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Heavy Metals in Wetland Soil of Greater Dhaka District, Bangladesh

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ABSTRACT: The current paper determines heavy metals in sediments of six freshwater wetlands of greater Dhaka district from November 1999 to September 2000. The sampling took place in summer, rainy season, and winter, wherein for each season five soil samples were collected from the wetland at a depth of 0 – 15 cm. To assess the status of heavy metal pollution in the sediments, geo-accumulation factor (I_{geo}), contamination factor (CF), degree of contamination (C_d), and enrichment factor (EF) have been evaluated, with the concentrations of Cd, Mn, Ni, Zn, Cu, Fe, and Pb in the sediments ranging within 0.005 – 0.055 mg/kg, 35.0 – 275.04 mg/kg, 0.35 – 2.19 mg/kg, 0.77 – 12.54 mg/kg, 4.11 – 19.17 mg/kg, 115.60 – 955.94 mg/kg, and 1.82 – 3.93 mg/kg, respectively, standing in the following order: Fe > Mn > Cu > Zn > Pb > Ni > Cd. The maximum concentrations of Mn, Ni, and Pb belonged to summer. Significant temporal variation was observed only in case of Cd, whereas concentrations of Cd, Fe, and Mn varied spatially. The I_{geo} for Mn indicates a strongly to extremely polluted condition in wetlands, whereas that of Ni and Pb show moderately polluted condition, and for Zn and Cu, it suggests moderately to strongly polluted conditions. The CF values for heavy metals in sediment have been below 1, indicating low contamination. In addition, $C_d < 6$ indicates low degree of heavy metal contamination. The EF for heavy metals in wetland sediments are in the following order: Cu>Mn>Pb>Cd>Zn>Ni, suggesting that the sediments very highly rich in Cu, while Mn, Pb, and Cd exhibit significant enrichment. In the studied wetlands the EF for Zn and Ni shows moderate and deficiency to minimal enrichment, respectively. Implications of these findings can be used as baseline information to monitor and assess the degree of sediment pollution in lentic wetlands.

Keywords: heavy metal, sediment, geoaccumulation factor, contamination factor, enrichment factor, wetland.

INTRODUCTION

Heavy metals occur naturally in freshwater and soil sediments of wetland (George et al., 1999; Karbassi et al., 2008; Inaotombi and Gupta, 2017). Their use by humans has greatly increased their rates in natural wetlands (Cox, 1997; Vesali Naseh et al., 2012; Esmaeilzadeh et al., 2016a). Wetlands

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are subjected to pollution from various sources like sewage, industrial effluents, agro-chemicals, etc. (George et al., 1999; Esmaeilzadeh et al., 2016b). Heavy metals reduce productivity through stunted growth and chlorosis (Moriarty, 1988). Assimilation of heavy metals in food chains significantly influences aquatic ecosystem (Baldantoni et al., 2004; Mansouri et al. 2013; Esmaeilzadeh et al., 2017), acting as a potential toxic substance for living organisms (Storelli et al., 2005; Hargalani et al., 2014). In aquatic environments, metals persist forever, never to break down into harmless substances via microbial activity (Sengupta and Kureishy, 1989). Determination of heavy metals in aquatic environment is an important monitoring tool to assess the degree of pollution in wetlands (Kumar and Mahadevan, 1995).

Heavy metals in soil vary spatiotemporally, with the concentrations of heavy metals such as Cd, Mn, Ni, Zn, Cu, and Pb in soils being assessed to range within 0.01 – 0.7 mg/kg, 20 – 3000 mg/kg, 2 – 50 mg/kg, 3 – 100 mg/kg, 1 – 40 mg/kg, and 0.1 – 20 mg/kg, respectively (Sauerbeck, 1985). Concentrations of heavy metals such as Cd, Ni, Zn, Cu, and Pb in soils have been recoded between 0.5 and 3 mg/kg, 5 and 50 mg/kg, 10 and 80 mg/kg, 2 and 40 mg/kg, and 2 and 60 mg/kg, respectively (Scheffer and Schachtschabel, 1989). In the soil, all metals with the exception of Fe (i.e. Cd, Cu, Mn, Ni, Pb, and Zn) witnessed their maximum concentration during the post-monsoon season (George et al., 1999).

Bangladesh possesses vast wetland areas with diverse nature and variable dimension. In Bangladesh both lotic and lentic wetland ecosystems are available. Wetlands in Bangladesh have great ecological, economic, commercial, and socioeconomic importance and values (Akond, 1989; Khan et al., 1994), playing a dominant role in the lives of adjoining human beings with biotic components acting as resource bases (Karim, 1993; Khan and Halim, 1987). However, these resources have suffered considerably from the impact of a burgeoning human population. The wetlands are polluted due to anthropogenic activities such as discharge of untreated effluents from industries, agricultural run-off, and waste disposal. Soils of lotic wetland ecosystem in Bangladesh are polluted by heavy metals as a result of various anthropogenic activities (Ahmad et al., 2010; Ahmed et al., 2015; Ali et al., 2016). However, information on the concentrations of heavy metals in soils of lentic wetland ecosystem of Bangladesh is scanty. Keeping the abovementioned background in mind, the study was undertaken to assess the concentration of heavy metals in soil of some lentic freshwater wetlands of greater Dhaka district, Bangladesh.

