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Correlations Between Some Hazardous Inorganic Pollutants in the Gomti River and Their Accumulation in Selected Macrophytes Under Aquatic Ecosystem

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Abstract Water quality of the Gomti River and phytoremediation potential of native macrophytes dwelling therein at six different sites were evaluated. River water showed high biochemical oxygen demand, chemical oxygen demand, nitrate, ammonium and phosphate (12.84, 77.94, 36.88, 6.04 and 2.25 mg L^{-1}, respectively). Gomti water was found to be contaminated with different metals like Fe, Cd, Cu, Cr and Pb (5.54, 1.05, 3.74, 2.57 and 0.73 mg L^{-1}, respectively). Macrophytes growing in the river accumulated considerable amounts of Fe, Cd, Cu, Cr and Pb in different parts. Among the studied plants, *Eichhornia crassipes* showed maximum remediation potential for Fe, Cd and Pb; *Jussiaea repens* for Cr; and *Pistia stratiotes* for Cd. However, in *Typha latifolia*, Cu accumulation was maximum. Except for Fe, translocation factor of *E. crassipes*, *P. stratiotes*, *Hydrilla verticellata* and *T. latifolia* was >1 for the studied metals, showing their potential to accumulate multiple metals in different plant parts.

Keywords Bioaccumulation · Metals · Phytoremediation · Translocation factor

In urban areas, deterioration of water quality of rivers like the Gomti is strongly related to the increasing developmental activities in the watershed, such as changing land use pattern, increased discharge of untreated municipal and industrial wastewater, and runoff from nearby agricultural fields (Rai et al. 2012). Discharge of untreated wastewater containing metals of variable toxicity into rivers poses a serious threat not only to the aquatic ecosystem, but also to human health (Rai 2010; Sun et al. 2014). Consumption of water contaminated with metals may lead to their chronic accumulation in the kidneys, liver and bones of humans, resulting in disruption of metabolic activities, which can also lead to cardiovascular, neurological and renal diseases (Jarup 2003; Johri et al. 2010). Other inorganic pollutants like nitrogenous ions (especially NO_2^-) present in water can combine with organic pollutants to produce cancer causing nitrosyls in human beings. Various aquatic macrophytes (floating, submerged, rooted, and emergent) growing in river courses have shown the potential to accumulate certain toxic pollutants inside their tissues and are used to monitor pollution levels (Souza et al. 2013). These plant potentials have emerged as a major area of phytotechnological studies and have been evaluated for phytoremediation potential for the removal of toxic pollutants from contaminated water and soil (Bauddh and Singh 2012; Chiranjeevi et al. 2013). Macrophyte based treatment systems can be used by developing countries for recycling of wastewater and treatment of potable water, especially those contaminated with metals (Khan et al. 2009; Rahman and Hasegawa 2011).

Some monitoring studies on the Gomti River report variable, but alarming, contamination of water with certain inorganic and organic pollutants (Agarwal et al. 2007; Lohani et al. 2008). However, in-stream macrophytes have not been investigated for their removal efficiency for Fe, Cu, Cd, Cr and Pb, the major metal contaminants of industrial, municipal and agricultural origin during different seasons. The present study is aimed at monitoring water

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quality of the Gomti River from upstream (Gaughat) to downstream (Pipraghat) of Lucknow and to evaluate the potential of endogenous mixed macroflora as pollution biomonitors for phytoremediation of multiple pollutants in a semi-arid, urban tropical aquatic ecosystem.

Materials and Methods

The Gomti River, a freshwater ecosystem and a major tributary of the Ganges in India, flowing through the Lucknow city, is the only source of municipal water supply for the city. Various drains situated between Gaughat (upstream of Lucknow) and Pipraghat (downstream of Lucknow) discharge untreated sewage, including municipal and industrial wastewater into the Gomti River. Six sites along the bank of the Gomti were selected for water and plant sample collection from Gaughat (upstream) up to Pipraghat (downstream). Gaughat and Pucca Pull were categorized as upstream sites, while Hanuman Setu, Nishatganj, Gomti Barrage and Pipraghat sites were downstream. Triplicate water samples were collected in acid soaked 2 L, polyethylene bottles from the study sites during the pre-monsoon (April, May, June) and monsoon (July, August and September) period of 2013 and brought to the laboratory for further analysis. pH and electrical conductivity were determined onsite using portable digital pH and conductivity meters. Physicochemical parameters were determined using standard methods for the examination of water and waste water (APHA 2005). Aquatic plant samples naturally occurring at the study sites were randomly collected at the same time as water sampling. Whole plants including roots and shoots were carefully harvested at sampling sites. Plants at the selected sites were *Eichhornia crassipes*, *Pistia stratiotes*, *Hydrilla verticellata*, *Jussiaea repens*, *Typha latifolia*, *Vallesnaria spiralis* and *Polygonum glabrum*. The plants were put and sealed in air tight polyethylene bags and transported to the laboratory and kept there at 4°C. Thoroughly washed root and shoot plant samples were separated and oven dried at 90°C to a constant weight and metals (Fe, Cu, Cd, Cr and Pb) in the plant parts were determined after acid digestion of dry samples with an acid mixture (9:4 nitric acid:perchloric acid) at about 100°C. Metal concentration was determined by atomic absorption spectrophotometer (AAS 240 FS, Varian). Analytical data quality of metals was ensured through repeated analysis ($n = 3$) of EPA quality control in samples. The translocation factor (the ratio of metals in shoot vs. root of plants) was calculated by the formula of Padmavathiamma and Li (2007).

