonium* and *Eichhornia*. The effect of phosphate concentration, light intensities and sediment: aqueous phase contamination ratios on mercury and methylmercury assimilation ability of *Eichhornia crassipes* was also evaluated (Chattopadhyay et al. 2012). It was observed that, in contrast to phosphate concentration which is required for mercury and methylmercury uptake, the light intensities increase the translocation of mercury and methylmercury which was preferentially concentrated in roots. The sediment: aqueous phase contamination ratios were also found to affects the bioavailability of mercury and methylmercury. Molisani et al. (2006) evaluated the role of *Elodea densa, Sagittaria montevidensis, Salvinia auriculata, Pistia stratiotes* and *Eichhornia crassipes* for mercury accumulation in two artificial reservoirs. The results showed that free floating and juveniles were more efficient for mercury removal. Among the plant organs roots accumulate more mercury. It was proposed that *Eichhornia crassipes* can remove a considerable amount of mercury from water. The mercury remediation ability of water hyacinth and pondweed was also reported by Romanova and Shuvaeva (2016). Gomes et al. (2014) established a pilot scale experimental design to evaluate the remediation potential of *Typha domingensis* for mercury. It was observed that metal removal potential varies with exposure time. In contrast to the other species it was also reported that *T. domingensis* accumulates higher mercury when the transfer coefficient was 7750.9864 ± 569.5468 L kg^{-1}. *Vallisneria spiralis,* an aquatic plant, when subjected to different concentration of mercury at different durations, disclosed a mercury concentration of 250 μmol/g and 1120 μmol/g in dehydrated weight of leaf and root, respectively (Gupta and Chandra 1998). Phytoremediation potential of *Limnocharis flava* for mine effluents containing mercury was investigated in a constructed wetland (Marrugo-Negrete et al. 2017). Metal removal potential was found to vary with exposure time. It was also observed that controlled rate of mercury removal was 9 times lower than continued rate.

Similar, types of mercury removal experiments by using different plants such as, *Elodea densa (*Maury et al. 1988*), Eriocaulon septangulare* (Coquery and Welbourn 1944), *Oryza sativa L.* (Heaton et al. 2003), *Azolla pinnata* and *Vallisneria,* (Rai and Tripathi 2009). *Salvinia natans* and *Lemna minor* (Sitarska et al. 2015) had been performed (Table 1).

4 Conclusion

The response of the aquatic plants to heavy metals *viz,* lead, cadmium and mercury can be traced from the literature. However, the level of accumulation in different plant parts varied with species, period of exposure, metal concentration and composition of soil/nutrient. Generally, a trade-off had been reported between nutrients and metal toxicity up to a certain concentration called threshold limit above which toxicity effect was reported. Toxic levels of lead, cadmium and mercury was found to affect both physiology and biochemistry of plants. Reaction of metals to functional groups of enzymes alter several important functions some of them are critical for photosynthesis and nitrogen assimilation. Although several aspects of metal tolerance were identified however, there is a lack of model specie in which the entire process is well defined. It seems that it is an intricate phenomenon with some genetic influence. An improved and good understanding of the information is obligatory to knob the critical problem of growing metal toxicity to the flora and fauna. There is an urgent need to address this growing problem. Apart from providing the necessary information for developing models that will accurately and precisely forecast the

Table 1 The different heavy metal and their presence in different parts of aquatic plants

Heavy metal	Plant species	Plant part	References
Lead	*Eichhornia crassipes*	Root	Miretzky et al. (2005)
	Eichhornia crassipes	Root tissue	Muramoto and Oki (1983) and Nor (1990)
	Water hyacinth	Root/ shoot	Sutcliffe (1962)
	Duckweed (*Lemna* sp.)		Chong et al. (2003)
	Hydrila verticillata	Roots	
Cadmium	*Eichhornia crassipes*	Shoot and root	Lu et al. (2004), Zhu et al. (1999), Soltan and Rashed (2003) and Aisien et al. (2010)
	Limnocharis flava (L.)	Shoot	Abhilash et al. (2009)
	Colocasia antiquorum, Raphanus sativus L. and *Ipomoea aquatica*	Root	Kashem et al. (2008)
	H. verticillate		Dulay et al. (2010)
	Azolla pinnata, E. crassipes	Root	Noraho and Gaur (1996)
	Salvinia herzegoii		Maine et al. (2001)
	S. minima	Root	Olguin et al. (2002)
	Potamogeton natans, Myriophyllum aquaticum, Wolffia globosa, and *Typha*		Cardwell et al. (2002), Fritioff and Greger (2006) and Boonyapookana et al. (2002)
Mercury	*Eichhornia crassipes*	Root	Lenka et al. (1990)
	Eichornia crassipes, Pistia stratiotes, Scirpus tabernaemontani and *Colocasia esculenta*	Root	Skinner et al. (2007) and Chattopadhyay et al. (2012)
	HydrIlla verticillata (L.f.) Royle and *Oedogonium areolatum*	Root	Jana (1988)
	Sagittaria montevidensis, Salvinia auriculata,	Root	Molisani et al. (2006)
	T. domingensis	Root	Gomes et al. (2014)
	Vallisneria spiralis	Root	Gupta and Chandra (1998)
	Elodea densa	Root	Maury et al. (1988)
	Eriocaulon septangulare	Root	Coquery and Welbourn (1944)
	Salvinia natans and *Lemna minor*	Root	Sitarska et al. (2015)
	Azolla pinnata and *Vallisneria,*	Root	Rai and Tripathi (2009)
	Oryza sativa L.	Root	Heaton et al. (2003)

influence of metals on the plant functions, it may also provide means to detoxify metal contaminated sites by the employing metal removing plant species. As such there is a need to study the detoxification pathways in detail.

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