MATERIALS AND METHODS

A total of six freshwater wetlands of greater Dhaka district were selected for this study (Fig. 1) with table 1 presenting the study sites with their notations and general features. Three of these wetlands are located at Jahangirnagar University campus (J_1, J_2, J_3), two at Savar (Dogarmara, S; Baipail, Dhamsona, B), and one at Guptapara, Shibpur, Narsingdi (N). However, this study was performed during three seasons, namely summer (March – May), rainy season (July – September), and winter (November – January), all between November, 1999, and September, 2000.

Sediment samples were collected from the six wetlands. In each season, five sediment samples were collected in each wetland from a depth of 0 – 15 cm with the help of ‘Eijkelkamp Agrisearch Equipment’ (The Netherlands). They were mixed together in order to make a composite sample, then to be taken in a polybag. The collected sediment samples were dried in sun, grounded, and passed through a 2 mm sieve. The sieved sediment samples were taken into sample bags and preserved in order to determine heavy metal content.

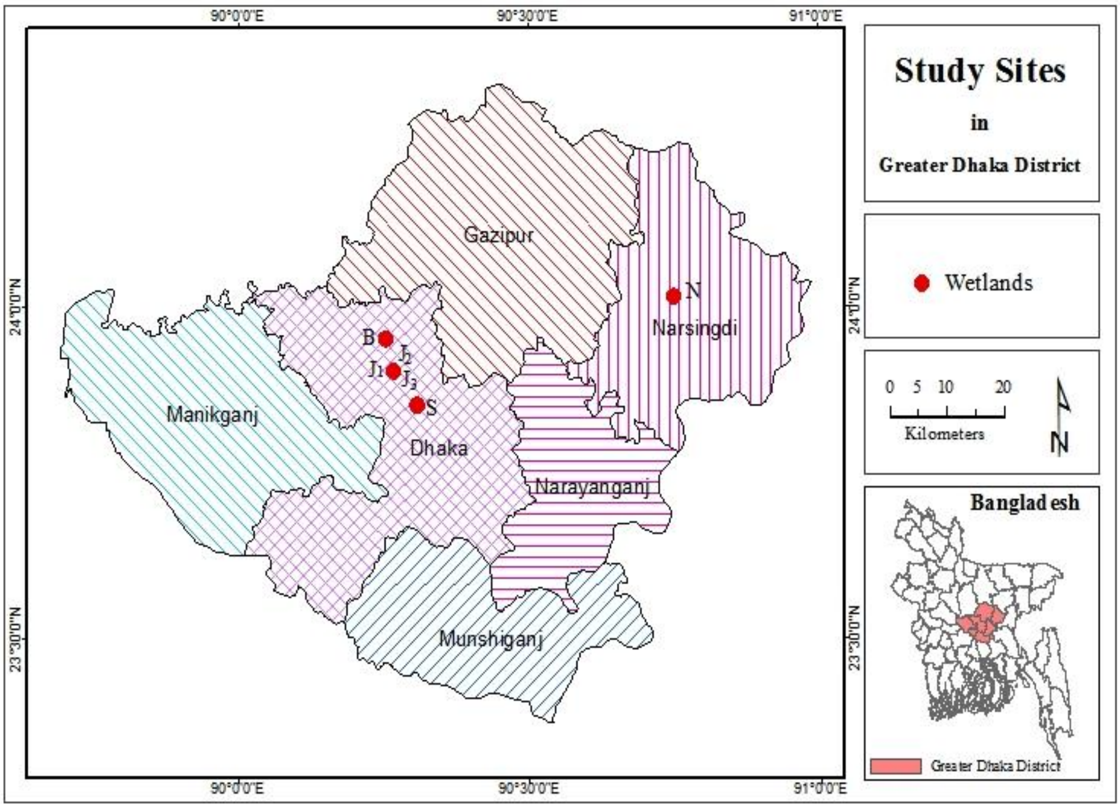

Fig. 1. The map, showing the study sites in greater Dhaka district: freshwater wetlands J_1, J_2, and J_3 are located at Jahangirnagar University campus; S is located at Dogarmara, Savar; B is located at Baipail, Dhamsona, Savar; and N is located at Guptapara, Shibpur, Narsingdi.

Table 1. General features of the lentic wetland ecosystems of greater Dhaka district

Wetland	Type	Average water depth	Sources of nutrients	Flooding	Fishing	Angling	Navigation	Migratory birds
J_1	Permanent	2.42 m	Run off rain water, ground water seepage, and wastewater, discharged from Jahanara Imam Hall and Pritilata Hall of Jahangirnagar University.	-	+	+	-	+
J_2	Permanent	1.67 m	Run off rain water, and automobile discharges, wastewater of Kamaluddin Hall, S.S.B. Hall and Fajilatunnesa Hall of Jahangirnagar University.	-	+	+	-	+
J_3	Permanent	0.62 m	Run off rain water, and ground water seepage.	-	-	+	-	-
S	Seasonal	0.86 m	Washouts of garage and run off rain water.	+	-	+	-	-
B	Permanent	3.47 m	Discharges and effluents of Dhaka Export Processing Zone, nearby paddy fields, petrol pumps, and poultry farms washouts.	+	+	+	+	-
N	Permanent	2.83 m	Run off rain water and paddy fields washouts.	+	+	+	-	-