Statistical analysis of data by one way analysis of variance (ANOVA) and Duncan multiple range tests were performed to determine the significance of differences among the mean values using SPSS (Version 16). Relationships between physicochemical parameters and metal concentrations in Gomti River water were studied by Pearson linear correlation method.

Results and Discussion

The physicochemical properties of water at sample sites during pre-monsoon and monsoon periods are represented in Table 1. Statistically significant differences ($p < 0.05$) were observed for physicochemical characteristics of Gomti River water at selected sites and periods. Irrespective of sites and periods, pH of Gomti water at Lucknow is alkaline. Maximum pH (8.66) was observed during the pre-monsoon period downstream at Gomti Barrage, while electrical conductivity (EC) was highest (604.33 $\mu s\ cm^{-1}$) during pre-monsoon at Pipraghat. Dissolved oxygen (DO) was lowest at Pipraghat (3.32 mg L^{-1}) during the pre-monsoon period, while the maximum biochemical oxygen demand (BOD) was recorded at Pipraghat (12.84 mg L^{-1}), depicting high organic pollution at the site. Chemical oxygen demand (COD) showed a maximum value (77.94 mg L^{-1}) at Pipraghat during the monsoon period. Among the inorganic nitrogenous compounds, nitrate (NO_3) concentration reached a maximum value (36.88 mg L^{-1}) downstream at Pipraghat during the monsoon period, while as highest nitrite (NO_2) concentration (0.1 mg L^{-1}) was recorded upstream at Pucca Pull during the pre-monsoon period.

Ammonium levels in river water were highest (6.04 mg L^{-1}) upstream at Gaughat during the monsoon period. Phosphate was highest downstream at Pipraghat (2.25 mg L^{-1}) during the rainy season. Domestic wastewater containing detergents and leaching of chemical fertilizers from terrestrial systems after heavy rainfall leads to inorganic nutrient loading of nutrients into rivers (Bellos and Sawidis 2005; Rai and Tripathi 2009). Gomti River water at Lucknow showed varying concentration of five metals investigated. Mean concentrations of different metals (Fe, Cd, Cu, Cr, and Pb) in Gomti water are presented in Table 2. Metal content in river water was in the order of Fe > Cu > Cr > Cd > Pb. Maximum concentration of Fe (5.54 mg L^{-1}), Cu (3.74 mg L^{-1}), Cr (2.57 mg L^{-1}), Cd (1.05 mg L^{-1}) and Pb (0.73 mg L^{-1}) were recorded during the pre-monsoon period downstream at Pipraghat. The concentration of all five metals in the Gomti River was higher than the critical ranges stated for drinking water standards (EPA 2009). Compared to the monsoon period, metals concentration was higher during the pre-monsoon period. The lesser values during the monsoon period could be due to a dilution effect. Since metals tend to settle and accumulate in the sediments of

Table 1 Physicochemical characteristics of water samples (n = 3, mean ± SD) collected from selected sites of the Gomti River during pre-monsoon and monsoon seasons in India

