Research Article

Nutrient and heavy metal composition in select biotic and abiotic components of Varthur wetlands, Bangalore, India

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Abstract

Lakes or wetlands in urban landscapes provide services such as groundwater recharge, provide fish, fodder and food to the dependent local population, mitigate floods, habitat for fauna, support recreation, etc. Unplanned rapid urbanization with globalization and industrialization has led to the sustained inflow of untreated wastewater from domestic and industrial sectors to water bodies leading to eutrophication and heavy metal contamination. This necessities treatment of sewage and industrial effluents, which needs to be technically feasible and economically viable. This communication investigates the distribution and accumulation of nutrients (carbon and nitrogen) and six heavy metals (cadmium, chromium, copper, nickel, lead and zinc) in the sediment and macrophyte samples of Varthur lake, Bangalore. Higher carbon and nitrogen values in sediment samples of the northwest and northeast shorelines were observed, whereas lower carbon and nitrogen values were observed in the samples of middle and outlets of the lake. Shoots of *Colocasia esculenta* and *Alternanthera philoxeroides* accumulated higher amount of carbon and nitrogen. Sediment samples of north shoreline and inlet portion of the Lake had high concentration of heavy metals in *Alternanthera philoxeroides* and *Eichhornia crassipes* accumulated heavy metals in higher extent among macrophyte species. Sediment samples had higher concentrations of copper (Cu) followed by zinc (Zn), chromium (Cr), lead (Pb), nickel (Ni) and cadmium (Cd). Compared to this, accumulation of heavy metals in macrophyte samples is in the order Cu > Zn > Cr > Pb > Ni > Cd. Assessment of bioconcentration factor and translocation factor of metals in macrophytes revealed the prospects of select macrophytes in phytoremediation for mitigating metal pollution through phytoextraction and phytostabilization.

Keywords Heavy metal · Sediment · Macrophytes · Phytoremediation · Bangalore · Varthur lake

1 Introduction

Wetlands being the transition zone of land and water plays a significant role in nutrient cycling, treatment of water, attenuation of floods, maintaining stream flow, recharge ground water, moderate local microclimate, provision goods (fish, fodder, fuel, drinking water, etc.) and services (regulating, cultural, etc.) to the dependent population [1]. Sustained discharge of untreated or partially treated sewage has been altering the chemical integrity of aquatic environment by enriching the system with nutrients, leading to the eutrophication of urban water bodies [2]. Wastewater generated in the domestic and industrial sectors consists of chemical ions, nutrients and heavy metals [3–6].

Lakebed provides a platform for sediment deposition, which traps heavy metals [7], aiding in the remediation as well as regulating the biological processes. Sediments act as sink of nutrients [8], and analyses of sediments would reveal extent and history of eutrophication. The nutrient

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budget, ecology, trophic status and rate of evolution of lakes are influenced by plant detritus and sediments. The particulate detritus of plants are the primary source of organic matter, and total organic carbon and small volume is contributed by animal and other sources [9]. Sediment–water interactions are important because of higher sediment surface per volume of water in shallow lakes [10].

Plant communities (macrophytes) in wetlands [11] act as nutrient sink by uptake of elements released by sediment to water column, which will influence water chemistry. Assessment of the chemical composition in the macrophytes provides an information about the uptake ability of plants to nutrients [12], nutrients availability for metabolism and the nutrient value of the plants [13]. The ability of macrophytes to uptake nutrients and metals from soil and water forms the basis of phytoremediation [14]. Nutrient composition or accumulation in the tissues is an important feature for identifying the ecological strategy of the plant species, and this aids in predicting the competitive complex interactions among the plant communities [15, 16] and aboveground biomass stores higher proportion of nutrients [17]. Phytoremediation capability of aquatic macrophytes has been studied earlier by researchers [18–27], and hence, they are being used in monitoring the status of an ecosystem (biomonitoring).

Heavy metals have increased enormously in the environment from anthropogenic sources due to industrialization and enhanced agricultural activities (pesticides, etc.). Heavy metals in the environment have been posing challenges due to the hazardous properties such as toxicity, persistence, accumulation in the biological organism leading to biomagnification in food webs [28–33], which further get transformed into more toxic compounds [34] posing serious challenges to biotic health. The occurrence of toxic pollutants in water bodies (lakes, ponds, streams and rivers) would affect the health of population who depend on these water sources to meet their daily requirements (water, fish, food, etc.). Consumption of water and wetland goods laded with metals would lead to the accumulation in the kidneys, liver and bones of humans, resulting in chronic disruption of metabolic activities, and lead to cardiovascular, neurological and renal diseases [35, 36]. Table 1 provides the sources and toxic effects of heavy metals on plants and humans. Bottom sediments, plants and other organisms in polluted wetlands contain heavy metals [37] due to bioaccumulation. Analyses of spatial distribution of heavy metals in sediments and macrophytes of wetlands aid in tracing the sources and the extent of contamination, which is useful in remediation and prudent management of water bodies.

Wetlands are distributed across various topographic and climatic regimes and support diverse and unique habitats in India [53]. Due to inadequate management, many of the wetlands in urban and rural areas are subject to anthropogenic pressures, including pollution from industry and households, land use changes in the catchment, tourism, encroachments and over exploitation of their natural resources [53]. Bangalore is located at an altitude of 920 m above mean sea level, delineating three watersheds, viz. Hebbal, Koramangala–Challaghatta and Vrishabhavathi watersheds (Fig. 1). The undulating terrain in the region has facilitated creation of a large number of tanks for the traditional uses of irrigation, drinking, fishing and washing.

Bangalore, being a part of peninsular India, had the tradition of harvesting water through surface water bodies to meet the domestic water requirements in a decentralized way. After independence, the source of water for domestic and industrial purpose in Bangalore is mainly from the Cauvery River and ground water. Untreated sewage is let into the storm water drains, which progressively converge at the water bodies. Varthur lake is the second largest lake in Bangalore. It is a part of a system of interconnected tanks and canals, i.e., three chain of lakes in the upstream joins Bellandur lake with a catchment area of about 149 km^2 (14,979 Hectares), and overflow of this lake gets into Varthur lake and from where it flows down the plateau and joins Pinakini river basin [54]. Thus, Varthur lake receives all the surface runoff, wastewater and sewage from the Bangalore South taluk (about 40% of Bangalore city sewage). Sustained inflow of untreated sewage and effluents (from industries) has contaminated the lake resulting in eutrophication [55] as the inflow of pollutants has surpassed the lake's assimilative capacity. This has led to algal bloom with extensive growth and spread of invasive macrophytes, resulting in malodor decline of dissolved oxygen [55]. Hence, the current research investigates the level of nutrients (carbon and nitrogen) and predominant heavy metals [cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn)] concentrations in the Varthur lake through analysis of representative sediment and macrophyte samples.