+ indicates presence, - indicates absence

Sediment samples' diethylenetriamine-pentaacetic acid (DTPA) extractable Cu, Zn, Mn, Fe, Ni, Cd, and Pb were extracted by DTPA (Lindsay and Norvell, 1978) and the elements were determined by Atomic Absorption Spectrophotometer (AA - 6800, Shimadzu). The standard protocols for analytical Quality Assurance (QA), such as sampling, sample custody, re-checking, auditing, etc., were placed in the designated laboratory prior to the samples' analyses. For Quality Control (QC) of the AAS analyses, we measured six randomly-selected samples, employing the Standard Addition Calibration. The average concentration values (3 measurements) in each case agreed with the values determined by linear calibration, having a tolerance of +/- 1%. Thus, the latter method was adopted throughout the work for the sake of simplicity.

To assess metal pollution in the soil of the studied wetlands, the geo-accumulation factor was evaluated, based on its relevant index (I_{geo}) (Muller, 1969), which is expressed as follows:

$$I_{geo} = log_2\left(\frac{C_n}{1.5\times B_n}\right)$$

where, C_n=measured concentration of the metal in the sediment,

B_n= geo-chemical background value in average shale (Turekian and Wedepohl, 1961) of element n, and

1.5=background matrix correction factor due to lithogenic effects.

Table 2 presents pollution categories, based on geo-accumulation index (I_{geo}) which is suggested by Muller (1981).

To assess contamination status of heavy metals in the sediment of the studied wetlands, the Contamination Factor (CF) was evaluated by means of the following formula, suggested by Tomlinson et al. (1980).

$$\text{CF} = \frac{M_c}{B_c}$$

Where, M_c= measured concentration of the metal, and

B_c= background or pre-industrial concentration of the same metal.

Four contamination categories are documented on the basis of the contamination factor (Hakanson 1980) (Table 3). The degree of contamination (C_d) is defined as the sum of all contamination factors (CF). Such indices should be done carefully since the geology of the study area may totally differ from mean shale or mean crust (Karbassi et al., 2008).

Table 2. Geo-accumulation index (I_{geo}) for pollution levels in sediments

I_{geo} class	I_{geo} value	Classification
0	$0 \leqslant$	Practically unpolluted
1	$< 0 – 1$	Unpolluted to moderately polluted
2	$> 1 – 2$	Moderately polluted
3	$> 2 – 3$	Moderately to strongly polluted
4	$> 3 – 4$	Strongly polluted
5	$> 4 – 5$	Strongly to extremely polluted
6	> 5	Extremely polluted

Table 3. Contamination categories, based on contamination factor (CF) and degree of contamination (C_d)

CF value	Category for contamination factor (CF)	C_d value	Category for degree of contamination (C_d)
CF < 1	Low contamination	$C_d < 6$	Low degree of contamination
$1 \leqslant$ CF $\leqslant 3$	Moderate contamination	$6 \leqslant C_d < 12$	Moderate degree of contamination
$3 \leqslant$ CF $\leqslant 6$	Considerable contamination	$12 \leqslant C_d < 24$	Considerable degree of contamination
CF > 6	Very high contamination	$C_d > 24$	Very high degree of contamination

To assess possible anthropogenic influences of sedimentary samples, the Enrichment Factor (EF) was evaluated, using the following formula (Pekey, 2006; Hargalani et al., 2014; Obaidy et al., 2014). The current study considered the mean concentrations of heavy metals in the studied wetlands in order to calculate EF.

$$EF = \frac{(\frac{C_n}{C_{Fe}})_{sample}}{(\frac{C_n}{C_{Fe}})_{crust}}$$

where $(\frac{C_n}{C_{Fe}})_{sample}$ = the ratio of the concentration of the element of concern (C_n) to that of Fe (C_{Fe}) in the sediment sample, and

$(\frac{C_n}{C_{Fe}})_{crust}$ = the same ratio in an unpolluted reference sample.

The normalizing element, used in this study, was Fe (Fagbote and Olanipekun, 2010). Enrichment factor is utilized to assess the degree of anthropogenic influence on the medium-like sediment. Five contamination categories have beeen suggested on the basis of enrichment factor (Sutherland, 2000) (Table 4). As the values of EF increase, the contributions of anthropogenic impact also increase in the medium.

Table 4. Contamination level based on the values of enrichment factor (EF)

Values of enrichment factor (EF)	Level of contamination
EF < 2	Deficiency to minimal enrichment
2 ≼ EF ≼ 5	Moderate enrichment
5 < EF ≼ 20	Significant enrichment
20 < EF ≼ 40	Very high enrichment
EF > 40	Extremely high enrichment

Two-way variance analysis (ANOVA) of the data was performed to evaluate the variation of heavy metals in soils of wetlands by the sites and seasons. Duncun's Multiple Range Test (DMRT) (Montgomery, 1984) was performed to identify significantly different pairs when null hypothesis was rejected. The wetland J_3 was located within the conserved area at Botanical Garden of Jahangirnagar University; therefore, we took it as the control habitat, comparing the content of heavy metals in this site's soil with other five wetlands J_1, J_2, S, B, and N, using Statistical Package for Social Science (SPSS). The values were expressed as Mean ± SEM, where n = 3. Unpaired *t* test was performed as the test of significance and $p \leqslant 0.05$ was considered the minimal level of statistical significance.