Seasons	Sites	pH	EC (µs cm^{-1})	DO (mg L^{-1})	BOD (mg L^{-1})	COD (mg L^{-1})	NO$_3$ (mg L^{-1})	NO$_2$ (mg L^{-1})	NH$_4$ (mg L^{-1})	PO$_4$ (mg L^{-1})
Pre-monsoon	I	$8.23^{a} \pm 0.11$	$562.6^{b} \pm 6.42$	$7.64^{f} \pm 0.17$	$3.16^{a} \pm 0.08$	$14.5^{a} \pm 0.52$	$20.74^{a,b} \pm 0.61$	$0.088^{b} \pm 0.004$	$5.75^{c} \pm 0.34$	$0.70^{a} \pm 0.07$
	II	$8.53^{b} \pm 0.05$	$541.6^{a} \pm 12.58$	$5.89^{e} \pm 0.18$	$6.96^{b} \pm 0.16$	$29.67^{b} \pm 1.43$	$24.36^{c} \pm 2.08$	$0.1^{c} \pm 0.004$	$4.05^{a} \pm 0.57$	$0.90^{b} \pm 0.07$
	III	$8.26^{a} \pm 0.05$	$556^{a,b} \pm 5.29$	$4.62^{b} \pm 0.27$	$8.25^{c} \pm 0.26$	$40.83^{c} \pm 0.63$	$22.41^{b,c} \pm 0.96$	$0.082^{b} \pm 0.003$	$4.4^{a} \pm 0.17$	$0.87^{a,b} \pm 0.04$
	IV	$8.13^{a} \pm 0.05$	$569^{b} \pm 2.64$	$4.94^{c} \pm 0.04$	$9.09^{d} \pm 0.065$	$43.55^{c} \pm 0.64$	$19.50^{a} \pm 0.76$	$0.048^{a} \pm 0.006$	$4.37^{a} \pm 0.04$	$1.02^{b,c} \pm 0.085$
	V	$8.66^{c} \pm 0.05$	$588^{c} \pm 6.55$	$5.27^{d} \pm 0.08$	$7.34^{e} \pm 0.21$	$47.03^{d} \pm 0.23$	$29.08^{d} \pm 0.67$	$0.087^{b} \pm 0.004$	$5.15^{b} \pm 0.04$	$1.12^{c} \pm 0.01$
	VI	$8.13^{a} \pm 0.05$	$604.3^{c} \pm 18.14$	$3.32^{a} \pm 0.12$	$12.84^{f} \pm 0.23$	$57.97^{e} \pm 3.36$	$35.21^{e} \pm 1.9$	$0.099^{c} \pm 0.006$	$5.73^{c} \pm 0.14$	$2.05^{d} \pm 0.21$
Monsoon	I	$7.21^{a} \pm 0.1$	$362.66^{a} \pm 6.42$	$6.14^{d} \pm 0.14$	$4.22^{a} \pm 0.03$	$25.11^{a} \pm 0.48$	$22.76^{b} \pm 1.57$	$0.074^{c} \pm 0.001$	$6.04^{d} \pm 0.09$	$1.42^{a,b} \pm 0.09$
	II	$7.46^{c} \pm 0.05$	$375^{a} \pm 57.66$	$4.99^{c} \pm 0.27$	$5.98^{d} \pm 0.14$	$40.25^{b} \pm 0.86$	$18.1^{a} \pm 1.47$	$0.084^{d} \pm 0.003$	$4.14^{b} \pm 0.05$	$1.23^{a} \pm 0.06$
	III	$7.42^{c} \pm 0.1$	$455.6^{c} \pm 17.21$	$3.68^{a} \pm 0.58$	$6.12^{d} \pm 0.16$	$52.63^{c} \pm 2.34$	$19.94^{a} \pm 1.2$	$0.064^{b} \pm 0.003$	$5.59^{c} \pm 0.19$	$1.84^{b,c} \pm 0.06$
	IV	$7.13^{a} \pm 0.05$	$352.33^{a} \pm 4.5$	$4.27^{b} \pm 0.06$	$5.54^{c} \pm 0.12$	$64.16^{d} \pm 2.6$	$23.4^{b} \pm 1.9$	$0.075^{a} \pm 0.002$	$3.31^{a} \pm 0.02$	$1.58^{a,b} \pm 0.07$
	V	$7.6^{c} \pm 0.17$	$464.6^{c} \pm 11.23$	$5.38^{c} \pm 0.11$	$4.63^{b} \pm 0.1$	$74.96^{e} \pm 3.36$	$24.56^{b} \pm 1.4$	$0.045^{d} \pm 0.004$	$5.27^{c} \pm 0.13$	$2.14^{d} \pm 0.51$
	VI	$7.86^{d} \pm 0.09$	$495^{c} \pm 5.35$	$4.21^{b} \pm 0.06$	$7.41^{e} \pm 0.19$	$77.94^{e} \pm 1.53$	$36.88^{c} \pm 0.45$	$0.087^{c} \pm 0.006$	$4.44^{b} \pm 0.35$	$2.25^{c,d} \pm 0.22$

Different letters signify the statistical differences among physicochemical parameters at selected sites during pre-monsoon and monsoon seasons ($p < 0.05$). Site I = Gaughat; Site II = Pucca Pull; Site III = Hanuman Setu; Site IV = Nishatganj; Site V = Gomti Barrage and Site VI = Pipraghat

EC electrical conductivity, *DO* dissolved oxygen, *BOD* biochemical oxygen demand, *COD* chemical oxygen demand, NO_3 nitrate, NO_2 nitrite, NH_4 ammonium, PO_4 phosphate

Table 2 Metal content (mg L^{-1}) of water samples (n = 3, mean ± SD) collected from selected sites of the Gomti River during pre-monsoon and monsoon seasons in India

