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Research article

Spatial patterns of heavy metal accumulation in sediments and macrophytes of Bellandur wetland, Bangalore

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ABSTRACT

Heavy metals are one among the toxic chemicals and accumulation in sediments and plants has been posing serious health impacts. Wetlands aid as kidneys of the landscape and help in remediation through uptake of nutrients, heavy metals and other contaminants. The analyses of macrophytes and sediment samples help in evaluating pollution status in aquatic environment. In this study concentration of six heavy metals (Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb) and Zinc (Zn)) were assessed in sediment and dominant macrophyte samples collected from Bellandur Lake, largest Lake of Bangalore, India. Sediment samples reveal of heavy metals in the inlet regions and shore samples. The accumulation of metals in sediments were in the order of Zn > Cu > Cr > Pb > Ni > Cd. All metals exceeded the critical limits of metals in the sediment. Concentration of different metals in the macrophyte samples ranked as: Cr > Cu > Zn > Pb > Ni > Cd. Chromium and Copper were found to be more than critical range. *Typha angustata* had the higher accumulation of all metals except chromium.

1. Introduction

Heavy metals are one among the most toxic chemicals and accumulation in plants, etc. has been a global problem. These heavy metals move through various biogeochemical cycles and enter food chain resulting in bioaccumulation and consequent biomagnifications. The elements with atomic number greater than 20 with higher density (>5 g/cm^3) and metallic properties are chemically stable. These have long biological half-life compared to other xenobiotics and are non-biodegradable, toxic and persistent with serious ecological ramifications in ecosystems (Chopra et al., 2009). They pose a serious threat to humans due to of their persistence, toxicity, non-destructible nature in the environment and their bioaccumulation in the food web (Khan et al., 2008; Li et al., 2013; Fang et al., 2014; Bortey-Sam et al., 2015; Chopra and Pathak, 2015; Ye et al., 2015). These elements include cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), cobalt (Co), iron (Fe), nickel (Ni), manganese (Mn), zinc (Zn) and arsenic (As). These heavy metals are mainly released from industrial processes; industrial discharges, mining operations and acid mine drainage (Rungwa et al., 2013). The major sources of heavy metals are; fertilizers, pesticides, untreated or partially treated industrial waste water, leachates from mining sites, industrial wastes (e-wastes), wastes from smelting ores, sewage sludge, etc. Due to indiscriminate disposal of untreated sewage and industrial effluents into urban water bodies, heavy metals are getting accumulated in the sediment, plants (macrophytes) and other organisms. The distributions of these metals can also change among different compartments of wetlands. Macrophytes act as good bio-filters by accumulating heavy metals from the surrounding environment and hence aid as indicators of heavy metal contamination in aquatic ecosystems (Vardanyan et al., 2007). Earlier studies highlight of the phytoremediation and bio-monitoring ability of macrophytes (Ji et al., 2007; Yang et al., 2008; Hassan et al., 2010; Chatterjee et al., 2011; Fawzy et al., 2012; Galal and Farahat, 2015; Esmaeilzadeh et al., 2016; Meitei and Prasad, 2016). Sediments are important sinks for various pollutants like pesticides and play a significant role in the remobilization of contaminants in aquatic systems under favourable conditions with interactions between

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water and sediment (Ikem et al., 2003). The release of trace metals from sediments into water body depends on speciation of metals (precipitation, adsorption, and solubilisation) and other factors such as sediment pH and also the physical and chemical characteristics of aquatic system (Morgan and Stumn, 1991). Analysis of sediment and biological samples help to determine the overall assessment of heavy metals (Shukla and Sharma, 2009) and its impact on the aquatic life. This emphasises the need to analyse samples of macrophyte and sediment for assessing pollution status in the aquatic environment.

Bellandur Lake with the spatial extent of 367 ha constitutes the largest wetlands in Bangalore urban area. The sustained inflow of untreated and partially treated sewage and industrial wastewater over four decades has led to the nutrient enrichments. There are about 500 industries within the 5 km radius and most of them include dyeing, washing, garments, laundry, leather tanning, automobile related industries, etc. Due to the sustained inflow of nutrients (sewage), there is profuse growth of macrophytes like *Eichhornia crassipes, Alternanthera philoxeroides* etc. Farmers in the locality harvest these macrophytes and use as fodder, while macrophytes such as *Alternanthera* reaches the vegetable market.

