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Dynamics of Metal Pollution in Sediment and Macrophytes of Varthur Lake, Bangalore

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Abstract

Eutrophication and metal contamination are the principal pollution problem for almost all inland lakes in world. Phytoremediation is one of the viable solutions for this concern. The present study analysed the concentration and distribution of six metals (cadmium, chromium, copper, nickel, lead and zinc) in sediment and macrophyte samples of Varthur Lake, Bangalore. Higher concentrations of studied metals in sediment were observed at the inlet and north shoreline regions of the lake. *Alternanthera philoxeroides* and *Eichhornia crassipes* accumulated higher concentration of metals than other species. Accumulation of metals in the sediment were Cu > Zn > Cr > Ni > Pb > Cd, whereas the order in macrophyte samples was Cu > Zn > Cr > Pb > Ni > Cd. Bioconcentration factor (BCF) and translocation factor (TF) of metals in macrophytes revealed metal pollution could be remediated through phytoextraction and phytostabilization.

Keywords Phytoremediation · Bioconcentration factor · *Eichhornia crassipes* · Phytostabilization

Wetlands are transition zones that play a major role in nutrient dynamics and act as natural filters. The interaction of man with wetlands during the last few decades has been a concern largely due to rapid population growth accompanied by intensified industrial, commercial and residential development, further leading to wetland pollution by domestic, industrial wastewaters and agricultural runoff (Ramachandra et al. 2018). Wetland plant (macrophyte) communities constitute some of the most highly productive ecosystems in the world (Mitsch and Gosselink 2000).

Phytoremediation is the use of living green plants for in situ risk reduction of contaminated soil, sludge, sediments, and ground water through contaminant removal, degradation, or containment (U.S. Environmental Protection Agency 1998). The basis of phytoremediation is that plants may extract nutrients, including metals, from soil and water. Earlier studies highlight the phytoremediation and bio-monitoring ability of macrophytes. Galal and Farahat (2015) evaluated the nutrient (N, P, and K) and metal (Cu, Zn, Mn, Pb, Cd, and Ni) remediation ability of *Pistia stratiotes*. Remediation potential of soil and water (contaminated with Ca, Cr, Cu, Pb, Zn, Mn, and Fe) by ten regional wetland species was studied by Chatterjee et al. (2011). Bioaccumulation and bioremediation capability of *Phragmites australis* to Fe, Al, Mn, Zn, As, Cu, Cr, Pb, Ni, Co, V, and Cd was reported by Esmaeilzadeh et al. (2016). Rana and Maiti (2018) reported metal bioaccumulation ability of *Colocasia esculenta*, *Scirpus grossus* and *Typha latifolia*.

Metals such as Pb, Cd, Cr, Zn, and Cu are one of the most significant pollutants in lake ecosystems due to their environmental persistence, toxicity, and capacity to bioaccumulate and biomagnify in food webs (Yang et al. 2014). Under certain circumstances they can be further transformed into more toxic compounds (Chen et al. 2010). Metals may enter aquatic ecosystems in the dissolved or particulate phase from domestic, industrial, or agricultural runoff, as well as from atmospheric deposition (Ahmed et al. 2015). Metals released into aquatic systems are generally bound to particulate matter, which eventually settle and become incorporated into sediments. Surface sediment therefore is the most important reservoir or sink of metals and other pollutants in aquatic environments (Kejian et al. 2008). Analyses of spatial and temporal distribution of metals in wetlands are useful to recognize degradation processes and trace sources

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of pollutants for environmental assessment and management. Bottom sediments, water bodies, plants, and other organisms in polluted wetlands contain metals and their concentrations fluctuate from year to year (Govindasamy et al. 2011). Objectives of the current research are to assess the metal [cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn)] concentrations in sediments and accumulation strategies in macrophytes of Varthur Lake, Bangalore, using bioconcentration and translocation factors.

Materials and Methods

Varthur Lake (12.9407° to 12.9566° N and 77.67189° to 77.7476° E) is the second largest lake in Bangalore (Fig. 1) and has an average depth of 1.05 m. The lake is located in Varthur ward with a spatial extent of 180.8 ha and spreads across Amanikere Bellandur Khane village. Varthur Lake has a catchment area of nearly 279 km^2 with 96 cascading interlinked lakes. Land use analyses in Varthur using temporal (1970 to 2016) remote sensing data shows an increase in built-up (paved surfaces: buildings, roads, etc.) from 3.8% (1973) to 89% (2016), with a sharp decline in vegetation (58.7% to 6.1%), water bodies (4.5% to 1.2%) and other (open lands, agriculture) land uses (33.1% to 5.0%) (Ramachandra et al. 2017).