Sites	Pre-monsoon					Monsoon				
	Fe	Cd	Cu	Cr	Pb	Fe	Cd	Cu	Cr	Pb
I	$1.92^{a} \pm 0.26$	$0.04^{a} \pm 0.003$	$0.14^{a} \pm 0.02$	$0.56^{a} \pm 0.10$	$0.22^{a} \pm 0.008$	$1.71^{a} \pm 0.61$	$0.012^{a} \pm 0.001$	$0.094^{a} \pm 0.09$	$0.4^{a} \pm 0.05$	$0.17^{a,b} \pm 0.02$
II	$2.67^{b} \pm 0.29$	$0.085^{a,b} \pm 0.005$	$0.25^{a} \pm 0.03$	$0.79^{b} \pm 0.04$	$0.32^{b} \pm 0.02$	$2.02^{a} \pm 0.2$	$0.11^{b} \pm 0.004$	$0.118^{a} \pm 0.02$	$0.57^{a} \pm 0.03$	$0.24^{c,d} \pm 0.02$
III	$4.32^{d} \pm 0.06$	$0.14^{b,c} \pm 0.004$	$1.25^{b} \pm 0.16$	$1.08^{c} \pm 0.009$	$0.33^{b} \pm 0.02$	$3.62^{b} \pm 0.16$	$0.14^{b} \pm 0.04$	$1.07^{b} \pm 0.03$	$0.86^{b} \pm 0.05$	$0.2b^{c} \pm 0.003$
IV	$3.75^{c} \pm 0.09$	$0.16^{c} \pm 0.01$	$1.48^{b} \pm 0.24$	$1.25^{c,d} \pm 0.05$	$0.4^{b} \pm 0.07$	$2.99^{c} \pm 0.26$	$0.143^{b} \pm 0.005$	$1.025^{b} \pm 0.01$	$1.02^{b} \pm 0.05$	$0.15^{a} \pm 0.01$
V	$4.16^{d} \pm 0.05$	$0.65^{d} \pm 0.08$	$2.88^{c} \pm 0.25$	$1.35^{d} \pm 0.12$	$0.28^{c} \pm 0.01$	$4.12^{c,d} \pm 0.04$	$0.16^{b} \pm 0.03$	$1.93^{c} \pm 0.38$	$0.92^{b} \pm 0.04$	$0.25^{d} \pm 0.02$
VI	$5.54^{e} \pm 0.26$	$1.05^{e} \pm 0.001$	$3.74^{d} \pm 0.16$	$2.57^{e} \pm 0.16$	$0.73^{d} \pm 0.02$	$4.44^{d} \pm 0.08$	$0.605^{c} \pm 0.05$	$2.64^{d} \pm 0.09$	$1.39^{c} \pm 0.21$	$0.43^{e} \pm 0.03$

Different letters signify the statistical differences among metals at selected sites during pre-monsoon and monsoon seasons ($p < 0.05$). Site I = Gaughat; Site II = Pucca Pull; Site III = Hanuman Setu; Site IV = Nishatganj; Site V = Gomti Barrage and Site VI = Pipraghat rivers, the accumulation and remobilization of metals in river systems are two important mechanisms that regulate their concentration in an aquatic environment (Vardanyan and Ingole 2006; Ishaq and Khan 2013).

In the present study, quantification of Fe, Cu, Cd, Cr and Pb in plant tissues was also examined.

The concentration of metals accumulated by the plant root and shoot parts collected from six different sites of the Gomti River are presented in Figs. 1 and 2. Metal accumulation by selected plants varied by plant and season. Generally plants accumulated greater metal content in roots than shoots. Due to formation of complex compounds with carboxylic acid (–COOH) group, low mobility of metals from root to shoot may occur (Cardwell et al. 2002). Metals accumulation in selected aquatic plants was in the order of Fe > Cu > Cr > Pb > Cd. Significant differences were observed for metal accumulation by the plants at different sites ($p < 0.05$). Roots of *E. crassipes* accumulated higher concentrations of Fe (31.73 µg g^{-1}) at Pipraghat during the pre-monsoon period. The reason for greater Fe concentration in roots of plants may be due to the formation of iron hydroxide plaques that are mobilized and precipitated onto root surfaces (Weis and Weis 2004). Plants collected from Hanuman Setu and Pipraghat had accumulated the highest Fe content in their roots. This may be due to draining of effluents containing Fe from automobile works situated on the banks of river banks and subsequent accumulation by plant roots. Maximum Cd accumulation was observed in root of *E. crassipes* (4.19 µg g^{-1}) at Gomti Barrage during the monsoon period. *P. stratiotes* accumulated the highest Cd in shoot (3.81 µg g^{-1}) at Pipraghat during the pre-monsoon period. Greater shoot accumulation by *P. stratiotes* indicates this species may be useful for absorbing and accumulating Cd from polluted water (Shuvaeva et al. 2013). Similar findings pertaining to Cd accumulation were observed for the shoots of *J. repens* and *H. verticellata.* The distribution of Cd within the plants is quite variable and thus explains the rapid translocation from root to aerial parts of plants (Fawzy et al. 2012). Highest Cu accumulation (21.48 µg g^{-1}) was in shoot of *T. latifolia* during the monsoon period at Pipraghat. Roots of aquatic plants showing the highest Cu concentrations (20.33 µg g^{-1}) were observed for *J. repens* at Pipraghat. Bioaccumulation of Cu by plant roots was higher at sites with water pH > 8, as it was reported that at higher pH (>8.0) the presence of plaque enhanced Cu uptake into roots (Weis and Weis 2004). Similar results were also shown for Cu accumulation by *Cyperus papyrus* plant growing in an urban natural wetland of Rwanda (Sekomo et al. 2011). *J. repens* and *P. stratiotes* shoots accumulated the most Cr (8.53 and 7.33 µg g^{-1}) at Hanuman Setu and Pipraghat, respectively during the monsoon period. This may be due to their