RESULTS AND DISCUSSION

Fig. 2a demonstrates the amounts of Cd in the sediments of six freshwater wetlands during three seasons. Among the sites as well seasons, the maximum amount of soil Cd was found in wetland N (0.055 mg/kg) during winter, and the metal's content gradually ascended from summer to rainy season in wetland N. The minimum amount of soil Cd belonged to J_3 (0.0054 mg/kg) during winter. During summer and winter, the minimum amounts of soil Cd was found in J_3 (0.0096 mg/kg) and J_2 (0.0086 mg/kg), respectively.

Fig. 2b gives Ni content in sediments of six freshwater wetlands during three seasons. The highest amount of Ni was found in J_1 (1.19 mg/kg) during summer and the lowest amount in wetland S (0.35 mg/kg) during winter. The maximum amount of Ni belonged to J_3 (1.28 mg/kg) during rainy season, followed by 1.01 mg/kg, 0.96 mg/kg, 0.86 mg/kg, 0.72 mg/kg, and 0.6 mg/kg in wetland J_2, B, N, J, and S, respectively. The concentration of Ni in the soils of the studied wetlands was low, because of the absence of any Ni-contamination sources in the surrounding areas of these wetlands.

Fig. 2c shows manganese (Mn) contents in sediments of six freshwater wetlands at three different seasons, demonstrating that the range of soil Mn varied from 35 to 275.04 mg/kg as either the sites or the seasons altered. During summer, the maximum and the minimum amounts of soil Mn belonged to J_2 (275.04 mg/kg) and N (35.76 mg/kg), respectively. In the rainy season, however, the highest amount of Mn was recorded in J_1 (148.08 mg/kg), followed by the other wetlands in the following order: $J_2 > J_3$, S > N > B. And in winter, the maximum and the minimum amounts of soil Mn were observed in J_1 (259.2 mg/kg) and N (35.0 mg/kg), respectively.

Fig. 2d presents the seasonal contents of soil lead (Pb) in six freshwater wetlands. Among the seasons and the sites, the highest amount of soil Pb was found in J_2 (3.93 mg/kg) and the lowest amount in N (1.82 mg/kg) during summer, while during the rainy season, the maximum amount of soil Pb belonged to J_1, followed by the wetlands of S, J_2, J_3, B, and N. During winter, the maximum amount of Pb was recorded in J_2 (3.17 mg/kg), followed by the other wetlands in the following order: $J_3 > J_1 >$ B > N > S. The highest amount of soil Pb (3.93 mg/kg) was found in J_2 during summer; the amount gradually decreased from summer to rainy season then to slightly increase in winter.

Fig. 2e illustrates the levels of Fe in sediments of six wetland during the investigation period. The values of Fe varied from 955.94 mg/kg to 115.6 mg/kg for all wetlands as well as seasons. During rainy season, the amount of soil Fe decreased in wetland J_1 and B, as compared to summer, yet it increased during winter. On the other hand, soil Fe content was found to ascend during the rainy season in wetlands J_2, J_3, S, and N, as compared to summer; however, it decreased during winter.

Fig. 2f shows Zinc (Zn) content of the sediments in wetlands. The content of soil Zn varied with the change of season as well as the sites, making Zn range between 12.54 mg/kg in wetland S and 0.77 mg/kg in J_1 during rainy season. During summer, the maximum soil Zn was found in S (7.08 mg/kg) followed by the other wetlands in the following order: $J_2 >$ B $> J_1 >$ N $> J_3$. During winter, the maximum soil Zn was recorded in J_1 (3.27 mg/kg), followed by other wetlands as $J_2 >$ N > B > S $> J_3$.

In the studied wetlands, soil Cu ranged from 4.11 to 19.17 mg/kg (Fig. 2g). During rainy season, the maximum and minimum contents of soil Cu belonged to wetland S (19.17 mg/kg) and J_1 (6.29 mg/kg), respectively. During summer, however, the maximum soil Cu was found in wetland N (15.98 mg/kg), followed by $J_2 > J_1 >$ S > B $> J_3$. During winter, the highest and the lowest amounts of soil Cu were found in wetlands N and J_2, respectively.

Table 5 shows the mean concentration of heavy metals, recorded in sediment samples of the wetlands of Greater Dhaka District (GDD), Bangladesh, along with Anzali wetland, Iran (Esmaeilzadeh et al., 2016b), limnetic ecosystem, Eastern China (Tang et al., 2014), Baiyangdian Lake, China (Gao et al., 2013), and Fusaro Lagoon, Southern Italy (Arienzo et al., 2014). The concentration of all studied metals in sediments were lower than the ones, recorded in Anzali wetland in Iran, limnetic ecosystem in Eastern China, Baiyangdian Lake in China, and Fusaro Lagoon in Southern Italy.