Macrophytes and sediments were collected from inlet to outlet following random method. A total of 45 macrophyte and sediment samples were collected from the lake (Fig. 2). *Eichhornia crassipes* and *Alternanthera philoxeroides* were the dominant species of macrophytes. Collected macrophytes were stored in polythene bags after species identification using taxonomic literature (Cook 1996). Approximately 1 kg of sediment was collected through a cylindrical PVC cores with 5 cm of internal diameter at a depth of 0–20 cm (root growing zone) from each sampling location. Collected macrophytes were washed to eliminate sediments and epiphytes and separated by species. Aboveground and belowground parts were then separated and oven dried at 60°C for 2–3 days until constant weight. Sediments were air dried and sieved (1 mm) to remove coarse debris. Samples were powdered using a mortar and sieved (1 mm) to get fine powders. Powdered samples (0.5 g; macrophyte and sediment) were subjected to acid digestion according to established protocols (APHA 1995). Digested samples were filtered using 0.45 µm filter paper and made up to 50 mL using double distilled water for further analyses. Digested samples were analysed for six metals (Cd, Cr, Cu, Ni, Pb, and Zn) with reagent blanks and standards using Flame Atomic Absorption Spectrophotometry (GBC Avanta version 1.31).

Bioconcentration factor (BCF) is the ratio of metal concentration in the plant to that in sediment. The larger the factor, the more easily the plant absorbs the metal from the sediment and the higher possibility of redistribution for the metal (Zhang et al. 2009). A BCF value higher than one may indicate that a plant species could act as a hyperaccumulator of trace elements (Zhang et al. 2002). Translocation factor (TF) describes the efficiency of a plant to translocate metal from its root to shoot. It is calculated as the ratio of concentration (mg kg^{-1}) of metal in plant shoot to the concentration of the same metal in plant root. TF provides information