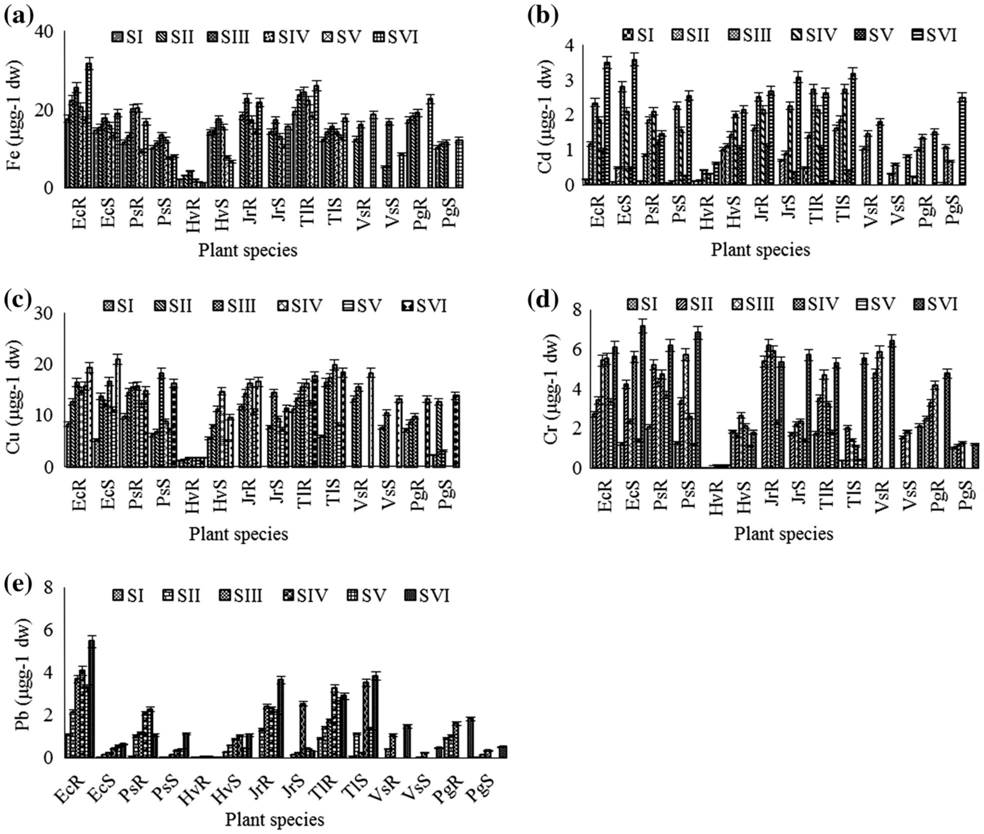

Fig. 1 Accumulation of metals (µg g^{-1} dw) in plant species at selected sites of the Gomti River during the pre-monsoon period: **a** = Fe, **b** = Cd, **c** = Cu, **d** = Cr and **e** = Pb (EcR = *Eichhornia crassipes* Root, EcS = *Eichhornia crassipes* Shoot, PsR = *Pistia stratiotes* Root, PsS = *Pistia stratiotes* Shoot, HvR = *Hydrilla verticellata* Root, HvS = *Hydrilla verticellata* Shoot, JrR = *Jussiaea repens* Root, JrS = *Jussiaea repens* Shoot, TlR = *Typha latifolia* Root, TlS = *Typha latifolia* Shoot, VsR = *Vallesnaria spiralis* Root, VsS = *Vallesnaria spiralis* Shoot, PgR = *Polygonum glabrum* Root and PgS = *Polygonum glabrum* Shoot; whereas: SI = Gaughat; SII = Pucca Pull; SIII = Hanuman Setu; SIV = Nishatganj; SV = Gomti Barrage and SVI = Pipraghat)