2 Materials and methods

2.1 Study area

Varthur Lake located at 12.9407° to 12.9566° N and 77.67189° to 77.7476° E is the second largest lake in the Bangalore city (BBMP) (Fig. 1). It is situated at Varthur ward in Bangalore east with an area of 180.8 ha (447 acres 14 guntas) and spread across Ammanikere and Bellandur Khane villages. The catchment of Varthur lake is around 279 km^2 with 96 cascaded lakes. Land use analyses study using temporal (1970–2016) remote sensing data showed

Table 1 Sources and effects of heavy metals exposure

Heavy metal	Sources	Toxic effects on humans and plants	References
Cd	Geogenic sources, anthropogenic activities, metal smelting and refining, fossil fuel burning, application of phosphate fertilizers, sewage sludge, nickel–cadmium batteries, cement industry	Lung cancer, osteomalacia, kidney damage chlorophyll senescence, growth inhibition, enzyme activity inhibition	[35, 38–52]
Cr	Electroplating industry, sludge, solid waste, tanneries, textile industry, pigments and paints	Pulmonary fibrosis, lung cancer Seed germination, growth, photosynthesis impairment, nutrient and oxidative imbalances	
Cu	Electroplating industry, smelting and refining, mining, biocides (pesticide, herbicides, preservations)	Vineyard sprayer's lung (inhaled); Wilson disease (hepatic and basal ganglia degeneration), metal fever, vomiting, brain damage Plant growth inhibition, photosynthesis inhibition, reduced yield, poor seed germination, stunted leaf and root growth	
Ni	Volcanic eruptions, land fill, forest fire, bubble bursting and gas exchange in ocean, weathering of soils and geological materials. Fertilizers, batteries	Occupational (inhaled): pulmonary fibrosis, reduced sperm count, naso-pharyngeal tumors Chlorosis, Necrosis, wilting, disruption of photosynthesis, growth and development inhibition	
Pb	Mining and smelting of metalliferous ores, burning of leaded gasoline, municipal sewage, industrial wastes enriched in Pb, paints, battery industry, fertilizers, pesticides	Anemia, abdominal pain, nephropathy Stunted growth, chlorosis, reduce germination, inhibits root elongation and has adverse effects on metabolism	
Zn	Batteries and other electrical materials, pigments and paints, biocides, fertilizers, metal processing units, zinc plating, silver plating, distillery units, landfill leachates, fly ashes of coal powered plants, poultry sewage	Muscular stiffness, loss of appetite, neutropenia, nausea and irritation Poor or reduced root and shoot growth as well as chlorosis of leaves	

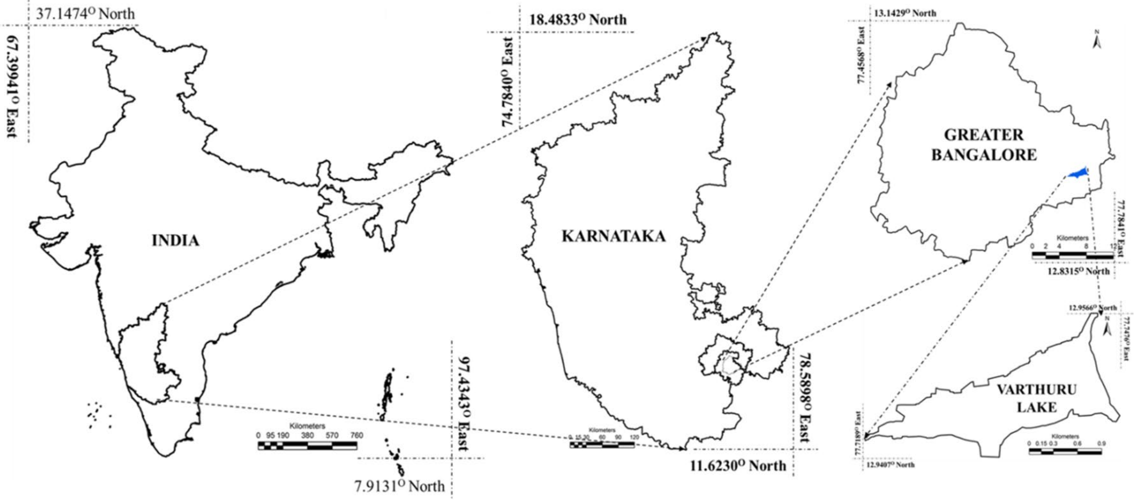

Fig. 1 Study area—Varthur Lake, Greater Bangalore, Karnataka State, India

an increase in built-up (paved surfaces: buildings, roads, etc.) from 3.8% (1973) to 89% (2016) with a sharp decline in vegetation (58.7–6.1%), water bodies (4.5–1.2%) and other (open lands, agriculture) land uses (33.1–5.0%) in the catchment [56].

2.2 Macrophyte and sediment sample collection

Representative samples of macrophytes and sediment were collected from the inlet to outlet regions of the lake, following quadrat-based transact method (quadrat of 1 m^2) (Fig. 2). Three to five samples were collected in each quadrat. Random sampling method was used for collection of macrophytes. The major species of macrophytes in this lake were *Eichhornia crassipes* and *Alternanthera philoxeroides*. Macrophytes were identified based on the standard taxonomic literatures [57] and stored in polythene bags. Approximately 1 kg of sediment (in triplicates) was collected at a depth of 0–20 cm at each sampling locations with the help of a cylindrical PVC cores with 5 cm of internal diameter.