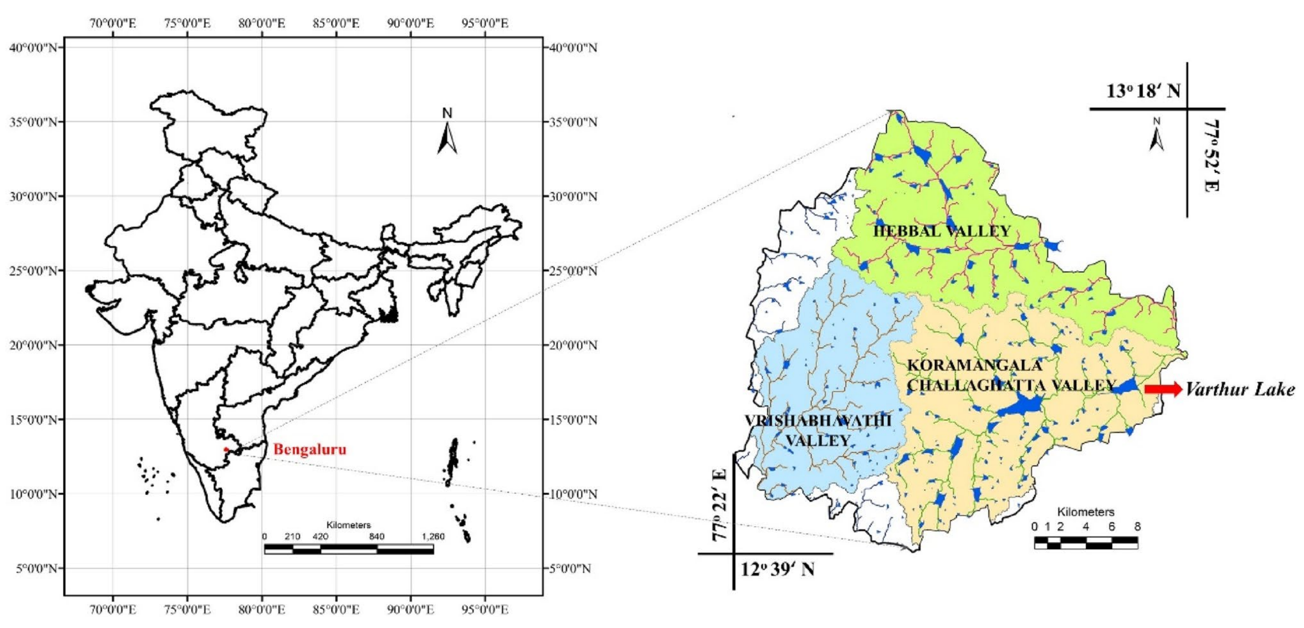

Fig. 1 Map of India showing location of Bangalore and Varthur Lake

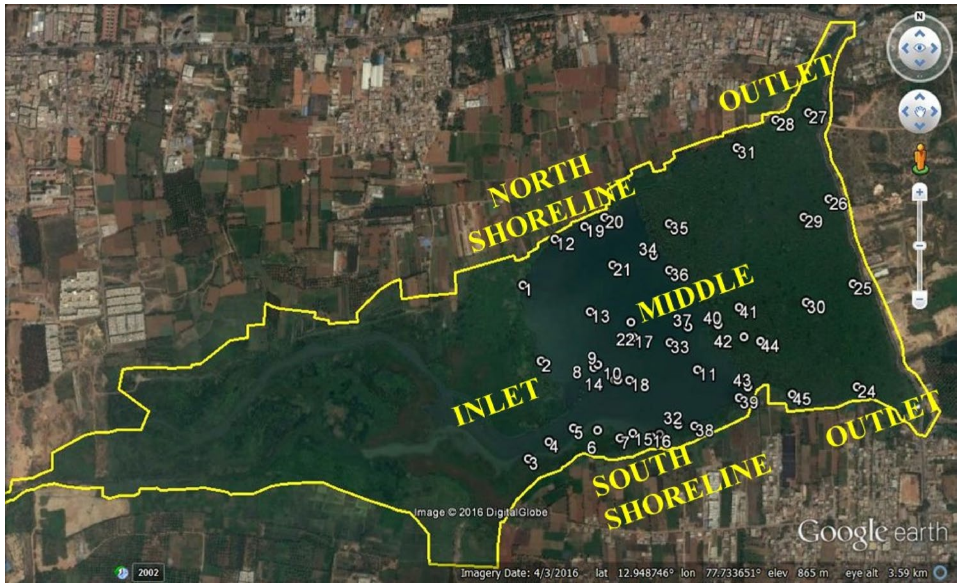

Fig. 2 Sampling locations of macrophytes and sediments in Varthur Lake

about the mobility of a given element from roots to leaves, and higher TF values result in greater mobility (Deng et al. 2004).

Results and Discussion

Metal concentrations in sediment and macrophyte samples are provided in Tables 1 and 2. Mean metal concentrations in sediments showed the following order Cu > Zn > Cr > Ni > Pb > Cd, whereas the order in macrophytes was Cu > Zn > Cr > Pb > Ni > Cd. All studied metals in sediment samples were above the threshold effect level (TEL), whereas Cd, Cr and Cu were above the probable effect level (PEL) and world common trace metal range levels in lake sediments (WCTMRL). More than half of the sampling points reported Cr above the PEL. Veeranam Lake and Bellandur Lakes had Cr concentrations similar to this study, whereas Renuka Lake, Yercaud Lake, Akkulam Veli Lake, and Kodaikanal Lake showed higher concentrations of Cr (Balamurugan et al. 2014; Das et al. 2008; Gopal et al. 2017; Ramachandra et al. 2018; Suresh et al. 2012; Swarnalatha et al. 2014). Almost all samples had Cu above the WCTMRL (Table 1). Nickel concentrations in current samples were within PEL and WCTMRL levels. Overall, the north shoreline (V12, V21) and inlet (V5) sediment samples had the highest concentration of studied metals. This is because of the untreated effluents entering the lake through these points. Middle samples (V36, V37) had lower concentration of metals.