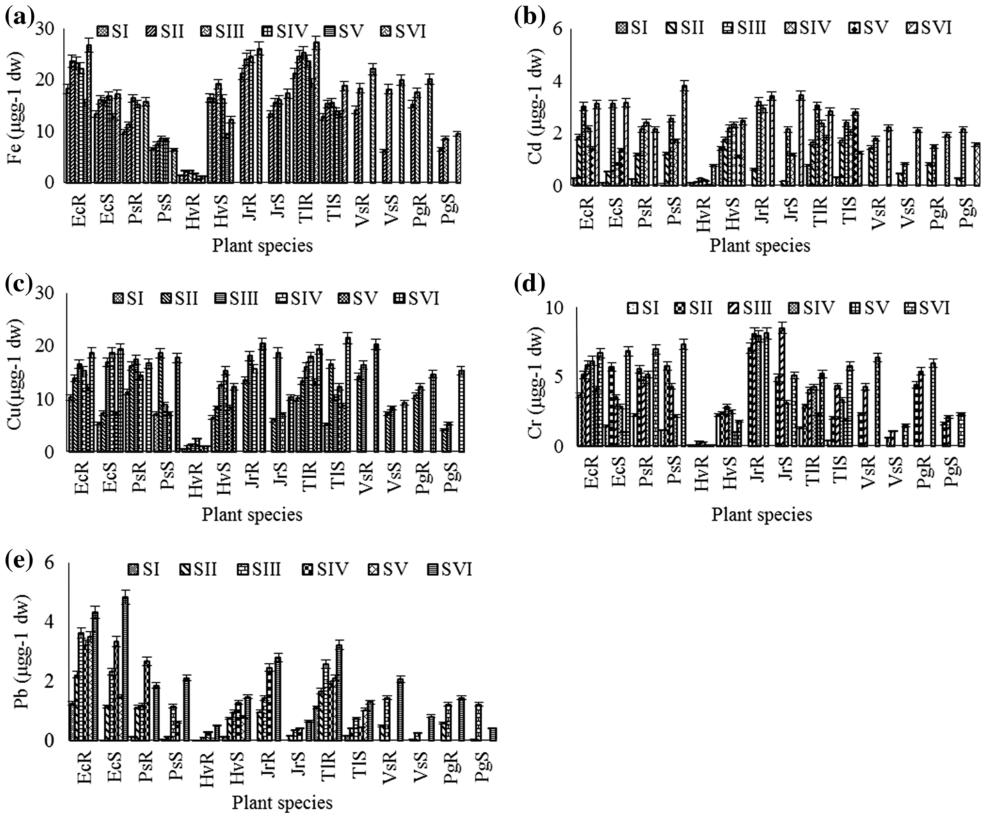

Fig. 2 Accumulation of metals (µg g^{-1} dw) in plant species at selected sites of the Gomti River during the monsoon period: **a** = Fe, **b** = Cd, **c** = Cu, **d** = Cr and **e** = Pb (EcR = *Eichhornia crassipes* Root, EcS = *Eichhornia crassipes* Shoot, PsR = *Pistia stratiotes* Root, PsS = *Pistia stratiotes* Shoot, HvR = *Hydrilla verticellata* Root, HvS = *Hydrilla verticellata* Shoot, JrR = *Jussiaea repens* Root, JrS = *Jussiaea repens* Shoot, TlR = *Typha latifolia* Root, TlS = *Typha latifolia* Shoot, VsR = *Vallesnaria spiralis* Root, VsS = *Vallesnaria spiralis* Shoot, PgR = *Polygonum glabrum* Root and PgS = *Polygonum glabrum* Shoot; whereas: SI = Gaughat; SII = Pucca Pull; SIII = Hanuman Setu; SIV = Nishatganj; SV = Gomti Barrage and SVI = Pipraghat)

potential of concentrating Cr in various plant organs without showing symptoms of toxicity.

Chromium levels above 0.5 mg kg^{-1} dw is considered toxic to plants (Allen 1989); however, plants analysed for Cr showed greater concentrations both in the root and shoot parts than the toxic levels. Maximum Pb accumulation by *E. crassipes* roots (5.46 µg g^{-1}) was at Pipraghat during the pre-monsoon period. The greater Pb concentration in roots of plants signifies lesser translocation of Pb to aerial parts of aquatic plants. Vesely et al. (2011) also reported ten times higher Pb in plant roots than in leaves of *P. stratiotes.* The differential metal uptake by the roots and shoots resulting in partitioning and translocation of metals in the vascular system of plants may be due to anatomy and morphology of different plant taxa coupled with their sorptive potentialities, plant growth rate and physiological conditions of each plant species (Ahmad et al. 2014).

