Metal distribution in the sediments, water and naturally occurring macrophytes in the river Gomti, Lucknow, Uttar Pradesh, India

Neha[1], Dhananjay Kumar[1], Preeti Shukla[1], Sanjeev Kumar[1], Kuldeep Bauddh[2], Jaya Tiwari[1], Neetu Dwivedi[1], S. C. Barman[3], D. P. Singh[1] and Narendra Kumar[1,*]

[1]Department of Environmental Science, Babasaheb Bhimrao Ambedkar University, Lucknow 226 025, India
[2]Centre for Environmental Sciences, Central University of Jharkhand, Ranchi 835 205, India
[3]Environmental Monitoring Division, Indian Institute of Toxicology Research, Lucknow 226 001, India

River Gomti receives treated/untreated industrial as well as municipal wastes from various drains of Lucknow city, India. In order to study heavy metal pollution (Cd, As, Pb and Cu) in the river, water and sediment samples were collected from 10 sampling stations along a 9 km stretch in the city of Lucknow. Results revealed that the concentrations of heavy metals in water samples were in the range: As: 0.035–0.061, Cd: 0.016–0.068, Cu: 0.029–0.062 and Pb: 0.031–0.065 mg l^{-1} whereas in sediments metal concentrations were found to be As: 3.72–14.98, Cd: 1.91–8.39, Cu: 8.97–95.35 and 35.82–90.92 μg g^{-1}. Bioaccumulation of these metals was assessed in four aquatic macrophytes, viz. *Pistia stratiotes*, *Eichhornia crassipes*, *Polygonum coccineum* and *Marsilea quadrifolia*. *Pistia stratiotes* and *Polygonum coccineum* accumulated maximum amount of Pb followed by Cu, Cd and As, whereas in the case of *Eichhornia crassipes* and *Marsilea quadrifolia* the relative metal accumulation pattern was found as Cu > Cd > Pb > As and Cu > Pb > Cd > As respectively. The present study suggests that though the concentrations of toxic metals were lower in water, chronic exposure could result in bioaccumulation to a degree many-fold higher than in growing medium. It was also concluded that the water and sediment of the river should be regularly monitored for heavy metal contamination and care should be taken while using river water in agriculture/aquaculture.

Keywords: Bioaccumulation, Gomti River, heavy metals, macrophytes, sediments.

MOST civilizations in the world flourished on or close to river banks. As a direct consequence and through passage of time, the water and the sediments of these rivers suffered contamination affected by municipal and industrial contaminants[1]. Studies have shown that toxic metals constituted significant proportion in these waste materials which impart acute and chronic virulent characteristics to the wastes and sediments[2]. Heavy metals present in water, sediments and macrophytes play a crucial role in identifying the sources and paths of heavy metal pollution in aquatic ecosystems[3–5]. River water quality broadly depends on natural processes such as precipitation, soil erosion, weathering, etc. and human input, mainly through exploitation of water for industrial, agricultural and urban activities[6,7]. Because river water is used as a primary water resource for irrigation and aquaculture, it is imperative to have a reliable knowledge about the quality of water for its wise and judicious utilization.

Earlier river sediments were considered as a depot of various chemical species; they are now recognized as active aquatic compartment which performs the principal role in redistribution of deposited chemical species to water and aquatic biota[8,9]. Studies have demonstrated that heavy metal concentrations in sediments are several orders of magnitude higher than their concentration in water and act as secondary source of metals to the aquatic environment[10]. Hence, metal deposition in river water and sediments should be regularly monitored to assess the overall health and suitability of water for various purposes[11–15].

Aquatic macrophytes growing in the natural ecosystem can be used to assess the overall health and past trends of aquatic environment[2]. Furthermore, being immobile in nature these macrophytes have developed the ability to accumulate toxic metals in their body parts, which makes them an effective bio-indicator of metal pollution[16]. Studies demonstrate that uptake of metal depends on the speciation of metal and the type of macrophytes; submerged, rooted submerged, floating and rooted merged. Further, the distribution, mobility and availability of metals to these plants are influenced by physicochemical characteristics of water[16,17].

In view of continuous interaction among the sediment, water and aquatic biota, a simultaneous evaluation of metal concentration in these segments is essential for

*For correspondence. (e-mail: narendrakumar_lko@yahoo.co.in)