2.3 Sample preparation and analysis

Collected macrophytes were washed to remove adhered sediments and epiphytes and segregated based on species. Shoot and root of each sample were separated and oven dried at 60 °C for 2–3 days until the attainment of constant

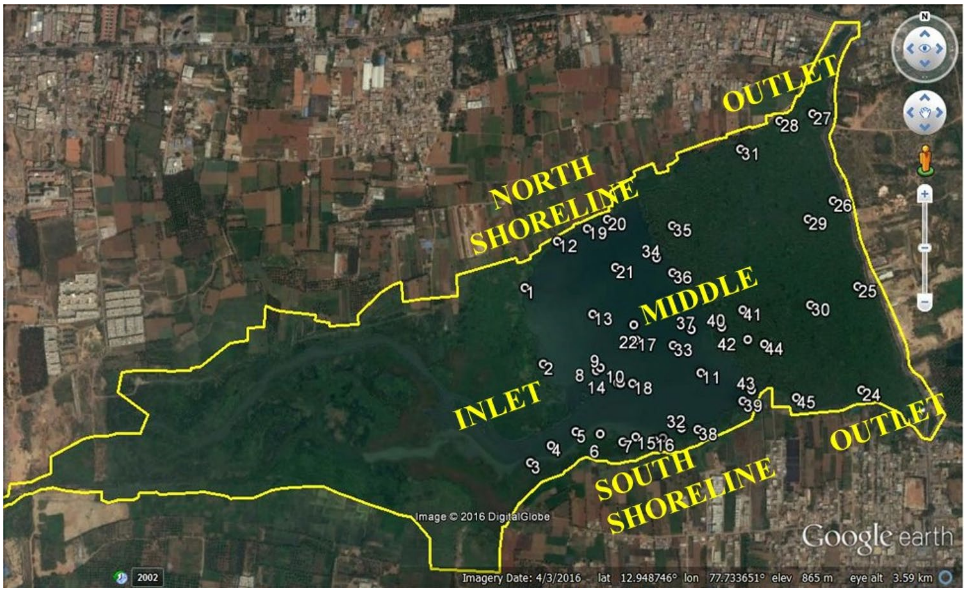

Fig. 2 Sampling locations of macrophytes and sediments in Varthur lake

weight. It is then powdered using mixer/grinder and sieved to get fine powders. The replicates of each sample were used for nutrient analysis. The samples were analyzed for C, H and N using TRUE-SPEC CHN Analyzer. Sediments were air-dried and sieved to remove coarse debris. Sediment samples were pulverized using a mortar and sieved to get fine powder. Nutrient analyses in sediment samples were assessed through TRUE-SPEC CHN Analyzer like macrophytes.

2.4 Heavy metal analysis

Pulverized sediment sample (0.5 g) was acid digested with 3:1 (v/v) HCl–HNO_3, evaporated to 2 ml, filtered using 0.45-µm filter paper and diluted to 50 ml using double distilled water [58] for heavy metal analysis. Macrophyte samples were acid digested with triacid mixture (HNO_3:H_2SO_4:$HClO_4$ in 5:1:1) until transparent solution was obtained. Flame atomic absorption spectrophotometry (GBC Avanta version 1.31) was used for analysis of six heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) in samples along with the reference reagent blanks and standards (Merck, USA).

2.5 Bioconcentration factor (BCF)

Bioconcentration factor (BCF) in macrophytes is the ratio of heavy metal concentration in the plant to that in the sediment at a sampling location (Eq. 1). Higher values of BCF indicate the easy assimilation of heavy metal by macrophytes from sediments and the higher possibility of heavy metal redistribution in the environment [59]. BCF expresses the ability of a plant to uptake a specific element from sediments and subsequent accumulation in its tissues. Higher BCF values imply of good bioaccumulation or accumulation capability of macrophytes. A BCF value higher than one indicates that a particular plant species is aiding as a hyper-accumulator of trace elements [60].

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

2.6 Translocation factor (TF)

Translocation factor (TF) describes the efficiency of a plant to translocate metal from its root to shoot and is computed as the ratio of concentration (mg/kg) of metal in plant shoot to the concentration of the same metal in plant root (Eq. 2). Higher TF values indicate higher capacity of mobility [61].

$$\text{Translocation factor (TF)} = \frac{\text{Heavy metal content in shoot of macrophytes}}{\text{Heavy metal content in root of macrophytes}} \quad (2)$$

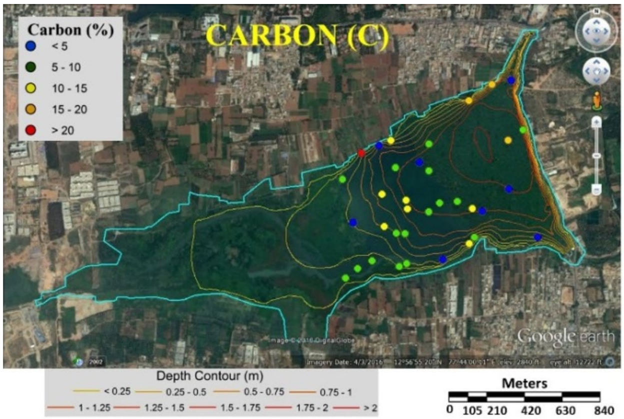

Fig. 3 Carbon content in sediment samples

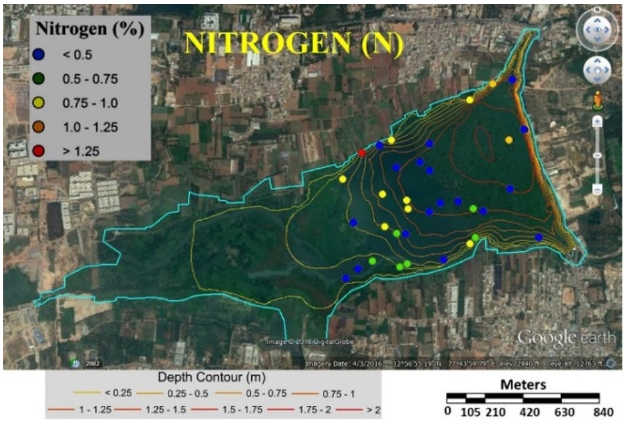

Fig. 4 Nitrogen content in sediment samples

3 Results

3.1 Total carbon and nitrogen in sediment

Carbon values ranged from 1.58 g/100 g dry weight (V44) to 21.1 g/100 g dry weight (V12) in the sediment samples of Varthur lake. Higher C values were in the samples of northwest and northeast shoreline side of the lake (Fig. 3) at a depth of 0.25–1 m, and lower concentrations were found in the middle and outlet regions. Nitrogen values as indicated in Fig. 4 ranged from 0.05 g/100 g dry weight (V27) to 1.37 g/100 g dry weight (V12), and the spatial variations in N concentrations are similar to carbon. C: N ratio ranging from 4.26 (V44) to 56.38 (V27) corroborates that organic matter is of terrestrial sources. It was observed that the middle regions of the lake had a higher C:N value than the other regions.