Land use analyses using temporal remote sensing data reveals an increase in built-up from 7.97% (1973) to 78.7% (2017) with the decline in vegetation cover (68.2%–6.46%), Water bodies (4.3%–1.4%) and other land uses (23.3%–2.1%) in the catchment area of Bellandur Lake (Ramachandra et al., 2017). Though water quality of Bellandur wetlands was reported earlier (Roselene and Paneerselvan, 2008; Pattusamy et al., 2013; Ramesh and Krishnaiah, 2014), the distribution of heavy metals in Bellandur wetland was less studied (Lokeshwari and Chandrappa, 2006; Jumbe and Nandini, 2009b) and there are still gaps on spatial distribution of metals in Bellandur wetland. Hence, the objective of the current research is to investigate the level of heavy metal (Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb) and Zinc (Zn)) accumulations in biotic (macrophytes) and abiotic (sediments) components of Bellandur Lake, Bangalore through analyses of surface sediments and dominant macrophyte (*Eichhornia crassipes, Typha angustata, Alternanthera philoxeroides* and *Urochloa panicoides*) representative samples collected from various locations.

2. Materials and methods

2.1. Study area

Bellandur wetlands (Fig. 1) is located in the south east part and constitute the largest lake in Bangalore city. It spreads across the administrative wards of Agaram (ward number 114), Bellandur (ward number 150) and spread across 6 villages (Ramachandra et al., 2017). Extending from North 12.9464° to 12.9277° and East 77.6420° to 77.6807°, the wetlands covers an area of 367.3 ha. The average depth of the lake is approximately 2 m. The wetlands has a catchment area of nearly 279 square kilometers with numerous cascading interlinked lakes in the upstream. The outfall of Bellandur Lake drains to Varthur Lake, which and further joins river Pinakini. Rampant development activities in the catchment with unplanned urbanisation has degraded the wetlands water quality posing serious threats to public health (Ramachandra et al., 2017). The major threats faced by the wetlands are sustained inflow of untreated wastewater and industrial effluents, dumping of solid waste, encroachment of wetlands and connecting drains.

2.2. Macrophyte and sediment sampling

Samples of sediment and macrophytes were collected following the standard sampling protocol of transact with quadrats (10 × 10 m) technique (Fig. 2) in accessible regions of the wetland. The sampling locations covered inlet, middle, shoreline and outlet parts of the lake (Fig. 2). Sediment samples were collected from 25 locations, while macrophyte samples were collected from 20 locations. *Eichhornia crassipes* and *Alternanthera philoxeroides* were the dominant species of macrophytes. Collected macrophytes were stored in polythene bags after species identification through standard protocol and taxonomic literature (Cook, 1996). Approximately 1 kg of sediment was collected at a depth of 0–20 cm from each sampling location.

2.3. Sample preparation and analysis

Collected Macrophytes were thoroughly washed to eliminate sediments and epiphytes and grouped based on species. Above ground parts were then separated and oven dried at 60° C for 2–3 days. It is then pulverised using grinder and sieved (1 mm) for uniform size samples. Sediment samples were air dried and pulverised into fine particles using a mortar and pestle and passed through 1 mm sieve to get fine powders. 0.5 g of powdered samples (macrophyte and sediment) were subjected to acid digestion according to established protocols (APHA, 1995). Digested samples were filtered using Whatman No. 42 Filter paper and made up to 50 ml using double distilled water for further analysis. The digested samples were analysed for six heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) with reagent blanks and suitable standards using Flame Atomic Absorption Spectrophotometry (GBC Avanta version 1.31).

2.4. Bio-concentration factor

Bio-concentration or bioaccumulation factor is the ratio of heavy metal concentration in the plant to that in the sediment. Higher values indicate of easy assimilation by plants from the sediment and also possibility of redistribution for the heavy metal (Zhang et al., 2009). Bioaccumulation factor for the concentration of heavy metals in macrophytes was calculated using equation (1).

$$\text{Bio} - \text{concentration factor (BF)} = \frac{\text{Heavy metal content in macrophyte}}{\text{Heavy metal content in sediment}} \quad (1)$$

3. Results and discussion

3.1. Heavy metals in sediment and macrophytes

The concentration of heavy metals in the sediment were in the order Zn > Cu > Cr > Pb > Ni > Cd and in macrophytes in the order Cr > Cu > Zn > Pb > Ni > Cd, Tables 1 and 2 lists heavy metal concentrations in sediment and macrophyte samples.