Translocation factor (TF) for the metals investigated in selected plants is shown in Table 3. TF indicates metal mobility from root to shoot parts, demonstrating metal accumulation capability of plants in different plant parts other than roots. Except for Fe, *E. crassipes*, *P. stratiotes T. latifolia* and *J. repens* had a TF > 1 for Cd, Cr, Cu and Pb at different sites during both periods. *H. verticellata* recorded highest TF for all five metals at all sites and periods. The exceptionally TF of *H. verticellata* for all metals may be due to the plants whorled leaves resulting in a large surface area and thus conferring metal uptake through them when a metal concentrations in the surrounding water were high (Srivastava et al. 2011). When TF > 1, the plant efficiently mobilizes and translocates metals from root to the shoot and may be useful for the phytoextraction of metals from water ecosystems (Baker and Brooks 1989); however TF < 1 signifies that the specific plant genera could serve as a potential plant for phytostabilisation (Rai et al. 2012). TF < 1 depicts greater metal accumulation in root than shoot of plants and this may enhance plants own ability to tolerate metal concentrations that are usually toxic (Weis and Weis 2004).

The relationship in dynamics of metals concentration with physicochemical characteristics of river water at different sites was evaluated using Pearson correlation

Table 3 Distribution and translocation factor of different metals in plants during the pre-monsoon (PrM) and monsoon (M) seasons in Lucknow, India

Sites	Plant species	Fe		Cd		Cu		Pb		Cr	
		PrM	M	PrM	M	PrM	M	PrM	M	PrM	M
Site I	*E. crassipes*	0.83	0.72	0.62	0.35	0.63	0.51	0.02	0.01	0.45	0.39
	P. stratiotes	0.88	0.66	0.54	0.28	0.67	0.63	0.25	0.23	0.61	0.5
	H. verticellata	6.25	11.65	9.36	14.1	4.63	13.08	8	13	61	36.83
	T. latifolia	0.63	0.60	0.24	0.41	0.52	0.51	0.05	0.14	0.22	0.3
	P. glabrum	0.59	–	0.35	–	0.32	–	0.03	–	0.41	–
Site II	*E. crassipes*	0.68	0.69	0.41	0.28	1.08	0.52	0.05	0.51	1.2	1.11
	P. stratiotes	0.85	0.66	0.15	1.03	0.47	1.15	0.02	0.11	0.65	1.04
	H. verticellata	4.6	6.88	8.07	14.58	5.39	7.42	28	37	41.5	23.5
	J. repens	0.77	0.63	0.43	0.26	0.66	0.44	0.09	0.16	0.32	0.69
	T. latifolia	0.6	0.62	1.14	1.03	1.22	1.24	0.78	0.24	0.57	0.7
	V. spiralis	0.43	0.43	0.3	0.31	0.58	0.5	0.02	0.08	0.32	0.27
	P. glabrum	0.61	0.42	1.07	0.34	1.46	0.39	0.12	0.08	0.35	0.36
Site III	*E. crassipes*	0.69	0.67	1.19	1.02	0.75	1.02	0.005	0.63	0.43	0.59
	P. stratiotes	0.66	0.52	1.21	1.18	1.17	0.51	0.1	0.96	1.32	0.9
	H. verticellata	4.07	8.58	3.37	8.42	6.54	8.72	14.33	9.8	22	8
	J. repens	0.75	0.65	0.36	0.66	1.0	1.03	0.09	0.24	0.35	0.62
	T. latifolia	0.64	0.61	0.68	0.78	1.17	0.64	0.12	0.29	0.3	0.98
	V. spiralis	1.01	0.98	0.39	0.47	0.68	0.5	0.2	0.17	0.31	0.24
	P. glabrum	0.6	0.49	0.49	1.44	0.31	0.43	0.19	1.0	0.3	0.39
Site IV	*E. crassipes*	0.76	0.75	1.12	0.37	1.12	1.22	0.1	1.03	1.01	0.46
	P. stratiotes	0.6	0.54	0.74	0.7	0.56	0.5	0.15	0.23	0.54	0.42
	H. verticellata	7.0	9.22	6.28	12.88	8.0	6.09	12.87	4.3	14.13	8.58
	J. repens	0.75	0.65	1.04	0.39	0.57	0.45	1.11	0.16	0.39	0.39
	T latifolia	0.63	0.58	1.26	0.85	1.22	0.68	1.08	0.23	0.34	0.78
Site V	*E. crassipes*	0.77	0.82	0.49	0.95	0.69	0.6	0.16	0.42	0.42	0.24
	P. stratiotes	0.82	–	0.22	–	0.58	–	0.16	–	0.32	–
	H. verticellata	5.35	14.79	13.37	27.75	4.46	8.29	14.33	11.2	14	12.5
	J. repens	0.73	–	0.33	–	0.67	–	0.18	–	0.62	–
	T. latifolia	0.69	0.68	0.4	1.53	0.66	0.65	0.51	0.49	0.23	0.81
Site VI	*E. crassipes*	0.6	0.64	1.02	0.89	1.08	1.04	0.11	1.12	1.17	1.02
	P. stratiotes	0.48	0.4	1.72	1.78	1.09	1.06	1.07	1.13	1.1	1.04
	H. verticellata	5.05	10.39	3.46	3.14	8.18	11.71	26.25	2.9	12	36
	J. repens	0.71	0.66	1.15	1.0	0.68	0.84	0.07	0.23	1.06	0.62
	T. latifolia	0.68	0.68	1.2	0.36	1.03	1.11	1.32	0.4	1.03	1.1
	V. spiralis	0.45	0.9	0.45	0.95	0.72	0.45	0.3	0.39	0.36	0.23
	P. glabrum	0.53	0.46	1.63	0.81	1.04	1.04	0..27	0.28	0.24	0.38