Table 2 Carbon (C) and nitrogen (N) content in sediment and macrophyte samples of Varthur lake

Sample	N (g/100 g dry weight)		C (g/100 g dry weight)	
	Range	Mean	Range	Mean
Sediment	0.05–1.4	0.57	1.57–21.1	8.56
Eichhornia crassipes shoot	2.57–4.34	3.59	33.87–37.51	34.84
Eichhornia crassipes root	2.84–4.32	3.2	29.74–35.97	33.65
Alternanthera philoxeroides shoot	4.12–5.27	4.85	33.98–35.78	34.61
Alternanthera philoxeroides root	3.16–4.43	3.80	35.29–37.2	36.25
Typha angustifolia shoot	1.2–3.5	1.99	30.1–32.2	31.14
Typha angustifolia root	2.1–4.25	2.92	32.6–35.5	34.69
Colocasia esculenta shoot	4–4.46	4.26	36.5–38.5	37.51
Colocasia esculenta root	3.75–4	3.88	38.08–38.41	38.25

Table 3 Mean, range and critical concentration of heavy metal (mg/kg) in sediments of Varthur lake

Metal	Mean (range) (mg/kg)	CPCB (2001)	TEL [62]	PEL [62]	Critical soil concentration [63]	Uncontaminated sediments [48]
Cd	5.82 (1.4–23.7)	BDL	0.596	3.53	3–8	–
Cr	101.92 (36.5–161.7)	389.3	37.3	90	75–100	12–44
Cu	210.57 (86.5–421.6)	113	35.7	197	60–125	–
Ni	54.76 (26.7–80)	54.5	35	91.3	100	1–20
Pb	45.26 (23.4–59.9)	64.9	18	36	100–400	2–50
Zn	131.65 (26.8–352.9)	–	123	315	70–400	1–50

CPCB Central Pollution Control Board, *TEL* threshold effect level, *PEL* probable effect level

3.2 Total carbon and nitrogen in macrophyte samples

Carbon and nitrogen content (range and mean) in shoot and root of macrophyte samples is given in Table 2. Carbon content in studied macrophyte samples ranged from 29.74 g/100 g dry weight to 38.5 g/100 g dry weight. *Eichhornia crassipes* and *Alternanthera philoxeroides* shoot had higher C content at sampling location V2 (inlet), while V15 (south shoreline) had lowest. Average C content in the shoots of *Eichhornia crassipes* is about 34.2 g/100 g dry weight, and *Alternanthera philoxeroides* is 34.6 g/100 g dry weight. C content in roots of *Eichhornia crassipes* had higher values in V34 (north shoreline) and lowest in V3 (south shoreline). Carbon content in roots of *Alternanthera philoxeroides* was lowest at V2 and highest at V27. C values (shoot and root) of *Colocasia esculenta* and *Typha angustifolia* were higher at V12 (north shoreline) and lower at V45 (outlet), respectively.

The range of nitrogen in macrophyte samples was 1.2–5.27 g/100 g dry weight. Nitrogen content in *Eichhornia crassipes* shoot was higher at south shoreline (V7: 4.3 g) and lower at north shoreline (V12: 2.6 g). The average value of N in *Eichhornia crassipes* shoot is 3.59 g/100 g dry weight and 3.2 g/100 g dry weight in roots. The highest N content in *Eichhornia crassipes* root was found at V27, and V3 had the lowest N content. *Alternanthera philoxeroides* shoot (4.8 g) and root (3.8 g) had highest and lowest nitrogen content at V2 and V27, respectively. In case of *Colocasia esculenta* and *Typha angustifolia*, the N content (above ground and below ground parts) was highest at V12 and lowest at V45 (Fig. 4).