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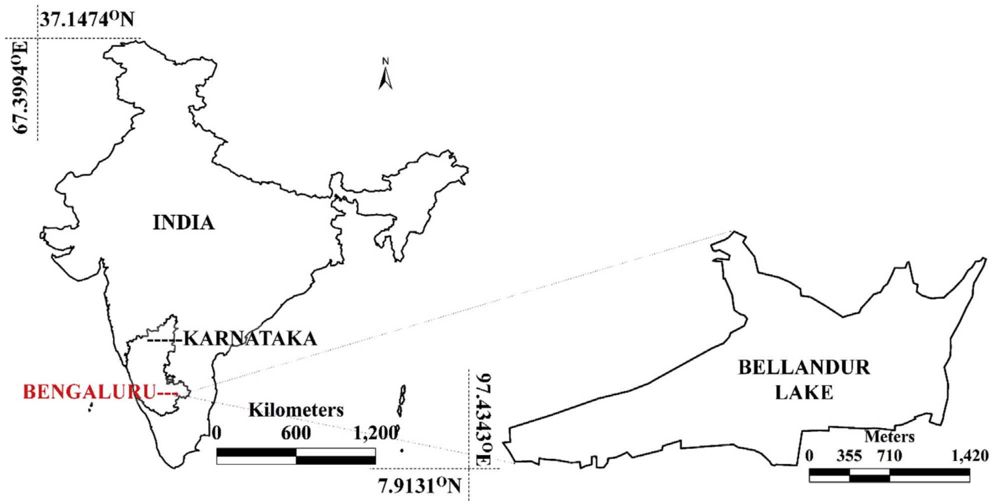

Fig. 1. Study area – Bellandur wetlands, Bangalore, Karnataka State, India.

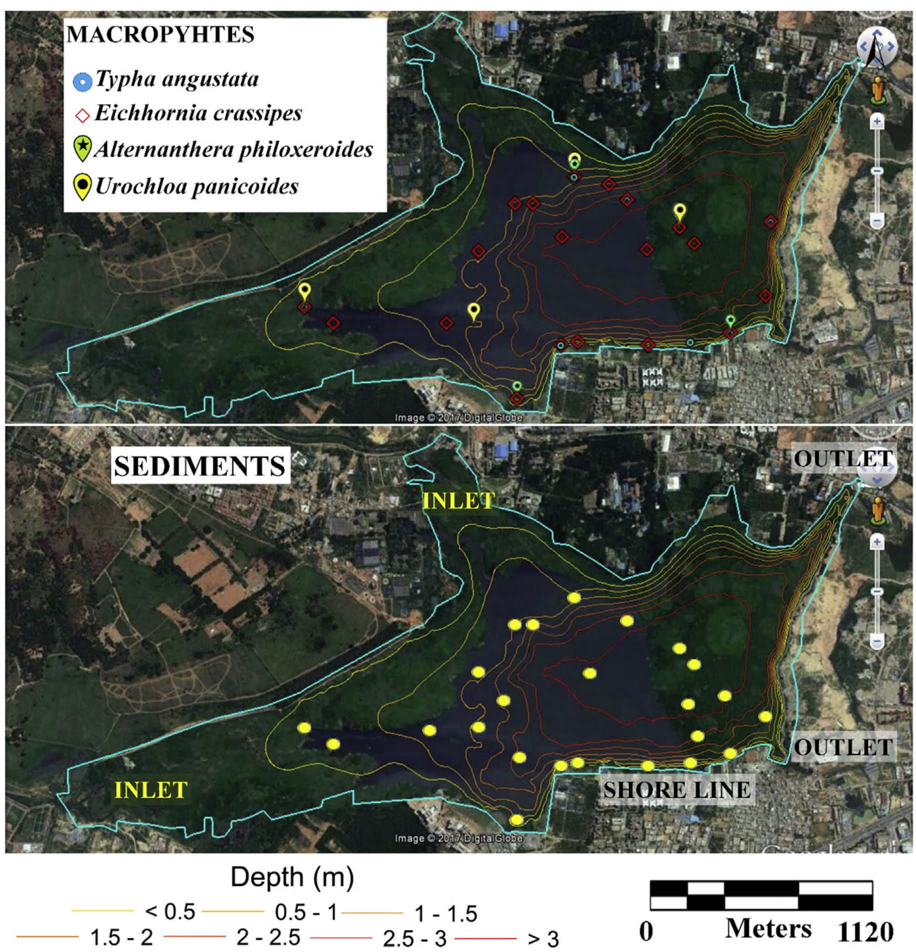

Fig. 2. Macrophyte and sediment sampling locations in Bellandur wetlands.