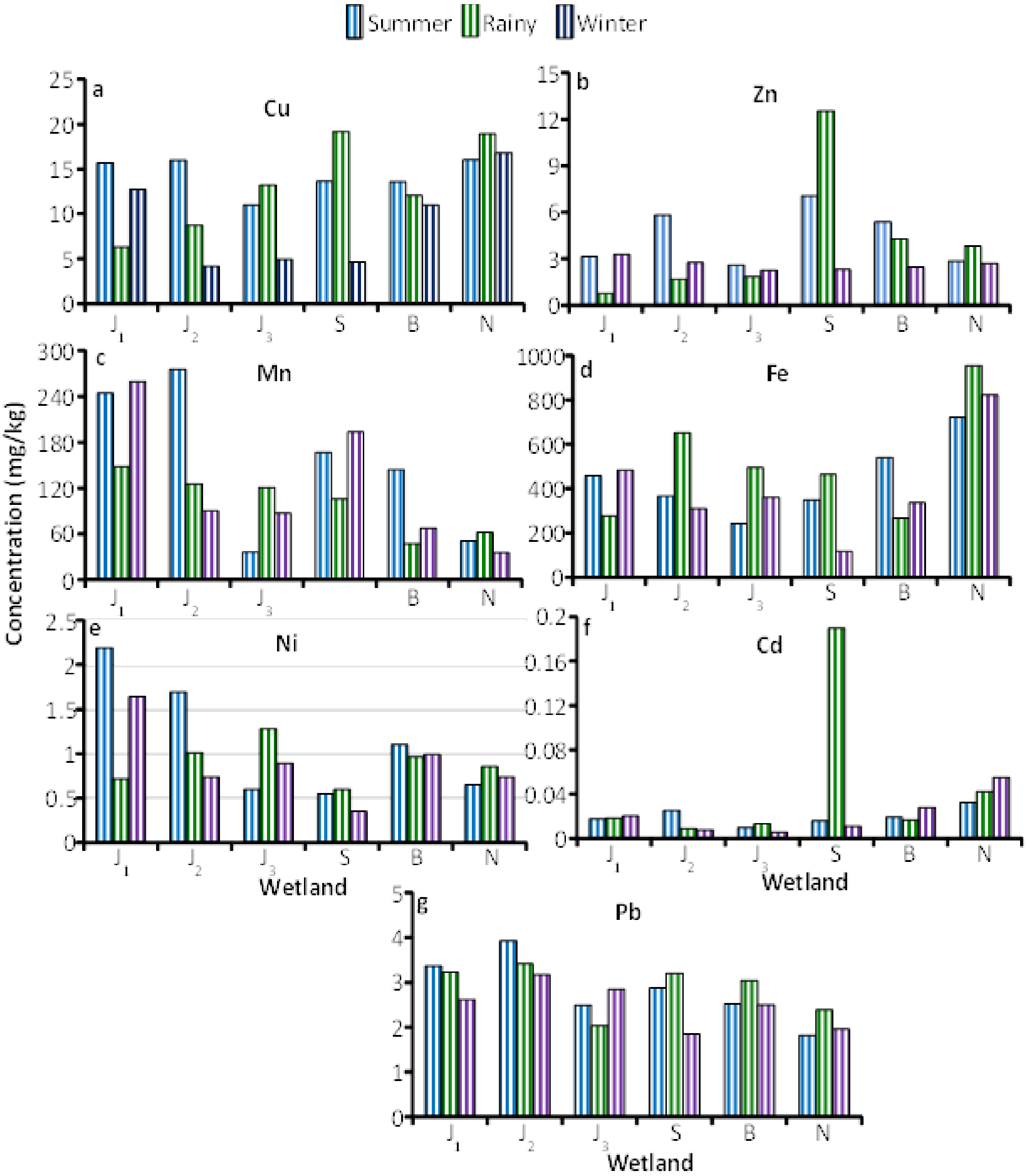

Fig. 2. Heavy metals in the sediment of six freshwater wetlands of greater Dhaka district, Bangladesh during summer, rainy season, and winter with concentrations of (a) Cu, (b) Zn, (c) Mn, (d) Fe, (e) Ni, (f) Cd, and (g) Pb. Wetlands J_1, J_2 and J_3 are located in Jahangirnagar University, S lies in Dogarmara, Savar; B is located at Baipail, Dhamsona, Savar; and N is in Guptapara, Shibpur, Narsingdi.

Table 5. Comparison of heavy metal concentration in wetlands' sediments of greater Dhaka district (GDD), Bangladesh and other locations of the world

Cd (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Pb (mg/kg)	Wetland
0.03	125.25	0.98	3.75	12.09	455.21	2.72	GDD, Bangladesh; current study
0.38	1270	89	120	55	–	24	Anzali wetland, Iran; Esmaeilzadeh et al., 2016b
0.93	–	60.5	192	54.7	–	61.9	Limnetic Ecosystem, Eastern China; Tang et al., 2014
0.67	–	44	129	43	–	31	Baiyangdian Lake, China; Gao et al., 2013
71	351	157	251	103	–	–	Fusaro Lagoon, Southern Italy; Arienzo et al., 2014

Geo-accumulation Factor

Table 6 gives the I_{geo} values of the heavy metals in wetland sediments of greater Dhaka district (GDD). I_{geo} for Cd indicates practically unpolluted condition in all studied wetlands, while Mn can be considered to be strongly to extremely polluted in all wetlands except J_1 where I_{geo} stands for extremely polluted condition. I_{geo} values for Ni and Pb show moderately polluted conditions, whereas those of Zn and Cu suggest a moderately to strongly polluted condition. I_{geo} values for Fe suggests extremely polluted condition in wetlands.