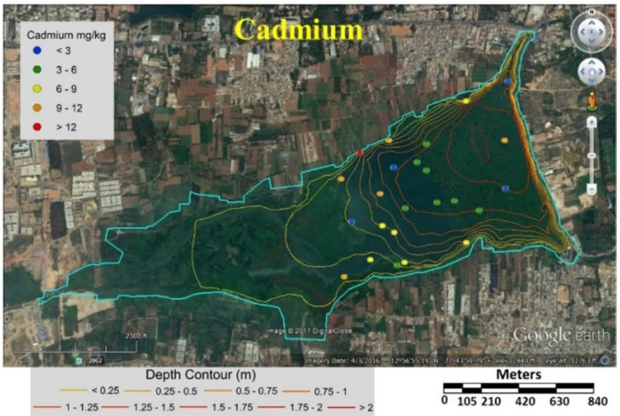

Fig. 5 Concentration of cadmium in sediment samples

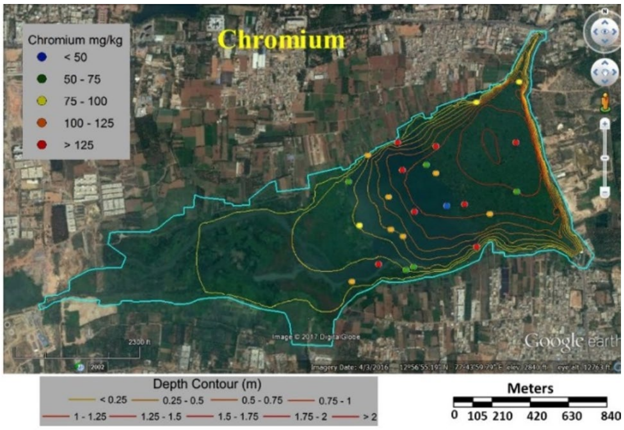

Fig. 6 Concentration of chromium in sediment samples

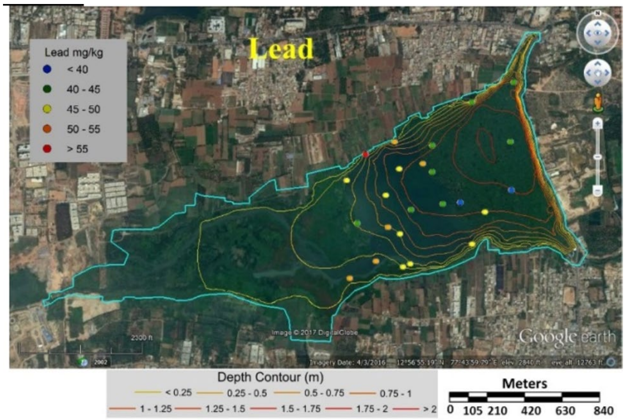

Fig. 8 Concentration of lead in sediment samples of Varthur lake

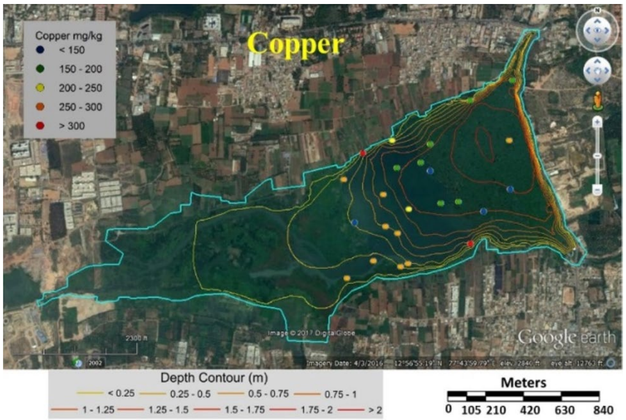

Fig. 7 Concentration of copper in sediment sample

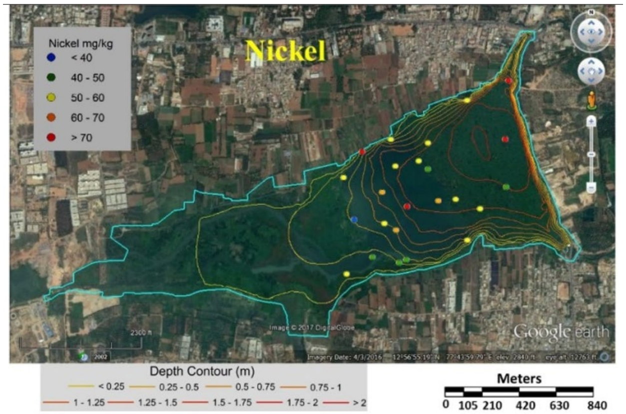

Fig. 9 Concentration of nickel in sediment samples of Varthur lake

3.3 Heavy metal concentration in sediment

Table 3 lists heavy metal concentrations in sediment samples. The mean concentration of all metals in sediments were above threshold effect level (TEL) and was in the order Cu > Zn > Cr > Ni > Pb > Cd. Cadmium content in sediments were above TEL and probable effect level (PEL) with V12 and V36 (middle) having highest and lowest (Fig. 5). Chromium concentration was lowest in middle (V37) and highest at northwest shoreline (V21) (Fig. 6). Copper concentration in sediment samples was in the range 86.5–421.6 mg/kg, which are above critical ranges. The inlet and shoreline regions had higher accumulation of copper (highest at northwest shoreline) while the lowest concentrations were in middle regions (Fig. 7). Samples from the middle region (V36) had the lowest concentration, and northwest shoreline sample (V12) had the highest concentration of lead (Fig. 8). Nickel concentration in sediment samples is in the range of 26.7–80 mg/kg with mean value of 54.76 mg/kg (Table 3, Fig. 9), and all samples are within critical level and PEL. The highest nickel concentration in sediment samples was recorded at northwest shoreline (V12) and the lowest in the samples of inlet and middle (Fig. 9). Zinc in the sediment samples ranges from 26.8 to 352.9 mg/kg (Table 3, Fig. 10) with an average value of 131.65 mg/kg, which is little higher than the earlier reports [40] and is within the critical range in all the samples. The highest zinc concentration was in the sample at northwest shoreline (V12) and the lowest in near inlet sample (V5) (Fig. 10).

3.4 Heavy metal concentration in macrophytes

Tables 4 and 5 provide heavy metal concentrations in macrophytes samples, which highlight the relative concentrations were Cu > Zn > Cr > Pb > Ni > Cd in macrophytes. Cadmium concentration in macrophytes samples was higher in *Typha angustifolia* root and lower in *Eichhornia crassipes* shoot. The order of accumulation in macrophytes was

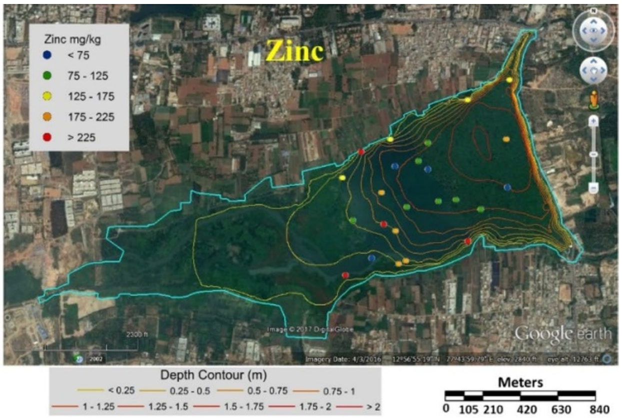

Fig. 10 Concentration of zinc in sediment samples of Varthur lake

Table 4 Comparison of heavy metal (mg/kg) in macrophytes of Varthur lake with critical and normal range in plants

Metal	Mean (range) (mg/kg)	WHO[a] standard	Critical range in plants [63]	Normal range in plants [63]
Cd	0.21 (0–0.8)	0.5	5–30	0.1–2.4
Cr	42.33 (34–54.8)	1.3	5–30	0.03–14
Cu	66.81 (21.3–263.5)	40	5–30	1–5
Ni	8.44 (3.5–17.1)	10	10–100	0.02–5
Pb	21.9 (8.7–56.7)	2.0	30–300	0.2–20
Zn	64.76 (14.8–155.5)	60	100–400	1–400