3.1.1. Cadmium (Cd)

Cadmium is used in electroplating, pigment, plastic stabilizers and Nickel-Cadmium batteries and released into the environment by power stations, heating systems, metal working industries or urban traffic (Jumbe and Nandini, 2009a). Cadmium is one of the phytotoxic metal which causes the reduction in the rate of photosynthesis caused by destruction of Chloroplast cells in the plants (Hasan et al., 2009). It also accumulates in several tissues and complexes with amino acids and other major parts of plant metabolism (Benavides et al., 2005). Cadmium is a non-essential element negatively affects growth and development of plants, and causes kidney damage in humans. Acute doses (10–30 mg/kg/

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Table 1
Concentrations of heavy metal (mg/kg) in sediment samples.

Metal	Range (mg/kg)	CPCB (2001)	TEL (MacDonald et al., 2000)	PEL (MacDonald et al., 2000)	Critical soil concentration (Maiti, 2003)	Uncontaminated sediments (Abbasi et al., 2005)
Cd	1.6–55.3	BDL	0.596	3.53	3–8	–
Cr	33.9–199.4	389.3	37.3	90	75–100	12–44
Cu	105–1147.8	113	35.7	197	60–125	–
Ni	15.1–138.4	54.5	35	91.3	100	1–20
Pb	31.2–308.2	64.9	18	36	100–400	2–50
Zn	125.7–2001	–	123	315	70–400	1–50

CPCB-Central pollution control Board; TEL-Threshold effect level; PEL-Probable effect level; BDL-Below detectable limit.

Table 2
Concentrations of heavy metal (mg/kg) in macrophytes samples.

Metal	Range (mg/kg)	WHO standard	Critical range in plants (Maiti, 2003)	Normal range in plants (Maiti, 2003)
Cd	0–0.8	0.5	5–30	0.1–2.4
Cr	34.2–166.4	1.3	5–30	0.03–14
Cu	14.5–164.8	40	5–30	1–5
Ni	2.3–17.1	10	10–100	0.02–5
Pb	12.8–59.7	2.0	30–300	0.2–20
Zn	11.9–151.6	60	100–400	1–400

Note: WHO-World Health Organisation.

day) of salivation, and doses of 25 mg of Cd/Kg body weight can cause death (International Cadmium Association). Use of contaminated water for irrigation, fertilizers, sewage and compost can remarkably increase the Cd uptake into plant tissues (Jackson and Alloway, 1991). Plants readily absorb Cd from soil where upon ingestion will enter into human food chain (Farooq et al., 2008). The most vulnerable organ system effected by Cd due chronic oral exposure is the kidney (ATSDR, 2012).

Cadmium shows the greatest mobility in the soil environment and is considered as a heavy metal of most concern (Wilson and Bell, 1996). Major impact of Cd is on the growth due to chlorophyll senescence and nutrient uptake. In this study the toxicity was not up to the level to affect growth of macrophytes. The range of Cadmium in sediment was 1.6–55.3 mg/kg. The mean value of cadmium was 14 mg/kg which is around 2 times higher than critical range in soils, near the inlets of the lake (West side). The lowest value was found in middle and near outlet of the lake. Except two sites the cadmium concentration was higher than PEL levels (MacDonald et al., 2000) and critical concentration (Fig. 3) in soils (Maiti, 2003). It varied from 0 to 0.8 mg/kg in macrophyte samples (Fig. 4) and were within the normal range in plants (Maiti, 2003; Jumbe and Nandini, 2012). The concentration of cadmium was higher in *Typha angustata* followed by *Eichhornia crassipes, Alternanthera philoxeroides* and *Urochloa panicoides*.