Cadmium concentrations were within toxic limits as reported by Kabata-Pendias (2010), in all macrophyte samples. A study by Jumbe and Nandini (2009) at Varthur Lake reported mean Cd concentration of 8 mg kg^{-1} in *E. crassipes*, which is higher than results from the current study. Findings from another study in *A. philoxeroides* and *E. crassipes* reported 5.64 and 5.79 mg kg^{-1} Cd (Jha et al. 2016), which were higher values of Cd than this study. Similarly, high concentrations of Cd were reported in *E. crassipes* shoot (128 mg kg^{-1}) by Singh et al. (2016), and 9.13 mg kg^{-1} and 5.59 mg kg^{-1} in root and shoot of *E. crassipes* (Singh et al. 2017) all of which were much higher than those values observed in the present study. Rana and Maiti (2018) reported Cd concentration of 2.3 mg kg^{-1} and 1.9 mg kg^{-1} in shoot and root (respectively) of *C. esculenta*, which is again higher than present study results. Chromium is generally considered toxic for plants because it may alter N metabolism by affecting protein formation (Bonanno and Cirelli 2017). The concentration of Cr ranged from 34 to 54.8 mg kg^{-1}, with a mean value of 42.33 mg kg^{-1} in macrophytes (Table 2). *Typha angustifolia* root had the lowest Cr concentrations, while *E. crassipes* shoot had higher Cr concentrations; however, all samples exceeded toxic levels (Kabata-Pendias 2010). Jha et al. (2016) observed Cr concentration of 41.5 mg kg^{-1} in *A. philoxeroides* in Kolkata wetlands, which is consistent with the current study. Rana and Maiti (2018) recorded Cr concentrations of 11.9 mg kg^{-1} and 7.6 mg kg^{-1} in root and shoot (respectively) of *C. esculenta* at a natural wetland contaminated with coke oven effluent. These reported values are lower compared to the present study. Chromium concentrations of 8.06 mg kg^{-1} and BDL in root and shoot (respectively) of *E. crassipes* at Kanjli wetland were observed by Singh et al. (2017) which were low compared to the current study. Copper in macrophytes ranged from 21.3 to 263.5 mg kg^{-1}, with the maximum concentration found in *A. philoxeroides* shoot material (Table 2). A study by Chatterjee et al. (2011) in

Table 1 Comparison of metal (mg kg^{-1}) in sediments of Varthur Lake, Bangalore, with other Indian lakes and standard values

Name of the Lake	Metal concentration (mg kg^{-1})						References
	Cd	Cr	Cu	Ni	Pb	Zn	
Varthur Lake, Bangalore	5.80 (1.40–23.7)	102 (36.5–162)	211 (86.5–422)	54.8 (26.7–80.0)	45.3 (23.4–59.9)	132 (26.8–353)	This study
Varthur Lake, Bangalore	BDL – 17.3	BDL – 21.4	131–134	16.2–68.0	4.40–88.5	25.7–220	Jumbe and Nandini (2009)
Bellandur Lake, Bangalore	1.60–55.3	33.9–199	105–1148	15.1–138	31.2–208	126–2001	Ramachandra et al. (2018)
Veeranam Lake, Chennai	0.20–3.90	40.0–150	65.0–125	34.0–95.0	20.0–41.0	65.0–599	Suresh et al. (2012)
Hussain Sagar Lake	–	40.0–60.0	–	170–210	40.0–60.0	–	Rao et al. (2008)
Renuka Lake	–	196	340	36.7	35.9	148	Das et al. (2008)
Jannapura Lake	1.90	–	89.8	40.1	–	259	Puttaiah and Kiran (2008)
Mansar Lake	–	63.0	26.4	46.0	32.7	67.0	Das et al. (2006)
Yercaud Lake	–	322–441	480–687	147	15.5–48.0	101–258	Gopal et al. (2017)
Anchar Lake Kashmir	0.70–3.60	3.10–8.70	2.80–28.7	2.10–10.1	0.40–4.30	1.40–13.8	Irfana et al. (2018)
Akkulam Veli Lake, Thiruvananthapuram	–	49.0–642	1.00–126	5.00–259	18.0–189	19.0–279	Swarnalatha et al. (2014)
Vembanad Lake	–	108	30.9	48.7	32.6	185	Selvam et al. (2012)
Kodaikanal Lake	–	452	54.5	115	44.7	113	Balamurugan et al. (2014)
Urban Pond, Dhanbad	1.70–5.00	74.0–109	–	–	23.3–36.0	1055–1804	Pal and Maiti (2018)
GB Pant Sagar	0.30–5.60	0.60–32.3	1.30–30.7	0.30–38.3	1.00–11.0	5.00–59.9	Rai (2010)
Korba Basin Pond	0.10–1.20	29.0–79.0	18.0–92.0	–	26.0–125	42.0–294	Sharma et al. (2017)
TEL	0.60	37.3	35.7	35.0	18.0	123	MacDonald et al. (2000)
PEL	3.53	90.0	197	91.3	36.0	315	MacDonald et al. (2000)
WCTMRL	0.10–1.50	20.0–190	20.0–90.0	30.0–250	10.0–100	50.0–250	Forstner and Whitman (1981)

TEL threshold effect level, *PEL* probable effect level, *WCTMRL* world common trace metal range in lake sediment