[a] World Health Organization

Typha angustifolia > *Eichhornia crassipes* > *Alternanthera philoxeroides* > *Colocasia esculenta* (Table 5). Chromium in macrophytes was in the range of 34–54.8 mg/kg (mean—42.33 mg/kg) (Table 4) with lowest in *Typha angustifolia* root and higher in *Eichhornia crassipes* shoot (Table 5). *Colocasia esculenta* had highest concentration followed by *Eichhornia crassipes, Alternanthera philoxeroides* and *Typha angustifolia* (Table 5). Chromium content in all macrophyte samples exceeded critical limits. The concentration of copper was maximum in *Alternanthera philoxeroides* shoot and minimum in *Eichhornia crassipes* shoot (Table 5). Lead concentration ranges from 8.7 to 56.7 mg/kg with mean value of 21.9 mg/kg with concentrations in *Alternanthera philoxeroides* > *Eichhornia crassipes* > *Typha angustifolia* > *Colocasia esculenta* (Table 5). *Colocasia esculenta* root had lowest concentration, and *Alternanthera philoxeroides* shoot had highest concentration of lead. *Alternnathera philoxeroides* and *Eichhornia crassipes* had lead concentrations in critical range. Nickel content was lowest in *Colocasia esculenta* and highest in *Typha angustifolia* root and was exceeding the critical range of 5 mg/kg in most of the samples. Concentrations of nickel was higher in *Typha angustifolia* > *Eichhornia crassipes* > *Alternanthera philoxeroides* > *Colocasia esculenta* (Table 5). Zinc in macrophyte samples were within normal and critical range [63]. *Alternanthera philoxeroides* shoot had the highest concentration, and *Eichhornia crassipes* shoot had the lowest concentration of zinc. Overall, *Alternanthera philoxeroides* was higher accumulator of zinc followed by *Eichhornia crassipes, Typha angustifolia* and *Colocasia esculenta* (Table 5).

Table 5 Heavy metal concentration in macrophytes (mean ± SD) of Varthur lake

Metal	Plant	Shoot	Root
Cd	*Eichhornia crassipes*	0.10 ± .05	0.17 ± 0.15
	Alternanthera philoxeroides	0.15 ± 0.08	0.1 ± 0
	Colocasia esculenta	0.1 ± 0.04	0.1 ± 0.02
	Typha angustifolia	0.2 ± 0.07	0.7 ± 0.06
Cr	*Eichhornia crassipes*	44.7 ± 5.99	42.37 ± 3.85
	Alternanthera philoxeroides	45.03 ± 3.43	37.85 ± 5.44
	Colocasia esculenta	38.1 ± 3.23	50.8 ± 3.56
	Typha angustifolia	43.8 ± 3.59	33 ± 3.21
Cu	*Eichhornia crassipes*	58.46 ± 31.05	89.43 ± 12.48
	Alternanthera philoxeroides	148.18 ± 109.07	103.05 ± 10.25
	Colocasia esculenta	28.9 ± 3.89	44.4 ± 5.66
	Typha angustifolia	42.1 ± 6.23	32.1 ± 2.13
Ni	*Eichhornia crassipes*	6.18 ± 2.57	12.57 ± 0.65
	Alternanthera philoxeroides	5.57 ± 0.71	7.85 ± 2.19
	Colocasia esculenta	5.6 ± 1.62	4.95 ± 1.11
	Typha angustifolia	7.7 ± 2.26	16.2 ± 0.56
Pb	*Eichhornia crassipes*	22.7 ± 5.18	24.8 ± 2.39
	Alternanthera philoxeroides	32.42 ± 18.65	33.2 ± 18.95
	Colocasia esculenta	13.5 ± 2.87	9.25 ± 0.25
	Typha angustifolia	20.5 ± 5.65	18.8 ± 6.22
Zn	*Eichhornia crassipes*	38.78 ± 39.16	121.67 ± 6.85
	Alternanthera philoxeroides	28.6 ± 6.54	139.45 ± 22.7
	Colocasia esculenta	20.6 ± 2.96	28.85 ± 4.74
	Typha angustifolia	23.1 ± 3.96	117 ± 5.87

3.5 Bioconcentration and translocation factor

Bioconcentration factor (BCF) and translocation factor (TF) were used for understanding the heavy metal distribution pattern in macrophytes of Varthur lake (Figs. 11, 12). Bioconcentration factors for Pb, Zn, Ni, Cr, Cd and Cu 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, 0.35 to 1.14, respectively (Fig. 11) with

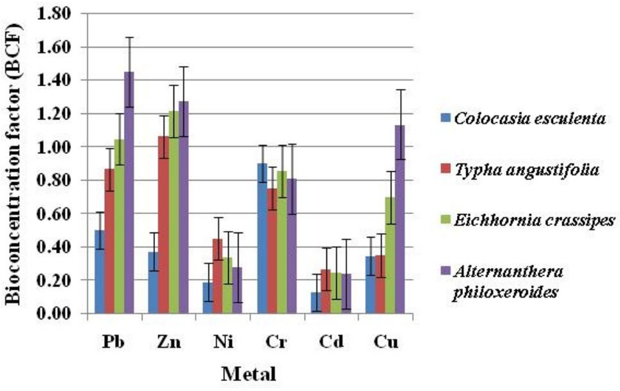

Fig. 11 Bioconcentration factor (BCF) of macrophyte samples

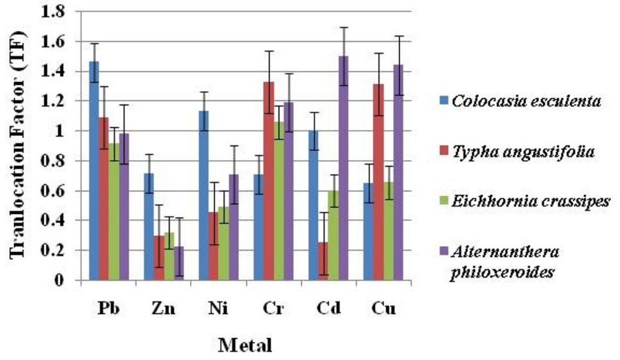

Fig. 12 Translocation factor (TF) of macrophyte samples

Zn > Pb > Cr > Cu > Ni > Cd. Higher BCF for lead, zinc and copper was in *Alternanthera philoxeroides*, while higher BCF for nickel and cadmium in *Typha angustifolia* and for Chromium in *Colocasia esculenta*. The translocation factor for Pb, Zn, Ni, Cr, Cd and Cu 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, respectively (Fig. 12) and the translocation factor of Pb > Cr > Cu > Cd > Ni > Zn. Among the studied macrophytes, *Colocasia esculenta* had higher TF for lead, zinc and nickel. *Alternanthera philoxeroides* had maximum TF for cadmium and copper while *Typha angustifolia* had maximum TF for chromium.