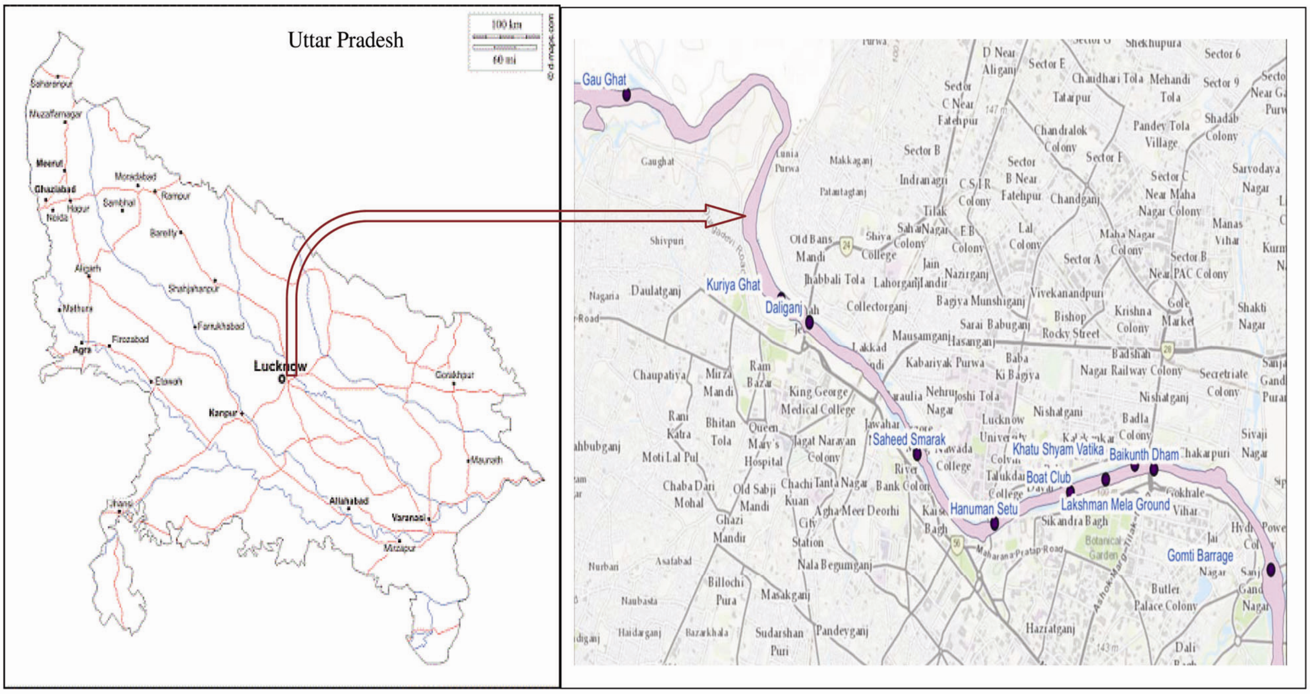

Figure 1. Sampling sites on river Gomti, Lucknow, India.

generating reliable information on the fate and behaviour of metal in a river ecosystem. As the river fulfils most needs of irrigation water, the contamination level needs to be monitored regularly. Further, to design an efficient pollution control and water resource management programme, data of this type is important.

The Gomti river, one of the major tributaries of Ganga, originates from a reservoir in the swampy and densely forested area near Madho–Tanda (Miankot, elevation of about 200 m amsl, 28°34′N and 80°07′E) about 3 km east of Pilibhit in Uttar Pradesh and about 50 km south of the Himalayan foot hills. The river flows in the great Gangetic alluvial plain, which is of Pleistocene–Holocene age, and redistributes the weathered sediments of the Gangetic alluvial plain derived from Himalayas. The river flowing through the districts of Pilibhit, Sahjahanpur, Jaunpur and Ghazipur in Uttar Pradesh covers a distance of about 730 km before finally joining the river Ganga near Udyarghat in Ghazipur district, about 30 km north of Varanasi. The domestic water demand of Lucknow city is partially met by the Gomti river water, delivered from Gaughat upstream of Lucknow. The river subsequently receives approximately 450 MLD of untreated domestic waste water from Lucknow city in addition to various point and non-point discharges from agricultural run-off. Like many other important rivers of the country Gomti is characterized by a sluggish flow except in the monsoon period. Sediments of the Gomti river are characterized by fine sand with slight changes along the course of the river[18].

Several studies have assessed the metal contamination in water[3,18–22] and sediments[3,20] of river Gomti (Table 1). However, as far as we are aware, no comprehensive study has been conducted to monitor the metal contamination simultaneously in river water, sediments and naturally grown macrophytes. In the present study, we have assessed heavy metal concentration in water, sediments and macrophytes simultaneously and toxic metals in the river ecosystem.

Materials and methods

Site description

Sampling was carried out at 10 sites along river Gomti in Lucknow city (Figure 1). The chosen sites were: Gau Ghat, Kuriya Ghat, Daliganj, Shaheed Smarak, Hanuman Setu, Boat Club, Lakshman Mela Ground, Khatu Shyam Vatika, Baikunth Dham and Gomti Baragge (Figure 1). A sampling network was designed to account for inputs from waste water drains that have an impact on river quality.

Sample collection and analysis

Water

Water samples were collected from the river bank in polyethylene bottles. The physicochemical parameters were determined following standard methods for analysis of water and waste water[23]. For physicochemical parameters, samples were preserved by adding an appropriate reagent and brought to the laboratory in sampling kits maintained at 4°C for analysis. The unfiltered water samples for total metal analysis were preserved using ultrapure nitric acid to lower the pH to <2.0. Samples were digested on a hot plate using acid mixture ($HNO_3 : HClO_4 : 5 : 1$). The digested samples were then filtered and the final volume was made up to 25 ml with deionized water and analysed on atomic absorption spectrophotometer (AA 240 FS, Varian)[2,22].

Sediment

The bed sediments of the Gomti river were collected at 10 sampling sites. The sediment samples were transferred to wide mouth 500 cm^3 polypropylene bottles. The samples were air-dried and ground in a porcelain pestle mortar. Samples of the bed sediments (1.0 ± 0.05 g) were digested with concentrated $HNO_3 : HClO_4$ (5 : 1). The final volume was made up to 25 ml and analysed by atomic absorption spectrophotometer.

Macrophytes

Four aquatic macrophytes, viz. *Pistia stratiotes*, *Eichhornia crassipes*, *Polygonum coccineum* and *Marsilea quadrifolia*, were collected from the same sites along the river bank from where water and sediment samples had been collected. These aquatic plants were brought to the laboratory and then washed with running tap water followed by distilled water to remove extraneous matter. After washing, the plant material was oven-dried at 65°C till constant weight. For metal estimation, one gram plant tissue was taken and digested in a solution of $HNO_3 : HClO_4$ (3 : 1) at 70–80°C. The solution was allowed to evaporate by increasing the temperature to 105°C until the solution became transparent. The final volume was diluted to 25 ml with 0.1 N HNO_3, filtered through 0.25 μm filter paper and analysed on atomic absorption spectrophotometer[24,25]. All readings were taken in six replicates ($n = 6$) and the results are expressed as mean ± SE.