Contamination Factor (CF) and Contamination Degree (C_d)

CF values for heavy metals in wetland sediments were below 1, indicating low contamination during the study period (Table 7). In addition, $C_d < 6$ ($C_d = 4.28$) indicates low degree of heavy metal contamination over the studied wetlands during the study period.

Table 6. I_{geo} values for heavy metals in GDD wetlands' sediments

	I_{geo}						
Wetland	**Cd**	**Mn**	**Ni**	**Zn**	**Cu**	**Fe**	**Pb**
J_3	0	4.66	1.62	2.15	2.46	7.06	1.51
J_1	0	5.09	1.84	2.18	2.54	7.10	1.61
J_2	0	4.97	1.72	2.33	2.46	7.14	1.66
S	0	4.94	1.35	2.66	2.57	6.99	1.55
B	0	4.69	1.66	2.41	2.56	7.08	1.55
N	0	4.44	1.53	2.29	2.71	7.42	1.44

Table 7. CF and C_d values for heavy metals in sediments of GDD wetlands

	CF							C_d
Wetland	**Cd**	**Mn**	**Ni**	**Zn**	**Cu**	**Fe**	**Pb**	
J_3	0.03	0.09	0.01	0.02	0.22	0.007	0.12	4.28
J_1	0.06	0.26	0.02	0.03	0.26	0.008	0.15	
J_2	0.05	0.19	0.02	0.04	0.21	0.009	0.17	
S	0.24	0.18	0.01	0.08	0.28	0.006	0.13	
B	0.07	0.10	0.01	0.05	0.27	0.008	0.13	
N	0.14	0.06	0.01	0.03	0.38	0.018	0.10	

Enrichment Factor (EF)

The enrichment factors of heavy metals in the sediments indicated that Cd's enrichment in sediments of wetlands J_3 (EF = 3.88) and J_2 (EF = 4.99) was moderate; in J_1 (EF = 7.39), B (EF = 8.7), and N (EF = 8.13), significant; and in S (EF = 36.72), extremely high (Table 8). The EF values of Mn showed moderate enrichment in sediments of wetland N (EF = 3.27) and significant enrichment in wetlands J_3 (EF = 12.33) and B (EF = 12.55). On the contrary EF values for Mn in sediments of wetlands J_1 (EF = 29.8), J_2 (EF = 20.58), and S (EF = 27.9) showed an extremely high enrichment. The EF values for Ni in sediments of wetlands S and N indicate deficiency to minimal enrichment, whereas in sediments of wetlands EF they suggest moderate enrichment. The low EF value (EF < 2) for Ni shows that this metal was probably originated from a natural source. The EF for Zn in sediments of wetland N (EF = 1.86) indicates deficiency to minimum enrichment, while in sediments of wetlands J_1, J_2, and J_3 it suggests moderate enrichment and in sediments of wetlands S and B, significant enrichment. Cu had extremely high enrichment in the sediments of wetland S (EF = 42.41) and very high enrichment in sediments of wetlands J_2 (EF = 22.7), J_3 (EF = 27.8), B (EF = 33.76), and N (EF = 27.8). Its enrichment in the sediments of wetland J_1

(EF = 15.14) was also significant. However, Pb enrichment was significant in the sediments of all studied wetlands, except for wetland S, where it was very high (Table 8).

Wetlands are made up of a mixture of soil, water, and micro and macro flora and fauna. The growth and development of hydrophytes depend on the nutritional status of soil and water. Thus, abundance of rooted floating and emergent amphibious hydrophytes depend on soil nutrients as well as water quality and other environmental factors. The current investigation determined the amount of Cd, Mn, Ni, Zn, Cu, Fe, and Pb in the soil of six freshwater wetlands of greater Dhaka district. Soil's heavy metals like Cu, Zn, and Ni varied from 4.11 to 19.17 mg/kg, 0.77 to 12.54 mg/kg, and 0.35 to 2.19 mg/kg, respectively (Fig. 2a, b, e). But these micro-elements did not vary significantly as either seasons or the sites changed. The contents of Pb in soils of wetlands ranged between 1.82 and 3.93 mg/kg (Fig. 2g). Among six freshwater wetlands, the highest amount of Pb (3.93 mg/kg) belonged to J_2, which was adjacent to the main bus stop of Jahangirnagar University. Presumably, Pb accumulation in the soil of this particular site could be related to garage washouts and vehicular cleanings.