3.1.2. Lead (Pb)

Lead is toxic to humans, as it gets sequestered in the bones and teeth, resulting in brittle bones and weakness in the wrists and fingers (Todd, 1996). Furthermore, lead stored in bones re-enter the blood stream during periods of increased bone mineral recycling

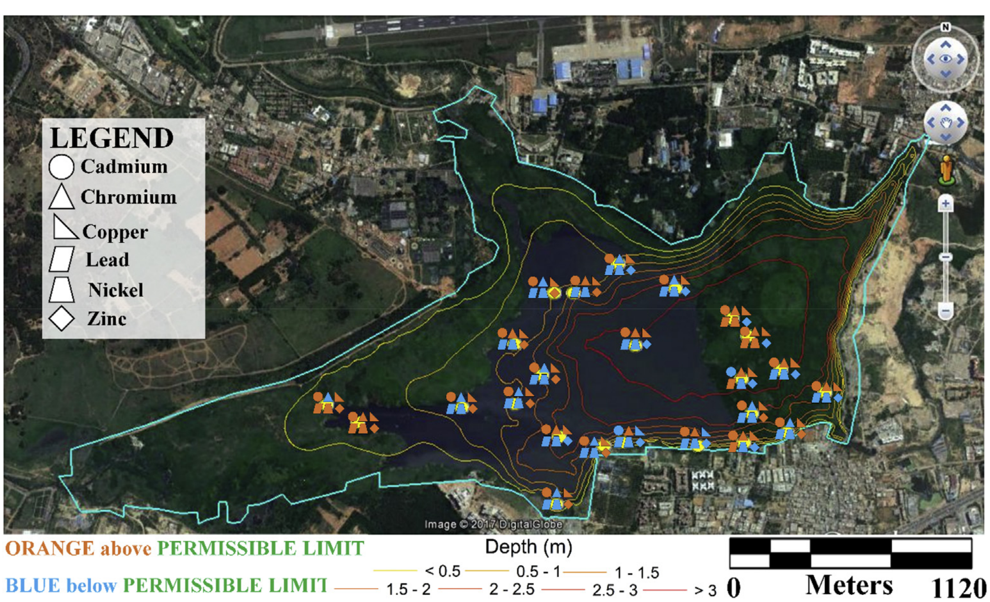

Fig. 3. Heavy metal concentration in sediments.

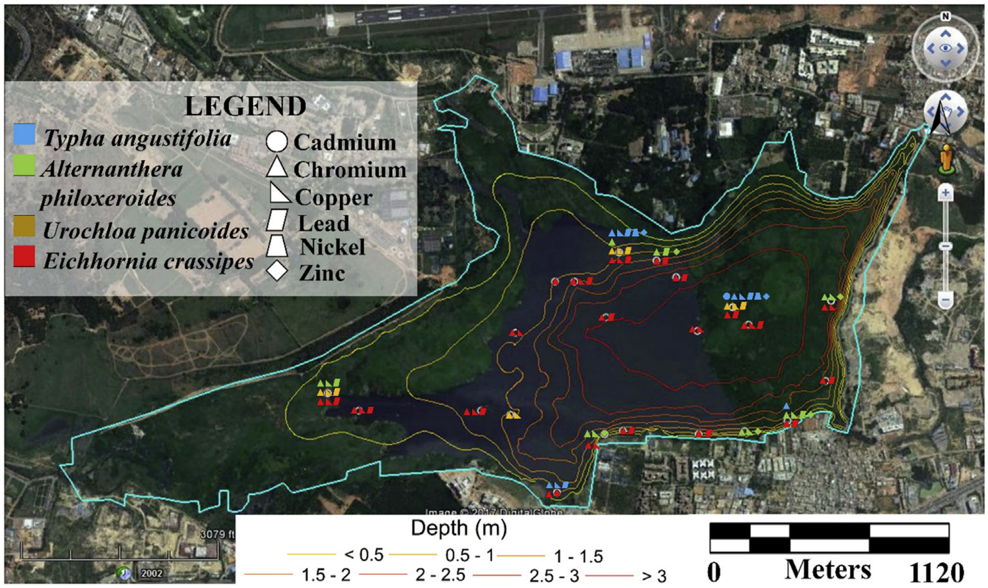

Fig. 4. Heavy metal concentration in Macrophytes above normal range.

causing further anomalies (i.e., pregnancy miscarriages, lactation, menopause, advancing age, etc.). Mobilized lead gets re-deposited in the soft tissues of the body leading to musculoskeletal, renal, ocular, immunological, neurological, reproductive, and developmental impacts (ATSDR, 2007). The principal source of lead in urban wetlands are from gasoline additives, metal plating, e-wastes, discarded battery cells, electrical equipment, textile mills, dye and pigments, paper mills, chemical and fertilizer industries, ghee manufacturing industries (Abbasi et al., 2005), etc.