Enrichment coefficient and translocation factor

Enrichment coefficient (EC) was determined to derive the degree of heavy metal accumulation in plants growing on contaminated environment[26,27]

$$EC = \frac{\text{Concentration of metal in roots/shoots}}{\text{Concentration of metal at contaminated site}}.$$

Translocation factor (TF) or mobilization ratio of each metal was calculated to determine the translocation of metals from the root to shoot of the plant species[26,27]

$$TF = \frac{\text{Concentration of metal in plant shoots}}{\text{Concentration of metal in plant roots}}.$$

Results and discussion

Water

Each water body possesses a specific pattern of physicochemical characteristics which is primarily governed by the climate, geomorphology and geochemistry prevalent in that river basin. The results of physicochemical analysis and heavy metal concentrations of water are presented in Tables 2 and 3. In the present study, the pH of water ranged between 6.54 and 8.14. The pH of river water was found to be alkaline at all sites except at two locations viz. Daliganj and Hanuman Setu; 6.54 ± 0.29 and 6.71 ± 0.92 respectively. Alkaline pH is known to favour the bioavailability of metals[28]. The mean value of dissolved oxygen (DO) varied between 3.69 and 7.3 mg l^{-1}. The maximum DO was found in the upstream section, i.e. Gaughat. In the downstream path it was depleted. This may be due to discharge of municipal and industrial effluents into the river[29]. The chloride and sulphate content in water ranged between 4.07–8.8 and 16.04–26.03 mg l^{-1} respectively, and found to be within the tolerance limit given by the Bureau of Indian Standards (BIS), 2012 (ref. 30) (chloride = 600 and sulphate = 1000 mg l^{-1}). These ions may have become part of river water due to interaction with the soil system and/or due to use of various inorganic chemicals discharged from industries and agriculture land[2,31]. Heterogeneous hardness of water was recorded at different sampling sites. Ca^{++} and Mg^{++} are the principal cations imparting hardness to water; however, Fe^{++} and Mn^{++} may also contribute cations. The anions influencing the hardness are mainly carbonate, bicarbonate, sulphate, fluoride and silicate[32]. Solid particles are natural constituents of river water systems and are introduced by both natural and anthropogenic sources. At all sampling locations, the value of total dissolved solids was found below the tolerance limit (2100 mg l^{-1}) given by BIS (ref. 30). The maximum nitrate concentration was found at site 3. The high concentration of nitrate along the stream in the city may be attributed to the discharge of agricultural and domestic waste water into the river[18]. The value of nitrite was found below 1 mg l^{-1} at sites other than 3 and 4, which may be due to discharge of industrial effluents near these sampling sites. High nitrite concentration indicates contamination due to industrial effluents with unsatisfactory microbial quality of water[11]. The values of heavy metals found in water at different sites are presented in Table 3.

Table 1. Heavy metal profile in water (mg l^{-1}) and sediment (μg g^{-1}) of river Gomti

		Sampling sites												
		Gau Ghat		Mohan Maikin/ Daliganj		Martyr memorial		Hanuman Setu		Nishatganj/ Khatu Shyam Vatika		Pipra Ghat		
Metal	Year	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Reference
Cu	2005	0.012	14.76	0.014	50.23	0.014	79.54	0.015	48.18	0.016	33.28	0.014	4.36	3, 18–20
	2006	0.015		0.021		0.019		0.022		0.023		0.029		
	2007	0.017		0.025		0.024		0.028		0.030		0.033		
	2008	0.016		0.027		0.026		0.030		0.032		0.036		
	2014	0.029	8.97	0.053	38.72	0.042	41.06	0.036	25.89	0.038	47.59	–	–	Present work
Cd	2005	0.0001	1.64	0.0002	17.26	BDL	16.01	BDL	11.98	BDL	4.61	0.0003	2.25	3, 18–20
	2006	BDL		BDL		BDL		BDL		BDL		BDL		
	2007	BDL		BDL		BDL		BDL		BDL		BDL		
	2008	BDL		BDL		BDL		BDL		BDL		BDL		
	2014	0.016	1.91	0.023	7.14	0.017	7.12	0.024	5.87	0.021	7.37	–	–	Present work
Pb	2005	0.032	14.21	0.030	22.28	0.024	51.11	0.005	38.94	0.007	40.04	0.027	5.80	3, 18–20
	2006	0.15		0.26		0.042		0.037		0.011		0.015		
	2007	0.19		0.31		0.047		0.041		0.015		0.019		
	2008	0.26		0.36		0.053		0.048		0.021		0.026		
	2014	0.031	35.82	0.055	70.1	0.047	73.43	0.038	60.46	0.043	86.73	–	–	Present work