Table 9 shows the pollution indices for heavy metal concentration in sediments of wetlands of Greater Dhaka District (GDD), Bangladesh, as well as other studies in sediments of Anzali wetland and Hara Biosphere Reserve of Iran. Igeo for Cd indicates an unpolluted condition in wetlands of GDD, yet a moderately to strongly-polluted one in Anzali and moderately polluted in Hara Biosphere Reserve (Hargalani et al., 2014; Nowrouzi and Pourkhabbaz, 2014). Igeo for Mn suggests a strongly to extremely-polluted condition in wetlands of GDD, but an unpolluted to moderately-polluted one in Anzali wetland. Igeo for Ni and Pb indicates a moderately polluted condition in wetlands of GDD, but an unpolluted to moderately-polluted one in sediments of both Anzali and Hara Biosphere Reserve, as well as a practically unpolluted condition of Ni in sediments of Hara Biosphere Reserve.

Overall Enrichment Factors (EF) of heavy metals in the sediments of GDD wetlands for Cd, Mn, and Pb suggested significant enrichment, being equal to 11.64, 11.74, and 15.78, respectively. As for Cu, EF = 27.22 indicated very high enrichment, whereas in case of Cd in the sediments of Anzali wetland (EF=8.54) and Hara Biosphere Reserve (EF=16.91), it was shown that the enrichment had been significant (Table 9); however, the EF of 2.73 for Mn indicated moderate enrichment in sediments of Anzali wetland. In sediments of wetlands of GDD, Ni (EF=1.91) had deficiency to minimal enrichment, whereas Ni (EF=2.16) had moderate enrichment in Anzali wetland and deficiency to minimal enrichment in sediments of Hara Biosphere Reserve (Ni, EF=1.62). Also, the EF of 4.79 for Zn in sediments of GDD wetlands indicated moderate enrichment. On the contrary, in sediments of Anzali wetland, enrichment of Zn indicated some deficiency to minimal, having an EF of 1.63.

Table 8. EF values of heavy the metals in sediments of GDD wetlands

		EF				
Wetland	**Cd**	**Mn**	**Ni**	**Zn**	**Cu**	**Pb**
J_3	3.88	12.33	2.06	3.04	27.8	15.88
J_1	7.39	29.8	3.05	2.94	15.14	17.91
J_2	4.99	20.58	2.11	3.84	22.77	18.19
S	36.72	27.9	1.32	11.77	42.41	20.2
B	8.7	12.55	2.18	5.29	33.76	16.68
N	8.13	3.27	0.73	1.86	21.46	5.82

Table 9. Comparison among pollution indices for heavy metal concentration in sediments of wetlands of Greater Dhaka District (GDD), Bangladesh with other studies

Metals	Igeo this study	Igeo Anzali wetland	Igeo Hara Biosphere	CF this study	EF this study	EF Anzali wetland	EF Hara Biosphere
Cd	0	2.13	1.36	0.09	11.64	8.54	16.91
Mn	4.8	0.35	–	0.15	17.74	2.73	–
Ni	1.62	0.39	0	0.01	1.91	2.16	1.62
Zn	2.34	0	–	0.04	4.79	1.63	–
Cu	2.55	0	–	0.27	27.22	0.84	–
Fe	7.13	–	–	0.01	–	–	–
Pb	1.55	0.16	0.28	0.14	15.78	2.8	2.7

The highest amount of soil Fe was found in wetland N (955.94 mg/kg) and the lowest in wetland S (115.6 mg/kg). No significant variation of soil available Fe was noted for different seasons, though it varied significantly at different sites ($F = 5.0248^*$, $p \leqslant 0.05$) (Table 10). DMRT showed significant differences in average soil Fe content of freshwater wetlands for the pairs of N and S, N and J_3, N and B, N and J_1, and N and J_2, with the exception of other habitat pairs (sites).

The content of soil Mn varied from 35 to 275.04 mg/kg in the studied wetlands during different seasons. Habitat variation of soil Mn of six freshwater wetlands was found to be significant ($F = 3.787^*$, $p \leqslant 0.05$) (Table 11). After DMRT, the significant differences of soil Mn contents belonged to the following pairs of wetlands: J_1 and N, J_1 and J_3, J_1 and B, and J_2 and N, while the remaining pairs of wetlands did not differ significantly.

The content of soil Cd ranged between 0.055 mg/kg and 0.0054 mg/kg. Spatial variation of soil Cd was found to be significant ($F = 110.9^*$, $p \leqslant 0.05$) (Table 12). Multiple comparisons (DMRT) indicated significant differences in average soil Cd content of freshwater wetlands in all pairs of habitats, except wetlands B and J_1, J_1 and S, and S and J_3. Furthermore, it was found that the seasonal variation of soil Cd of six freshwater wetlands were significant ($F = 85.2^*$, $p \leqslant 0.05$) with soil Cd recorded as the highest amount in the rural wetland N, which was surrounded by agricultural fields. Cd entered soil in nearby agricultural fields where phosphorus fertilizers (phosphate and superphosphate) were being used (Stevenson, 1986).

Spatial Comparison of Heavy Metals' Content in the Soil of J_3 with Other Five Wetlands J_1, J_2, S, B, and N

Compared to J_3, which was located within the conserved area at Botanical Garden of Jahangirnagar University, the content of soil Cd increased significantly in J_1 ($p = 0.016$), B ($p = 0.045$), and N ($p = 0.009$). Mn content increased significantly in J_1 ($p = 0.033$), whereas in N, it was the content of Cu to follow such an example, increasing significantly with $p = 0.045$. Also, Fe increased significantly in N ($p = 0.010$) and Pb in J_2 ($p = 0.031$), in comparison to the control (Table 13).