East Calcutta wetlands, West Bengal, reported Cu concentrations of 23.2 mg kg^{-1} and 12.5 mg kg^{-1} in *E. crassipes* and *C. esculenta*, which are below values observed in the current study. Meitei and Prasad (2016) observed lower levels of Cu than the present study in *E. crassipes* (5.6 mg kg^{-1} in root and 2.5 mg kg^{-1} in shoot), *A. philoxeroides* (4.8 mg kg^{-1} in root and 0.5 mg kg^{-1} in shoot) and *C. esculenta* (1.3 mg kg^{-1} in root and 0.8 mg kg^{-1} in shoot). Rana and Maiti (2018) reported Cu concentration of 80.7 mg kg^{-1} in *C. esculenta* root, and Kumar et al. (2008) observed Cu level of 104.2 mg kg^{-1} in *T. angustifolia* which are both higher compared to current results. Lead is not an essential element for plant metabolism and is considered among the most toxic metals, even at low concentrations (Bonanno and Cirelli 2017; Prasad 2004). Macrophyte Pb concentrations ranged from 8.7 to 56.7 mg kg^{-1}, with a mean value of 21.9 mg kg^{-1} (Table 2). *Colocasia esculenta* root had lowest Pb concentration, while *A. philoxeroides* shoot had the highest Pb concentration. Singh et al. (2016) reported a Pb concentration of 256 mg kg^{-1} in *E. crassipes* shoot which is 10 times higher than present results. Similarly studies by Jha et al. (2016) (26.97 mg kg^{-1} in shoot and 80.95 mg kg^{-1} in root) and Singh et al. (2017) (83.42 mg kg^{-1} in root and 79.99 mg kg^{-1} in shoot) showed higher concentrations of Pb in *E. crassipes* compared to the current study. Findings from Mazumdar and Das (2015) reported Pb concentrations of 21.6 mg kg^{-1} in shoot and 27.9 mg kg^{-1} in root

Table 2 Mean, range, and critical concentration of metal in macrophytes of Varthur Lake, Bangalore

Metal	Mean (range) (mg kg^{-1})	Plant	Shoot (mean ± SD)	Root (mean ± SD)	Excess/toxic level in plants Kabata-Pendias, (2010) (mg kg^{-1})
Cd	0.21 (0.00–0.80)	*Eichhornia crassipes*	0.10 ± 0.05	0.20 ± 0.15	10.0–30.0
		Alternanthera philoxeroides	0.20 ± 0.08	0.10 ± 0.01	
		Colocasia esculenta	0.10 ± 0.04	0.10 ± 0.02	
		Typha angustifolia	0.20 ± 0.07	0.70 ± 0.06	
Cr	42.3 (34.0–54.8)	*Eichhornia crassipes*	44.7 ± 5.99	42.4 ± 3.85	5.00–30.0
		Alternanthera philoxeroides	45.1 ± 3.43	37.9 ± 5.44	
		Colocasia esculenta	38.1 ± 3.23	50.8 ± 3.56	
		Typha angustifolia	43.8 ± 3.59	33.0 ± 3.21	
Cu	66.8 (21.3–264)	*Eichhornia crassipes*	58.5 ± 31.1	89.4 ± 12.5	20.0–100
		Alternanthera philoxeroides	148 ± 109	103 ± 10.1	
		Colocasia esculenta	28.9 ± 3.89	44.4 ± 5.66	
		Typha angustifolia	42.1 ± 6.23	32.1 ± 2.13	
Ni	8.44 (3.50–17.1)	*Eichhornia crassipes*	6.20 ± 2.57	12.6 ± 0.65	10.0–100
		Alternanthera philoxeroides	5.60 ± 0.71	7.90 ± 2.19	
		Colocasia esculenta	5.60 ± 1.62	4.90 ± 1.11	
		Typha angustifolia	7.70 ± 2.26	16.2 ± 0.56	
Pb	21.9 (8.70–56.7)	*Eichhornia crassipes*	22.7 ± 5.18	24.8 ± 2.39	30.0–300
		Alternanthera philoxeroides	32.4 ± 18.7	33.2 ± 19.0	
		Colocasia esculenta	13.5 ± 2.87	9.30 ± 0.25	
		Typha angustifolia	20.5 ± 5.65	18.8 ± 6.22	
Zn	64.8 (14.8–156)	*Eichhornia crassipes*	38.8 ± 39.2	122 ± 6.85	100–400
		Alternanthera philoxeroides	28.6 ± 6.54	140 ± 22.7	
		Colocasia esculenta	20.6 ± 2.96	28.9 ± 4.74	
		Typha angustifolia	23.1 ± 3.96	117 ± 5.87	