Table 2. Physicochemical quality of Gomti river water, Lucknow, India

Sampling sites	pH	DO	Chloride	Hardness	TS	TSS	TDS	Sulphate	Nitrate	Nitrite
Gau Ghat	7.62 ± 0.52	7.3 ± 0.15	8.8 ± 1.31	187.09 ± 3.28	619 ± 45.1	264 ± 10.14	355 ± 20.16	24.77 ± 2.50	41.106 ± 5.8	0.474 ± 0.5
Kuriya Ghat	8.05 ± 0.13	6.4 ± 0.22	28.4 ± 2.10	168 ± 5.154	680.5 ± 32.1	339.5 ± 18.71	409 ± 12.3	24.643 ± 1.05	39.63 ± 3.52	0.418 ± 0.03
Daliganj	6.54 ± 0.29	5.4 ± 0.05	46.07 ± 7.1	217.01 ± 10.1	693.5 ± 60.2	441.6 ± 32.06	468.7 ± 20.9	26.034 ± 1.40	48.04 ± 1.26	0.307 ± 0.04
Shaheed Smarak	7.74 ± 0.43	4.9 ± 0.13	21.3 ± 2.03	160 ± 12.16	867 ± 41.2	388 ± 26.21	579 ± 37.16	22.726 ± 2.06	51.049 ± 3.8	0.201 ± 0.17
Hanuman Setu	6.71 ± 0.92	4.55 ± 0.05	23.01 ± 2.43	180.7 ± 15.42	761.9 ± 31.4	378.83 ± 21.1	508.01 ± 35.2	19.82 ± 2.03	60.87 ± 5.02	0.165 ± 0.03
Boat Club	7.18 ± 0.243	4.95 ± 0.01	37.285 ± 3.8	201 ± 11.63	859.5 ± 47.1	398.5 ± 26.2	461 ± 41.25	24.57 ± 4.20	57.934 ± 5.6	0.159 ± 0.07
Lakshman Mela Ground	7.515 ± 0.02	4.15 ± 0.05	21.3 ± 2.01	224 ± 12.41	871.5 ± 78.1	487 ± 21.73	484.5 ± 37.12	22.37 ± 2.32	79.57 ± 3.09	0.645 ± 0.04
Khatu Shyam Vatika	7.55 ± 0.12	4.2 ± 0.12	14.66 ± 1.72	207 ± 21.6	858.5 ± 66.1	465 ± 21.13	423.5 ± 28.19	16.04 ± 1.91	44.288 ± 4.7	0.214 ± 0.02
Baikunth Dham	7.56 ± 0.05	3.96 ± 0.15	19.32 ± 2.35	183.2 ± 14.40	891.03 ± 67.3	467.2 ± 32.17	478.45 ± 48.1	21.05 ± 1.21	53.72 ± 5.08	0.42 ± 0.03
Gomti Baragge	8.14 ± 0.01	3.59 ± 0.05	28.62 ± 1.02	213.06 ± 16.2	978.82 ± 71.7	596.2 ± 48.77	601.6 ± 63.11	2 3.712 ± 2.20	61.04 ± 2.05	0.38 ± 0.03

Results are expressed in mg l^{-1}, except for pH. The data are represented by means of six replicates ±SE.

Table 3. Heavy metals concentration (mg l^{-1}) in the water of Gomti river, Lucknow, India

Sampling sites	Cd	As	Cu	Pb
Gau Ghat	0.016 ± 0.002	0.035 ± 0.010	0.029 ± 0.004	0.031 ± 0.009
Kuriya Ghat	0.019 ± 0.002	0.040 ± 0.004	0.033 ± 0.002	0.035 ± 0.003
Daliganj	0.023 ± 0.004	0.049 ± 0.011	0.053 ± 0.014	0.055 ± 0.004
Shaheed Smarak	0.017 ± 0.005	0.037 ± 0.006	0.042 ± 0.007	0.047 ± 0.007
Hanuman Setu	0.024 ± 0.004	0.041 ± 0.009	0.036 ± 0.005	0.038 ± 0.007
Boat Club	0.043 ± 0.019	0.043 ± 0.007	0.049 ± 0.005	0.037 ± 0.006
Laxman Mela Ground	0.061 ± 0.019	0.057 ± 0.009	0.039 ± 0.006	0.044 ± 0.001
Khatu Shyam Vatika	0.021 ± 0.003	0.043 ± 0.004	0.038 ± 0.007	0.043 ± 0.002
Baikunth Dham	0.039 ± 0.006	0.044 ± 0.006	0.050 ± 0.009	0.045 ± 0.005
Gomti Baragge	0.068 ± 0.002	0.061 ± 0.009	0.062 ± 0.004	0.065 ± 0.005

The data are represented by means of six replicates ± SE.

Table 4. Concentration of heavy metals (μg g^{-1}) in sediments of Gomti river

Sampling sites	Cd	As	Cu	Pb
Gau Ghat	1.907 ± 0.17	3.723 ± 0.86	8.967 ± 1.02	35.823 ± 4.73
Kuriya Ghat	2.740 ± 0.96	10.913 ± 1.38	10.283 ± 1.48	40.187 ± 5.71
Daliganj	7.137 ± 0.89	8.873 ± 0.57	38.723 ± 3.79	70.097 ± 8.29
Shaheed Smarak	7.117 ± 0.88	9.047 ± 1.08	41.063 ± 2.16	73.434 ± 7.79
Hanuman Setu	5.863 ± 0.09	6.207 ± 0.54	25.887 ± 3.80	60.463 ± 4.01
Boat Club	4.484 ± 0.53	11.113 ± 1.97	48.817 ± 3.51	57.910 ± 9.72
Laxman Mela Ground	2.710 ± 0.26	6.900 ± 0.50	53.843 ± 3.84	81.630 ± 9.64
Khatu Shyam Vatika	7.370 ± 0.73	8.024 ± 0.38	47.590 ± 4.37	86.727 ± 8.31
Baikunth Dham	5.913 ± 0.79	8.557 ± 1.15	61.650 ± 9.12	72.453 ± 8.91
Gomti Baragge	8.390 ± 0.83	14.980 ± 3.02	95.350 ± 7.83	90.920 ± 7.82

The data are represented by means of six replicates ± SE.