4 Discussion

4.1 Total carbon and nitrogen in sediment and macrophytes

Nutrients such as carbon and nitrogen play a vital role in maintaining trophic levels in lake ecosystems. Assessment of organic matter concentrations helps in understanding the nutrient dynamics in a lake ecosystem. The organic matter in sediments is given by the ratio of total organic carbon to total nitrogen (C/N ratio), which aids in estimating the percentage of autochthonous planktonic matter in sediments [64], and C/N ratios in lake sediments reflect the composition of organic matter [65, 66]. Increase in cellulose content increases C/N ratio. C/N ratios of 5 to 6 in phytoplankton and zooplankton are due to proteins consisting primarily of nitrogen compounds. The C/N ratio in the terrestrial vascular plants is 15 or > 20 [67], and in the case of macrophytes C/N ratio is about 39.4. Variations in C: N ratios within lake sediments help in determining the historical changes in the sources of organic matter. Increases in C: N ratio in sediment profiles have been useful to interpret the period (in a lake's history) when sediments received a high proportion of terrestrial organic matter [68].

Higher C values in sediment were in the northwest and northeast shoreline side of the lake, attributed to higher terrestrial C sources of domestic sewage from the urbanized pockets of the catchment. Lower C values in the lake sediments were observed at southern side and outlets of the lake, where depth is greater than 1 m. Similar C and N distributions were reported in the earlier studies [66]. Higher C:N in middle regions is due to the sustained inflow from the neighboring residential layouts on both sides and the middle regions are with stagnant water. This highlights the storm water drains are being misused with the discharge of sewage, contributing terrestrial organic matter into the lake.

Macrophyte sample analyses revealed that higher concentration of carbon was in *Colocasia esculenta* root and lowest in *Eichhornia crassipes* root, and these values were lesser compared to earlier study [55]. Emergent macrophytes had higher carbon concentration than floating plants because of fibers in developed support system [14]. Nitrogen was higher in *Alternanthera philoxeroides* shoot and lowest in *Typha angustifolia* shoot. The results of this study showed higher nitrogen content than earlier report [55].

4.2 Heavy metal concentration in sediment and macrophytes

Tables 6 and 7 compare metal concentrations in sediment and macrophytes of Varthur lake with various other studies. Cadmium is of most concern due to the greatest mobility in soil environment [69] and is widespread heavy metal, which is extremely toxic to humans and plants [70]. Cadmium enters aquatic environment through anthropogenic sources like industrial effluent and agricultural runoff [71]. Cadmium concentration in this study was higher compared to the earlier study [40] and above PEL and critical

Table 6 Comparison of heavy metal (mg/kg) in sediments of the current study with other studies

Name of the lake	Metal concentration (mg/kg)						References
	Cd	Cr	Cu	Ni	Pb	Zn	
Varthur lake, Bangalore	5.8 (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)	Present study
Varthur lake, Bangalore	BDL–17.3	BDL–21.4	131–134	16.2–68.0	4.40–88.5	25.7–220	[40]
Bellandur lake, Bangalore	1.60–55.3	33.9–199	105–1148	15.1–138	31.2–208	126–2001	[2]
Wular lake	–	160.27	47.33	57	–	–	[74]
Ramgarh lake	0.015	–	1.33	–	0.27	2.28	[75]
Veeranam lake, Chennai	0.20–3.90	40.0–150	65.0–125	34.0–95.0	20.0–41.0	65.0–599	[76]
ICRISAT lake, Patancheru	0–0.1	16.6–75.4	6.1–40.3	6.7–41.5	4.2–19.6	3.8–55.2	[77]
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	[73]
Yercaud lake	–	322–441	480–687	147	15.5–48.0	101–258	[78]
Akkulam Veli lake, Thiruvananthapuram	–	49.0–642	1.00–126	5.00–259	18.0–189	19.0–279	[79]
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	[80]
Kolkata wetlands	–	12–57	17–145	19–37	13–118	80–425	[81]
Kodaikanal lake	–	452	54.5	115	44.7	113	[82]
Urban pond, Dhanbad	1.70–5.00	74.0–109	–	–	23.3–36.0	1055–1804	[83]

range [62, 63]. The highest concentration (23.7 mg/kg) was observed in the northwest shoreline sample (V12) and the lowest (1.4 mg/kg) in the middle sample (V36) (Fig. 5). These values were lower compared to the samples of Bellandur Lake [2]. The outlet and middle region had lower concentration of cadmium compared to other regions (Fig. 5). Chromium is toxic for plants as it alters N metabolism and impairs protein formation [27]. More than half of the sampling points had critical ranges of chromium. Sediments in the inlet and north shoreline regions had higher concentrations of chromium than other samples (Fig. 6). The present study values were 10 times higher than the earlier reports [40]. Copper concentrations in the current study were higher compared to the earlier study [40] and lower compared to Bellandur Lake [2]. Lead is one of the most toxic metals at low concentrations and non-essential element for plant [27, 72]. The main source of lead in the sediment is from lead pipes, mixing of gun powder, waste batteries, etc.[73]. Earlier studies [2, 40] recorded lower lead concentrations compared to the present study. Zinc in the sediment samples was little higher than the earlier reports [40]. Plant growth, metabolism and physiology are effected by toxic metal nickel. The concentration of nickel in sediments was` lower than PEL and critical values.