In sediments, the lead concentrations ranged from 31.2 to 308.2 mg/kg that are higher than PEL levels. Higher lead accumulation in sediment samples were at inlet, while outlet samples had the least. In six sites the concentration was more than critical range (Fig. 3). In macrophyte samples it ranged from 12.8 to 59.7 mg/kg and higher values were found in the inlet samples (Fig. 4). Concentrations of Pb in the plant were higher than the average concentrations (>5 mg/kg) of phytotoxic. Lead in excess content can reduce germination, inhibits root elongation and has adverse effects on metabolism. The accumulation was in the order *Typha angustata* > *Alternanthera philoxeroides* > *Eichhornia crassipes* > *Urochloa panicoides*.

3.1.3. Copper (Cu)

Copper reaches the aquatic environment through wet and dry depositions, mining activities, storm water run-offs, industrial, domestic, and agricultural waste disposal. Among industrial sources include copper plating, pulp and paper mills, e-waste, etc. (Jumbe and Nandini, 2009b). Higher concentrations of copper can lead to oxidative stress and growth inhibition in plants (Gill, 2014). Copper concentrations in the sediment samples were in the range of 105–1147 mg/kg and mean value was 473.9 mg/kg (Fig. 3). These values are in the critical concentration ranges (Maiti, 2003) with higher values in the inlet samples. These concentrations impact aquatic plant communities (Peng et al., 2008). In macrophytes, copper concentrations ranged from 14.5 to 164.8 mg/kg (Fig. 4), in the order *Typha angustata* > *Urochloa panicoides* > *Alternanthera philoxeroides* > *Eichhornia crassipes.* . Copper is an essential element for growth but the concentration exceeding 20 mg/kg in the shoot is injurious (Borkert and Cox, 1999).

3.1.4. Nickel (Ni)

Nickel is used extensively in electro plating, chemical, marine, electrical, oil refining, and other industrial processes including alloy manufacture. The high concentration of heavy metal in the vegetative organs of most plants reaches toxicity for Ni around 10–15 mg/kg (Leguizamo et al., 2017). At high concentrations, Ni can form reactive oxygen species in plants and induce membrane lipid peroxidase (Pandey and Sharma, 2002). The most evident symptoms of Ni toxicity are chlorosis and necrosis. The concentration of Nickel ranged from 15.1 to 138.4 mg/kg with mean values of 65.87 mg/kg in sediments (Fig. 3). Four samples (inlet and shoreline) had concentrations higher than both critical and PEL values. The concentration in Macrophytes was ranging from 2.3 to 17.1 mg/kg (Fig. 4) and followed the order *Typha angustata* > *Alternanthera philoxeroides* > *Eichhornia crassipes* > *Urochloa panicoides*. *Typha angustata* had higher concentration of Nickel than the normal range in plants (Maiti, 2003).

3.1.5. Zinc (Zn)

Zinc is an essential element for the growth of plants and plays a vital role in many metabolic and physiological processes within plants (Gill, 2014). Its toxicity in plants can lead to poor or reduced root and shoot growth as well as chlorosis of leaves (Malik et al., 2011). Zinc gets into aquatic system due to a variety of industrial effluents, phosphates fertilizers, ghee manufacturing, metal processing units, zinc plating, silver plating, distillery units, landfill leachates, urban storm water, fly ashes of coal powered plants, poultry sewage, and compost (Abbasi et al., 2005). Zinc at high concentrations can cause muscular stiffness, loss of appetite, nausea and irritation (Meittei and Prasad, 2014). The values of Zinc in sediments were in the range of 125.7–2001 mg/kg with mean value of 410 mg/kg (Fig. 3). The concentration of Zinc in sediments of all sampling sites exceeded the critical concentration (Maiti, 2003) and at twelve sampling locations, sediment samples had higher Zinc values than the PEL values (MacDonald et al., 2000). In macrophytes, concentrations were in the order *Typha angustata* > *Urochloa panicoides* > *Eichhornia crassipes* > *Alternanthera philoxeroides* ranging from 11.9 to 151.6 mg/kg with higher values at the inlet. All samples had concentration within normal range (Fig. 4).