The maximum concentration of all metals (Cu, Cd, As and Pb) was found at site 10, i.e. Gomti Barrage. The water was almost stagnant at this location, which might be responsible for high concentration of these metals. The Cd concentration in the river water ranged between 0.016 and 0.068 mg l^{-1}. Cadmium is a toxic element and is introduced into the water body by metal industries, plastic industries, domestic waste, fossil fuel and sewerage system[33]. Arsenic concentration ranged between 0.035 and 0.061 mg l^{-1}. Although the prime sources of arsenic in the environment are minerals and various geo-genic processes, human activities such as use of arsenic containing pesticides, burning of fossil fuel, mining activities, use of fertilizers and wood preservatives also add to arsenic abundance in the environment[34,35]. Though Cu is a micronutrient at higher concentrations, it is toxic to plant and animals. The concentration of Cu falls in the range 0.029 to 0.062 mg l^{-1}. Cu in river water might have been introduced along with waste discharged from automobiles, repair shops, electroplating units, utensil manufacturing units and workshops. Lead is a proven cumulative poison[36]. The concentration of Pb is in the range between 0.031 and 0.065 mg l^{-1}. The presence of Pb in water samples from all the sampling sites indicates the deposition of Pb particles from vehicular exhaust. Agricultural run-off may also have contributed to the observed levels of Pb because it can occur as impurity in fertilizers, pesticides, compost and manure[10,18]. The present findings are in good agreement with earlier studies on river Gomti[11,19,20]. When the present results were compared with those from earlier studies, it was observed that there was cumulative increase in the concentration of Cu, Cd and Pb in the water of Gomti river (Table 1). Arsenic was not reported earlier in the water of river Gomti.

Sediment

The results of heavy metal analysis in the sediments of river Gomti are given in Table 4. All the metals studied were found to be present in high concentration in the river bed sediments at all sites. This may be due to sluggish flow of the river which allows particles to settle down. Total metal concentration in the sediments of river Gomti was found to be: Cd: 1.907–8.390, As: 3.723–14.980, Cu: 8.967–95.390 and Pb: 35.823–90.920 μg g^{-1} (Table 4). The concentration of metals found in sediments are critically higher than that found in the river water. The alkalinity of river water is considered to favour the settling down of metals in the sediment. Higher concentration of metals in the river bed sediment subsequently poses high risk to benthic biota of the river due to metal toxicity. The occurrence of metals in sediments may be due to discharge of municipal and industrial effluents from various sources including untreated sewage, vehicular exhaust and agro-chemical run-off. The average concentration of

Table 5. Metal enrichment in the root and shoot of different macrophytes

Sampling sites	*Pistia stratiotes*				*E. crassipes*				*Polygonum coccineum*				*M. quadrifolia*			
EC_R	Cd	As	Pb	Cu	Cd	As	Pb	Cu	Cd	As	Pb	Cu	Cd	As	Pb	Cu
Gau Ghat	477.58	30.39	507.39	278.27	538.32	87.96	250.01	376.65	74.23	16.2	320.35	215.34	33.11	8.32	45.98	129.42
Kuriya Ghat	321.58	84.98	845.96	346.93	561.58	143.95	242.11	321.94	64.95	24.28	215.91	265.87	48.00	17.22	29.83	173.57
Daliganj	533.21	82.83	408.80	301.32	753.97	206.12	164.33	266.54	214.90	67.13	304.39	318.57	45.00	22.44	52.79	114.44
Shaheed Smarak	465.09	365.75	725.53	648.65	846.98	239.22	279.22	143.12	178.31	90.13	298.51	289.99	232.03	38.12	43.51	115.75
Hanuman Setu	847.40	91.51	549.65	530.79	660.29	164.68	471.13	475.90	84.97	60.17	487.98	280.33	43.40	50.34	94.49	168.22
Boat Club	152.79	47.31	80.10	204.49	280.88	278.08	43.40	443.33	31.09	21.51	33.14	172.24	46.79	60.78	10.90	41.51
Lakshman Mela Ground	279.34	53.65	497.94	333.07	161.03	159.53	279.42	311.97	68.22	53.89	220.24	231.44	34.08	15.74	47.52	23.39
Khatu Shyam Vatika	291.29	48.75	629.08	315.13	439.50	189.38	200.70	600.34	177.74	56.32	345.77	196.43	61.55	47.18	19.94	131.53
Baikunth Dham	336.47	134.27	354.26	238.40	411.98	180.07	265.70	536.84	130.19	92.42	367.35	205.66	51.98	46.79	110.76	64.66
Gomti Baragge	345.96	99.07	263.35	419.84	311.23	213.82	249.43	393.26	100.36	68.59	279.40	339.81	45.24	18.00	62.78	64.84
EC_S																
Gau Ghat	355.40	22.971	529.57	172.76	331.00	58.286	152.18	298.27	48.76	7.57	230.35	138.73	27.60	4.80	29.67	93.45
Kuriya Ghat	238.42	55.21	703.85	326.63	522.11	101.32	191.54	162.76	51.05	15.66	186.43	185.08	43.32	9.13	20.40	110.94
Daliganj	479.12	79.32	432.11	265.36	795.00	264.25	199.16	208.58	135.00	26.05	254.02	341.36	9.71	17.32	23.31	95.05
Shaheed Smarak	448.33	267.61	389.08	560.88	791.69	187.19	231.28	70.64	118.69	55.12	20.26	241.63	185.08	26.33	28.85	72.02
Hanuman Setu	865.81	34.15	444.00	380.09	535.07	111.32	340.43	504.15	76.93	49.61	407.58	251.83	74.79	30.39	52.90	134.51
Boat Club	129.07	70.15	51.17	188.37	253.95	264.92	29.811	388.37	11.63	14.65	38.32	45.85	42.37	24.12	3.49	22.29
Lakshman Mela Ground	219.02	70.06	697.41	334.21	108.70	140.65	249.47	405.97	47.12	52.29	250.61	217.52	16.65	6.92	38.48	21.05
Khatu Shyam Vatika	127.74	45.23	662.38	307.04	368.71	185.86	208.22	518.40	89.52	25.01	336.77	65.48	43.65	39.45	14.40	94.72
Baikunth Dham	333.62	105.14	263.38	280.60	415.94	196.74	243.15	361.74	126.54	61.58	265.95	179.64	26.64	25.72	52.63	57.42
Gomti Baragge	324.59	79.02	202.27	353.71	267.00	160.98	283.30	355.85	83.11	48.85	217.55	291.00	28.52	13.44	56.83	32.77

EC_R, Enrichment coefficient root, EC_S, Enrichment coefficient shoot.