E. crassipes = *Eichhornia crassipes*, *P. stratiotes* = *Pistia stratiotes*, *H. verticellata* = *Hydrilla verticellata*, *J. repens* = *Jussiaea repens*, *T. latifolia* = *Typha latifolia*, *V. spiralis* = *Vallesnaria spiralis* and *P. glabrum* = *Polygonum glabrum* whereas; Site I = Gaughat; Site II = Pucca Pull; Site III = Hanuman Setu; Site IV = Nishatganj; Site V = Gomti Barrage and Site VI = Pipraghat; (–) indicates the plant species were not present during that season at the site

coefficient (Table 4). All metals showed significant positive correlation with COD, phosphate (PO_4), nitrate and negative correlation with DO. Individually, each metal showed positive correlations with other metals. Among physicochemical characteristics, Fe in water showed a significant positive correlation with COD (0.898; $p < 0.01$), phosphate (0.743; $p < 0.01$) and nitrate (0.645; $p < 0.05$).

Among various metals recorded, Fe showed a positive correlation with Cu (0.917), Pb (0.739), Cr (0.808; $p < 0.01$) and with Cd (0.650; $p < 0.05$). Cd in water showed a positive correlation with COD (0.774; $p < 0.01$)

Table 4 Correlation matrix between physicochemical characteristics and metals of the Gomti River water at Lucknow, India

	pH	E.C	DO	BOD	COD	NO_3	NO_2	NH_4	PO_4	Fe	Cd	Cu	Pb	Cr
pH	1	0.910**	0.215	0.404	−0.269	0.289	0.527	0.033	−0.466	−0.048	−0.095	0.022	−0.239	0.078
E.C			0.025	0.563	−0.116	0.379	0.432	0.224	−0.247	0.134	0.015	0.216	−0.165	0.172
DO				−0.684*	−0.704*	−0.396	0.244	0.224	−0.584*	0.777**	−0.202	−0.577*	−0.564	−0.498
BOD					0.294	0.541	0.148	−0.080	0.167	0.450	0.011	0.411	0.245	0.389
COD						0.527	−0.211	−0.254	0.847**	0.898**	0.774**	0.901**	0.720**	0.756**
NO_3							0.379	0.136	0.547	0.645*	0.568	0.761**	0.700*	0.781**
NO_2								0.372	−0.031	−0.109	0.188	0.000	−0.007	0.005
NH_4									0.172	−0.078	0.111	0.005	−0.194	−0.176
PO_4										0.743**	0.799**	0.796**	0.713**	0.635*
Fe											0.650*	0.917**	0.739**	0.808**
Cd												0.842**	0.578*	0.707*
Cu													0.717**	0.871**
Pb														0.882**
Cr														1

Values represent Pearson correlation coefficient and significant at ** $p = 0.01$ and * $p = 0.05$

and phosphate (0.799; $p < 0.01$). However, Cd didn't show any significant relation with nitrate. Among various metals, Cd showed a positive correlation with Cu (0.842; $p < 0.01$), Pb (0.578; $p < 0.05$) and Cr (0.707; $p < 0.05$). Among physicochemical characteristics, Cu in water showed a significant positive correlation with COD (0.901; $p < 0.01$), nitrate (0.761; $p < 0.01$) and phosphate (0.796; $p < 0.01$). Cu showed a positive correlation with Pb (0.717) and Cr (0.871; $p < 0.01$). For Pb, a significant positive correlation with COD (0.720; $p < 0.01$), nitrate (0.700; $p < 0.01$) and phosphate (0.713; $p < 0.01$) were observed. Pb also showed a positive correlation with Cr (0.871; $p < 0.01$). Among various physicochemical properties, Cr showed a significant positive correlation with COD (0.765; $p < 0.01$), nitrate (0.781; $p < 0.01$) and phosphate (0.635; $p < 0.05$). In the aquatic environment, accumulation of metals and subsequent transformations due to physicochemical and biological processes are important mechanisms for their changing levels in water (Rai 2010).

The present study reveals that the Gomti River is subjected to alarming inputs of metals and other inorganic pollutants. Variations in metal accumulation by plants from site to site could be attributed to the dwelling of plants at distinct microhabitats, their growth patterns, metal availability for absorption and metal levels in the water column. It is worth noting that plants accumulated more metals than the corresponding levels in water, indicating these species could be used in ecological surveys as in situ biomonitors of water quality. Further studies should be conducted in this river during all seasons throughout the year to evaluate the dynamics of metal accumulation and release back into river by these macrophytes for efficient water quality management.

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