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3.1.6. Chromium (Cr)

Earlier used for colour and pigment and now being used in a variety of applications such as leather tanning, chromium plating, timber preservation, corrosion protection, textiles, etc. Around 90% of leather is tanned using chromium salts. Toxicity of Chromium species is known to cause heritable genetic damage; harmful in contact with skin and toxic if swallowed or inhaled. Cr causes irritation to respiratory system and skin and risk of serious damage to eyes. It is also very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment (Grant, 2001).

The Chromium was in the range 33.9–199.4 mg/kg in sediment samples with average value of 93.2 mg/kg (Fig. 3), which was above PEL levels. 13 samples had higher chromium levels than critical range (Maiti, 2003). Chromium is a non-essential element to the plants. Its compounds are toxic and detrimental to growth and development of plants. In hexavalent form, it is a potential carcinogenic element for humans and plants. Cr affects several processes in plants, namely seed germination, growth, yield and also physiological processes as photosynthesis impairment and nutrient and oxidative imbalances (Mishra et al., 2008). In macrophyte samples, concentrations in *Alternanthera philoxeroides* > *Eichhornia crassipes* > *Typha angustata* > *Urochloa panicoides* and the values ranged from 34.2 to 166.4 mg/kg (Fig. 4) exceeding the critical limits.

3.2. Bio-concentration factor

Bio-concentration factor indicates the assimilative capability of heavy metals by the plants from its surrounding environment. Metal accumulation in aquatic plants depends on various factors including metal concentration in the environment, physical and chemical properties of sediments, contact time, condition of plant growth, absorption mechanisms and time of sampling (Bonanno, 2011). In this study the sediment played an important role in accumulation of metals in plants. The higher accumulations of metals in sediments were directly responsible for the accumulation of metals in macrophytes. The bio-concentration factor (metal concentration in plant to sediment ratio) given in Table 3, show the trend of Cr > Cu > Pb > Zn > Ni > Cd. *Typha angustata* had the higher bio-concentration factor for all metals except Chromium. The chromium was found to be accumulated higher in *Alternanthera philoxeroides*. Higher bioaccumulation was seen in the sediment rooted macrophytes such as *Typha angustata,* which highlights of uptake by plants of the metals existing in sediments.

4. Conclusion

Accumulation of heavy metals in sediment and macrophyte samples of Bellandur wetland was investigated, which reveals of higher heavy metal concentrations in the sediment samples at inlet regions and shoreline. The accumulation of metals in sediments were in the order of Zn > Cu > Cr > Pb > Ni > Cd. All these metals exceeded the critical limits of metals in sediment. In the macrophytes, *Eichhornia crassipes* samples had higher metal concentrations in the middle and inlet reaches. In case of *Alternanthera philoxeroides* the heavy metals were higher in north and south shoreline samples. The concentration of different metals in the macrophyte samples were ranked as: Cr > Cu > Zn > Pb > Ni > Cd. Chromium and Copper were found to be more than critical range in plants. *Typha angustata* had the higher accumulation of all metals except chromium. This confirms of high bioavailability of heavy metals in the wetland sediments. *Typha angustata* has many advantages such as worldwide distribution, good growth and high toxic tolerance particularly to heavy metals. It has good bioaccumulation rate and is useful in biomonitoring to assess metal pollution in sediments.

The increased level of various heavy metal concentrations in the sediment and macrophytes, necessitates immediate appropriate measures to reduce the discharge of pollutants into Bellandur wetlands. The measures include treatment of municipal and industrial wastewater and selection of appropriate bio-indicator species for phytoremediation.

Table 3
Bio-concentration factors in various macrophyte species.

Macrophyte species	Cu	Cd	Ni	Cr	Zn	Pb
Eichhornia crassipes	0.09	0.02	0.09	0.65	0.08	0.38
Typha angustata	0.34	0.02	0.15	0.62	0.29	0.50
Alternanthera philoxeroides	0.12	0.01	0.09	0.69	0.08	0.32
Urochloa panicoides	0.22	0.01	0.06	0.52	0.18	0.37

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