Table 6. Translocation factor of different macrophytes, collected from the Gomti River

	Pistia stratiotes				*E. crassipes*				*Polygonum coccineum*				*M. quadrifolia*			
Sampling sites	Cd	As	Pb	Cu	Cd	As	Pb	Cu	Cd	As	Pb	Cu	Cd	As	Pb	Cu
Gau Ghat	0.744	0.758	1.044	0.621	0.615	0.667	0.609	0.792	0.657	0.467	0.719	0.644	0.863	0.577	0.645	0.722
Kuriya Ghat	0.741	0.650	0.968	0.941	0.930	0.704	0.791	0.506	0.786	0.645	0.863	0.696	0.902	0.530	0.684	0.816
Daliganj	0.899	0.958	1.057	0.881	1.054	1.182	1.212	0.783	0.628	0.388	0.840	1.072	0.216	0.772	0.442	0.831
Shaheed Smarak	0.965	0.772	0.888	0.865	0.935	0.782	0.828	0.494	0.666	0.612	0.068	0.833	0.752	0.691	0.663	0.622
Hanuman Setu	1.022	0.417	0.808	0.716	1.002	0.676	0.723	1.059	0.905	0.824	0.835	0.898	1.723	0.894	0.560	0.795
Boat Club	0.845	0.722	0.788	0.921	0.904	1.036	0.689	0.876	0.374	0.681	1.156	0.266	0.906	0.625	0.810	0.537
Lakshman Mela Ground	0.784	1.306	1.401	1.005	0.675	0.882	0.893	1.301	0.691	0.676	1.138	0.940	0.489	0.439	0.810	0.900
Khatu Shyam Vatika	0.439	0.928	0.953	0.974	0.839	0.981	1.037	0.786	0.504	0.444	0.974	0.333	0.709	0.538	0.722	0.720
Baikunth Dham	0.992	0.783	0.743	1.177	1.010	1.093	0.915	0.822	0.972	0.652	0.724	0.873	0.512	0.550	0.475	0.888
Gomti Baragge	0.938	0.798	0.768	0.842	0.858	0.753	1.136	0.815	0.828	0.712	0.852	0.856	0.631	0.747	0.905	0.505

different metals in the Gomti river sediments during 1994–1998 was reported as: Cd: 0.092–17.83, Pb: 1.56–4.86, Cu: 3.60–245.33 μg g^{-1} (ref. 11). In another study, the heavy metal concentration in Gomti river sediments was reported as Cd: 1.64–17.26, Pb: 5.8–51.11, Cu 4.98–47.14 in summer; Cd 1.20–5.44, Pb 10.77–40.33, Cu: 4.36–79.54, in winter and Cd 0.41–12.96, Pb 29.63–100.38, Cu 3.98–91.17 μg g^{-1} in rainy seasons[19]. The concentration of metals in the sediment obtained in the present study is comparable to that reported earlier[11,20].

Macrophytes

In freshwater ecosystem, macrophytes are used as *in situ* bio-indicators of water quality due to their ability to accumulate chemicals including heavy metals[37]. Macrophytes take up heavy metals from the growing medium either passively, through mass flow of water in the roots or by active transport through epidermal cells of roots[38]. Under natural circumstances macrophytes can accumulate toxic metals to the magnitude several times greater than those in the substrate[2,39]. The metal accumulations by different macrophytes studied are presented in Table 5. The metal accumulation efficiencies of different macrophytes as observed are: *E. crassipes* > *Pistia stratiotes* > *Polygonum coccineum* > *M. quadrifolia* for As, Cd and Cu, whereas, Pb was accumulated maximum by *Pistia stratiotes* followed by *Polygonum coccineum*, *E. crassipes* and *M. quadrifolia* on an average. The concentration of metals recorded in different macrophytes is far above the concentration of respective metals in water. Among the different macrophytes, *Pistia stratiotes* and *Polygonum coccineum* have accumulated maximum amount of Pb followed by Cu, Cd and As. In *E. crassipes* and *M. quadrifolia* the relative metal accumulation pattern was found as Cu > Cd > Pb > As and Cu > Pb > Cd > As respectively. Similar metal accumulation patterns have been reported in *Myriophyllum spicatum* growing in contaminated water sources in Egypt[33], *E. crassipus*, *Ceratophyllum demersum*, *Typha domengensis* growing naturally in the waters of river Nile[28], and *E. crassipus*, *Pistia stratiotes*, *M. quadrifolia* grown in an anthropogenic lake in India[18].

Translocation factor (TF) expresses the ability of a plant to transfer the metal from roots to its aerial part and is defined as the ratio of metal concentration in the shoot with that in the roots[38]. In the present study variable TF was observed among the different macrophytes (Table 6). It was reported that TF value greater than one (>1) was observed in metal accumulator species, while less than one (<1) was observed in metal excluder species[2]. Results reveal that none of the macrophytes has TF > 1, which indicates that metals are mainly stored in roots which is a basic characteristic of rhizo-filtration[40]. Other studies have also reported a higher concentration of metals in the roots of aquatic macrophytes[2,41].

Enrichment coefficient (EC) expresses the metal accumulation efficiency of a plant with respect to its concentration in the growing medium[2]. For better understanding the metal storage within the plants, EC was separately calculated for root (EC_R) and shoot (EC_S) (Table 5). The variation in EC_S and EC_R of different macrophytes at different sites may be attributed to variation in physico-chemical characteristics of water. Further, variation in plant genotype, active/passive transfer processes within the plant, sequestration and speciation, type and nature of roots system and preferential availability of different metals may have been responsible for heterogeneous EC[42,43].