The Varthur lake catchment also receives surface runoff containing fertilizers and pesticides from agriculture and floriculture lands, which is contributing to Cd, Pb, Ni in the lake surface sediments. Untreated wastewater from industries such as electroplating, metallurgical, batteries manufacturing, vehicle garages, etc. has contributed to the accumulation of heavy metals (Cr, Cu. Cd and Zn), which is evident from the analysis of sediment samples at the north shoreline. Among macrophyte samples, *Alternanthera philoxeroides* and *Eichhornia crassipes* had higher concentration of all investigated heavy metals.

Plants with high BCF and low TF (BCF > 1 and TF < 1) aid in efficient remediation with phytostabilization, while phytoextraction happens with both BCF and TF > 1 [98]. In the current study, scope for remediation of heavy metals (lead and zinc) through phytostabilization was exhibited by *Alternanthera philoxeroides* and *Eichhornia crassipes*, respectively. *Alternanthera philoxeroides* showed phytoextraction capability of copper. *Colocasia esculenta*, *Typha angustifolia* and *Alternanthera philoxeroides* displayed higher mobility for nickel, chromium and cadmium, respectively (BCF < 1 and TF > 1).

The study highlights the presence of organic and heavy metals in sediments and macrophytes, indicating contamination due to the sustained inflow of untreated sewage and industrial effluents. Environmental changes in the lake catchment during the past 5 decades due to rapid urbanization have been responsible for the lake contamination. The organic contamination is mainly due to untreated sewage and runoff entering the lake. The metal pollution is due to entry of industrial wastewater and agricultural runoff. The study recommends proper treatment of sewage before letting into the lake to prevent contamination and associated health hazards in the vicinity.

Table 7 Comparison of heavy metal (mg/kg) in macrophytes of current study with other studies

Macrophyte	Metal concentration (mg/kg)						References
	Cd	Cr	Cu	Ni	Pb	Zn	
Eichhornia crassipes	0.17 ± 0.15	42.37 ± 3.9	89.43 ± 12.5				This study
	8 (0.72–21.5)	71.5 (1.2–160.9)	9.63 (BDL-21.0)	47.9 (26–65.3)	63.4 (22–98.5)	42.9 (27.4–58.3)	[40]
	1500 ± 47	309 ± 13.1	560 ± 15	260 ± 8.1	267 ± 9.0	1400 ± 74.3	[84]
	9.13 ± 0.15	8.06 ± 0.93	92.4 ± 0.3	–	83.42 ± 0.7	572.8 ± 2.3	[85]
	61.5	–	–	–	356.2	–	[86]
	0.82	0.32	0.14	0.15	6.29	–	[87]
	8.7	33.1	25.3	1077	40	243	[88]
	–	–	62.5 ± 17.5	12.9 ± 8.4	25.2 ± 1.2	238.1 ± 76.4	[89]
	8.3–30.9	6.2–133.8	–	–	34.9–80.9	–	[90]
	21.8	–	2868	253	–	–	[91]
	128	69.3	–	78.5	256	–	[92]
	0.79	–	44.5	28.83	9.81	709.1	[93]
	–	–	–	–	13.89	140.97	[94]
	–	160 ± 12.0	23.2 ± 1.7	–	11.5 ± 1.8	170 ± 40.6	[21]
Alternanthera philoxeroides	0.15 ± 0.08	45.03 ± 3.43	148.2 ± 109.1	7.85 ± 2.19	33.2 ± 18.95	139.5 ± 22.7	This study
	8.5–45.1	0.3–81.3	–	–	46.6–91.8	–	[90]
	16.4	–	2839	441	–	–	[91]
	–	–	–	–	53.3–383.3	54–199.5	[95]
Colocasia esculenta	0.1 ± 0.04	50.8 ± 3.56	44.4 ± 5.66	5.6 ± 1.62	13.5 ± 2.87	28.85 ± 4.74	This study
	4.16 ± 1.98	–	28.6 ± 8.8	–	25.5 ± 11.6	–	[96]
	3.2	1545	–	43.6	148.5	–	[92]
	2.3 ± 0.5	11.9 ± 1.0	80.7 ± 5.8	–	–	–	[97]
	–	–	–	–	27.94 ± 0.45	105.3 ± 0.09	[94]
Typha angustifolia	0.7 ± 0.06	43.8 ± 3.59	42.1 ± 6.23	16.2 ± 0.56	20.5 ± 5.65	117 ± 5.87	This study
	9.5	14.5	43.2	370	32.66	216	[88]
	–	–	8.98 ± 1.7	9.95 ± 2.9	29.5 ± 3.4	97.6 ± 5.2	[89]
	1.44	–	104.21	20.26	6.92	276.13	[93]

5 Conclusion

The nutrient and heavy metal concentration in sediment and macrophyte samples from Varthur lake was assessed through standard protocol of representative samples. Carbon and nitrogen values in sediment were higher at depths ranging from 0.25 to 1 m and at the northwest and northeast side of the lake. Lower C and N values were observed in the samples collected at the depth greater than 1 m, at middle and at lake outlets. Among macrophytes, the highest C and N were in the shoots of *Colocasia esculenta* and *Alternanthera philoxeroides*, respectively. Heavy metals concentrations were higher in the sediment samples of north shoreline and inlets. *Alternanthera philoxeroides* and *Eichhornia crassipes* had higher concentrations of heavy metals. Sediment samples had heavy metals in the order Cu > Zn > Cr > Ni > Pb > Cd, while in macrophytes samples Cu > Zn > Cr > Pb > Ni > Cd. Thus, the Varthur lake acted as a sink to nutrients and metals. The study highlights phytoremediation potential of macrophytes and caution to be exercised while using these macrophytes as either vegetable or fodder to prevent heavy metal contamination in the biotic food chain. The present study also demonstrated the potential of macrophytes and sediments in the removal of nutrients and heavy metals. Hence, taking advantage of phyto- and phycoremediation prospects, constructed wetlands integrated with algal pond at the inlet of each water body would help in the treatment and mitigates contamination of water bodies.

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Data availability Data used in the analyses are compiled from the field. Data is analyzed and organized in the form of table, which are presented in the manuscript. Also, synthesized data are archived at http://wgbis.ces.iisc.ernet.in/energy/water/paper/researchpaper2.html#ce, http://wgbis.ces.iisc.ernet.in/biodiversity/.

Compliance with ethical standards

Conflict of interest We have no conflict of interest either financial or non-financial.

Human and animal rights The research does not involve either humans, animals or tissues.

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