of *C. esculenta*, which is higher compared to the current study. Suthari et al. (2017) observed Pb concentration of 383.3 mg kg^{-1} in *A. philoxeroides* root, which is more than ten times higher compared to current findings. Yadav and Chandra (2011) observed Pb content of 32.5 mg kg^{-1} in root of *T. angustifolia* which is almost two times higher compared to the current study. Chatterjee et al. (2011) in *C. esculenta* and Ramachandra et al. (2018) in *T. angustifolia*, *A. philoxeroides* and *E. crassipes* reported similar Pb concentrations as in the current study. Nickel is another toxic metal that may affect plant growth, metabolism and physiology. In the macrophyte samples the concentration of Ni ranged from 3.5 to 17.1 mg kg^{-1}, which was below toxic levels (Table 2) (Kabata-Pendias 2010). Studies by Ramachandra et al. (2018) (*T. angustifolia*, *E. crassipes*, *A. philoxeroides*) and Yadav and Chandra (2011) (*T. angustifolia*) reported similar Ni concentrations to those of the current study. The range of Zn in macrophytes ranged from 14.8 to 155.5 mg kg^{-1} (mean 64.76 mg kg^{-1}), with *A. philoxeroides* accumulating highest Zn concentrations and *E. crassipes* accumulating the lowest (Table 2). Higher accumulation of Zn was reported in the same macrophytes by Chatterjee et al. (2011), Yadav and Chandra (2011), Singh et al. (2017), and Mazumdar and Das (2015). A similar Zn concentration range was seen in *T. angustifolia*, *A. philoxeroides*, and *E. crassipes* by Ramachandra etal. (2018) and *C. esculenta* by Meitei and Prasad (2016). *Alternanthera philoxeroides* and *E. crassipes* had most of the metals in higher concentration among the studied macrophyte samples.

The metal accumulation strategy of macrophytes was studied using BCF and TF. The BCFs ranged from 0.5 to 1.45, 0.38 to 1.28, 0.19 to 0.28, 0.75 to 0.9, 0.13 to 0.27, and 0.35 to 1.14 for Pb, Zn, Ni, Cr, Cd, and Cu, respectively. The order of BCF for metals was Zn > Pb > Cr > Cu > Ni > Cd. *Alternanthera philoxeroides* had higher BCFs for Pb, Zn, and Cu, which was similar to that reported by Suthari et al. (2017). *Typha angustifolia* had higher BCFs for Ni and Cd which were similar to results obtained by Yadav and Chandra (2011). The BCF for Cr was highest for *C. esculenta*. The TFs ranged from 0.9 to 1.45, 0.22 to 0.71, 0.45 to 1.13, 0.7 to 1.32, 0.25 to 1.5, and 0.65 to 1.43 for Pb, Zn, Ni, Cr, Cd, and Cu, respectively. The TFs for metals was Pb > Cr > Cu > Cd > Ni > Zn. *Colocasia esculenta* had higher

TFs for Pb, Zn, and Ni than other macrophytes. Similar TFs were observed for Pb and Zn by Mazumdar and Das (2015) in *C. esculenta*. The TFs for Cd and Cu were highest in *A. philoxeroides*, and *T. angustifolia* had the highest TF for Cr.

Phytostabilization acts as an efficient remediation technique when plants show high BCF and low TF (BCF > 1 and TF < 1), while phytoextraction is suitable when both BCF and TF > 1 (Yang et al. 2015). Thus, *A. philoxeroides* and *E. crassipes* had potential for phytostabilization of Pb and Zn, respectively. Lead and Zn phytostabilization by *E. crassipes* was reported earlier by Jha et al. (2016) and Meitei and Prasad (2016), respectively. Copper was accumulated mainly by phytoextraction by *A. philoxeroides*. Nickel, Cr and Cd had higher mobility in *C. esculenta*, *T. angustifolia*, and *A. philoxeroides*, respectively, as BCF < 1 and TF > 1.

The present study revealed metal concentration and accumulation capabilities of sediments and macrophytes from Varthur Lake, Bangalore. Studied metals were higher in inlet and shoreline regions of the lake. Sediments were sinks for metals. The phytoremediation ability of macrophytes were revealed through metal accumulation. *Alternanthera philoxeroides* and *E. crassipes* remediated most metals through phytostabilization and phytoextraction.

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