Conclusion

The present geochemical study of Gomti river water, river bed sediment and macrophytes suggested that the river water is polluted along the whole stretch of the river in Lucknow city. Various anthropogenic activities in and around the city contribute to the pollution. Low level of DO indicates the presence of various organic wastes in the river. Cd, Cu and Pb in the water, sediments and macrophytes have been reported earlier as well, but arsenic in water and sediments has been reported for the first time. The concentration of metals in the river bed sediment was many times higher than that in river water. The river sediments not only act as depot of metals, but also act as secondary source of metals to the water and aquatic biota. Although the concentration of Cd, Cu, Pb and As is low in water, due to continuous exposure of aquatic plants to the river water, the metals are bio-accumulated in *Pistia stratiotes*, *E. crassipes*, *Polygonum coccineum* and *M. quadrifolia* at levels beyond the toxicity threshold for many plants. These macrophytes provide food and shelter to other aquatic life. Hence there is increased probability of metal transfer to higher trophic levels by entering into the food chain. As the river water is being used for irrigation by local farmers, the risk of metal toxicity to man and animals cannot be ignored. In the coming years, increase in population will result in additional discharge of treated and untreated municipal and industrial effluents into the river which will further exacerbate the problem.

1. Ahmed, M. K., Islam, S., Rehman, S., Haque, M. and Islam, M., Heavy metals in water, sediment and some fishes of Buriganga river, Bangladesh. *Int. J. Environ. Res*., 2010, **4**(2), 321–332.
2. Kumar. N., Buaddh, K., Drivedi, N., Barman, S. C. and Singh, D. P., Accumulation of metals in selected macrophytes grown in mixture of drain water and tannery and their phytoremediation potential. *J. Environ. Biol*., 2012, **33**, 923–927.
3. Singh, K. P., Malik, A., Sinha, S., Singh, V. K. and Murthy, R. C., Estimation of source of heavy metals contamination in sediments of Gomti River (India) using principal component analysis. *Water, Air Soil Pollut.*, 2005, **166**, 321–341.
4. Lui, B., Hu, K., Jiang, Z., Yang, J. Luo, X. and Liu, A., Distribution of enrichment of heavy metals in a sediments core from the pearl River Estuary. *Environ. Earth Sci.*, 2011, **62**, 265–275.

5. Venkatramanan, S., Ramkumar, T., Anithamary, I. and Vasudevan, S., Heavy metal distribution in surface sediments of the Tirumalairajan river estuary and the surrounding coastal area, east coast of India. *Arab. J. Geosci.*, 2014, **7**, 123–130.
6. Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. and Smith, V. H., Non point pollution of surface water will phosphorus and nitrogen. *Ecol. Appl.*, 1998, **8**, 559–568.
7. Rzetala, M. A., Assessment of toxic metal contamination of bottom sediments in water bodies in urban areas. *Soil Sediment Contam.*, 2015, **24**, 49–63.
8. Malandrino, M., Abollino, O., Buoso, S., Casalino, C. E., Giacomino, A., La Gioia, C. and Mentasti, E., Geochemical characterization of Antractic soil and Lacustrine sediment from Terra Nova bay. *Microchem. J.*, 2009, **92**, 21–31.
9. Passos, E. A. *et al.*, Assessment of trace metals contamination in estuarine sediment using a sequential extraction technique and principle component analysis. *Microchem. J.*, 2010, **96**, 50–57.
10. Mei, J., Li, Z., Sun, L., Gui, H. and Wang, X., Assessment of heavy metals in the urban river sediment in Suzhou City, Northern Anhui Province, China. *Proc. Environ. Sci*., 2011, **10**, 2547–2553.
11. Singh, V. K., Singh, K. P. and Mohan, D., Status of heavy metals in water and bed sediments of river Gomti – a tributary of the Ganga river, India. *Env. Monit. Asses.*, 2005, **105**, 43–67.
12. Xiao, H. Y., Zhou, W. B., Wu, D. S. and Zeng, F. P., Heavy metal contamination in sediments and floodplain top soils of the Lean river catchment, China. *Soil Sediment Contam.*, 2011, **20**, 810–823.
13. Djordjević, L., Živković, N., Živković, L. and Djordjević, A., Assessment of heavy metals pollution in sediments of the Korbevačka river in southeastern Serbia. *Soil Sediment Contam.*, 2012, **21**, 889–900.
14. Huong, N. T. L., Ohtsubo, M., Higashi, T. and Kanayama, M., Heavy metal concentration in sediments of the Nhue river and its water-irrigated farmland soil in the Suburbs of Hanoi, Vietnam. *Soil Sediment Contam.*, 2012, **21**, 364–381.
15. Abdelhafez, A. A. and Li, J., Geochemical and statistical evaluation of heavy metal status in the region around Jinxiriver, China. *Soil Sediment Contam.*, 2014, **23**, 850–868.
16. Hussan, S., Schmieder, K. and Bocker, R., Spatial pattern of submerged macrophytes and heavy metals in the hypertrophic, contaminated, shallow reservoir lake qattieneh/Syaria. *Limono*, 2010, **40**, 54–60.
17. Sinha, S., Saxena, R. and Singh, S., Comparative studies on accumulation of Cr from metal solution and tannery effluent under repeated metal exposure by aquatic plant: its toxic effects. *Environ. Monit. Assess.*, 2002, **80**, 17–31.
18. Mishra, S. S. and Mishra, A., Assessment of physico-chemical properties and heavy metals concentration in Gomti river. *Res. Environ. Life Sci*., 2008, **1**(2), 55–58.
19. Gaur, V. K., Gupta, S. K., Panndey, S. D., Gopal, K. and Mishra, V., Distribution of heavy metals in sediment and water of river Gomti. *Environ. Monit. Asses.*, 2005, **102**, 419–433.
20. Singh, K. P., Mohan, D., Singh, V. K. and Malik, A., Studies on distribution and fractionation of heavy metals in Gomti river sediment – a tributary of the Ganga, India. *J. Hydrol.*, 2005, **312**, 14–27.
21. Gupta, S. K., Chabukdharab, M., Kumara, P., Singh, J. and Bux, F., Evaluation of ecological risk of metal contamination in river Gomti, India: a biomonitoring approach. *EcotoxicoEnv Saf.*, 2014, **110**, 49–55.
22. Kumar, D., Verma, A., Dhusia, N. and More, N. K., Water quality assessment of River Gomti in Lucknow. *Univ. J. Environ. Res. Technol.*, 2013, **3**, 337–344.
23. APHA., *Standard Methods for the Examination of Water and Wastewater*, Washington, DC, 21st edn, 2005.
24. Bauddh, K. and Singh, R. P., Cadmium tolerance and its phytoremediation by two oil yielding plants *Ricinus communis* (L.) and *Brassica juncea* (L.) from the contaminated soil. *Int. J. Phytoremed*., 2012, **14**, 772–785.
25. Kisku, G. C., Barman, S. C. and Singh, S. C., Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment. *Water, Air Soil Pollut*., 2000, **120**, 121–137.
26. Barman, S. C., Sahu, R. K., Bhargava, S. K. and Chaterjee, C., Distribution of heavy metals in wheat, mustard, and weed grown in field irrigated with industrial effluents. *Bull. Environ. Contamin. Toxicol.*, 2000, **64**, 489–496.
27. Kumar, N., Bauddha, K., Kumar, S., Dwivedi, N., Singh, D. C. and Barman, S. C., Accumulation of metals in weed species grown on the soil contaminated with industrial waste and their phytoremediation potential. *Ecol. Eng.*, 2013, **61**, 491–495.
28. Fawzy, M. A., Badr, N. E., El-Khatib, A. and El-Kaseem, A. A., Heavy metal biomonitoring and phytoremediation potentialities of aquatic macrophytes in River Nile. *Environ. Monit. Assess.*, 2012, **184**, 1753–1771.
29. Adelaid, M. R. V., Veado, A. H., Oliveria, G., Revel, G., Pinte, S. and Aytsult, P., Study of water and sediment interaction in the das Velhas River, Brazil-Major and Trace element. *Water SA*, 2000, **25**(2), 255–274.
30. BIS, 2012. Drinking Water Standard (IS 105000-91).
31. Sungur, A., Soylak, M., Yilmaz, E., Yilmaz, S. and Ozcan, H., Characterization of heavy metal fractions in agricultural soils by sequential extraction procedure: the relationship between soil properties and heavy metal fractions. *Soil Sediment Contam.*, 2015, **24**, 1–15.
32. Sahu, R. K., Katiyar, S., Yadav, A. K., Kumar, N. and Srivastava, J., Toxicity assessment of industrial effluent by bioassay. *Clean*, 2008, **5–6**, 517–520.
33. Galal, T. M. and Shehata, H. S., Evaluation of the invasive macrophyte *Myriophyllumspicatum* L. as a bioaccumulator for heavy metals in some water courses of Egypt. *Ecol. Indicator*, 2014, **41**, 209–214.
34. Sharma, V. K. and Sohan, M., Aquatic arsenic: toxicity, speciation, transformation and remediation. *Environ. Int*., 2009, **35**, 743–759.
35. Rahman, M. A. and Hasegawa, H., Aquatic arsenic: phytoremediation using floating macrophyets. *Chemosphere*, 2011, **83**, 633–646.
36. Fritioff, A. and Greger, M., Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant potamogeton. *Chemosphere*, 2006, **63**, 220–227.
37. Lewis, M. A. Use of fresh water plant for toxicity testing: a review. *Environ. Pollut*., 1995, **87**, 319–336.
38. Yoom, J., Cao, X., Zhou, Q. and Ma, L. Q., Accumulation of Pb, Cu, and Zn in native plants growing on a contamination fluoride site. *Sci. Total. Environ.*, 2006, **368**, 456–464.
39. Singh, R., Singh, D. P., Kumar, N., Bhargava, S. K. and Barman, S. C., Accumulation and translocation of heavy metals in soil and plants from fly ash contamination. *Environ. Biol.*, 2010, **3**, 421–430.
40. Sood, A., Uniyal, P. L., Prasanna, R. and Ahluwalia, A. S., Phytoremediation potential of aquatic macrophyte Azolla. *Ambio*, 2012, **41**, 122–137.
41. Tripathi, C. P., Singh, N. K. and Bhargava, D. S., Quality assessment of River Gomti in Lucknow emphasizing the trace metals. *J. Instn. Engrs. India*, 2006, **87**, 27–34.
42. Lum, A. F., Ngwa, E. S. A., Chikoye, D. and Suh, C. E., Phytoremediation potential of weeds in heavy metal contaminated soils of the Bassa industrial zone of Douala, Cameroon. *Int. J. Phytoremediation*, 2014, **16**, 302–319.
43. Malik, R. N., Husain, S. Z. and Nazir, I., Heavy metals contamination and accumulation in soil and wild plant species from industrial areas of Islamabad, Pakistan. *Pak. J. Bot.*, 2010, **3**, 210–220.

ACKNOWLEDGEMENT. We thank the Head, Department of Environmental Science, BBAU, Lucknow, India for providing infrastructural support.

Received 3 April 2015; revised accepted 24 May 2017

doi: 10.18520/cs/v113/i08/1578-1585