Table 10. ANOVA of soil Fe in six wetlands during summer, rainy season, and winter

Sources of Variation	D.F	SS	MSS	Fcalculated	F0.05
Seasons	2	39864.623	19932.312	0.9268	4.1
Locations	5	540317.37	108063.47	5.0248*	3.33
Errors	10	215061.22	21506.12		
Total	17	795243.2			

*p⩽0.05

Table 11. ANOVA of soil Mn in six wetlands during summer, rainy season, and winter

Sources of Variation	D.F	SS	MSS	Fcalculated	F0.05
Seasons	2	8049.389	4024.6945	1.2629	4.1
Locations	5	60340.23	12068.045	3.787*	3.33
Errors	10	31866.18	3186.6179		
Total	17	100255.8			

*p⩽0.05

Table 12. ANOVA of soil Cd in six wetlands during summer, rainy season, and winter

Sources of Variation	D.F	SS	MSS	Fcalculated	F0.05
Seasons	2	0.001109	0.000055	110.9*	4.1
Locations	5	0.00213	0.0000426	85.2*	3.33
Errors	10	0.00005	0.00005		
Total	17	0.00275			

*p⩽0.05

Table 13. Comparison of heavy metal contents in soils of wetland J_3 as the control habitat with other five wetlands J_1, J_2, S, B, and N in Greater Dhaka District (Mean±SEM, t/p, n = 3)

Wetland	Heavy metals (mg/kg)						
	Cd	Mn	Ni	Zn	Cu	Fe	Pb
J_3	0.009±0.002	81.093±24.673	0.923±0.197	2.233±0.211	9.680±2.469	365.160±73.172	2.457±0.232
J_1	0.019±0.001	217.093±34.785	1.517±0.429	2.393±0.813	11.550±2.767	404.527±65.108	3.070±0.228
t/p	-4.031/0.016*	-3.189/0.033*	-1.257/0.277	-0.191/0.865	-0.504/0.641	-0.402/0.708	-1.887/0.132
J_2	0.014±0.006	163.573±56.644	1.147±0.283	3.410±1.239	9.583±3.450	441.367±105.766	3.503±0.224
t/p	-0.722/0.511	-1.335/0.253	-0.648/0.552	-0.936/0.402	0.023/0.983	-0.593/0.585	-3.247/0.031*
S	0.072±0.059	154.987±26.000	0.500±0.076	7.307±2.958	12.473±4.239	308.483±102.068	2.640±0.406
t/p	-1.064/0347	-2.062/0.108	2.004/0.116	-1.711/0.162	-0.569/0.600	0.451/0.675	-0.392/0.715
B	0.021±0.004	85.786±29.809	1.017±0.043	4.047±0.860	12.220±0.758	379.700±81.338	2.683±0.179
t/p	-2.883/0.045*	-0.121/0.909	-0.463/0.667	-2.047/0.110	-0.983/0.381	-0.133/0.901	-0.775/0.481
N	0.043±0.007	48.960±7.727	0.750±0.061	3.113±0.346	17.227±0.869	832.047±68.367	2.053±0.172
t/p	-4.823/0.009**	1.243/0.282	0.841/0.448	-2.173/0.095	-2.883/0.045*	-4.662/0.010*	1.397/0.235

*p⩽0.05, **p⩽0.001

The most widely-occurring rooted hydrophyte in the wetland S was *Nymphaea pubescens* during rainy season. In this wetland during rainy season the contents of Zn, Cu, Cd, and Pb in the sediment were 12.54 mg/kg, 19.17 mg/kg, 0.19 mg/kg, and 3.20 mg/kg, respectively. The contents of Zn, Cu, Cd, and Pb in the sediments of the wetland S were higher in comparison to other wetlands and seasons. Washings cars and garages as well as adjoining small industries are the probable causes of high contents of Zn, Cu, Cd, and Pb in the soil of this wetland. The wetland S is located adjacent to Dhaka – Aricha Highway, being a seasonal wetland that dried out during summer. During summer, particulate Pb from automobile exhausts can settle on the soil along the highways with heavy automobile traffic.

CONCLUSION

In the studied wetlands' soil heavy metals like Fe, Mn, and Cd varied spatially, while Cd differed temporally in the studied wetlands. The findings indicated anthropogenic influences in wetlands. The I_{geo} for Mn indicated a strongly to extremely polluted condition in the wetlands, whereas I_{geo} for Ni and Pb showed moderately polluted condition. What is more, I_{geo} for Zn and Cu suggested moderately to strongly polluted condition, and for Fe, it was indicative of extremely polluted condition in the wetlands. However, the CF values for heavy metals in soils were below 1, indicating low contamination. In addition, the C_d below 6, indicated low degrees of heavy metal contamination in the studied wetlands. The EF values for heavy metals in sediments of wetlands were ranked in the following order: Cu>Mn>Pb>Cd>Zn>Ni, suggesting that sediment samples had very high enrichment with Cu, while Mn, Pb, and Cd just exhibited significant enrichment. In the studied wetlands, EF for Zn and Ni showed moderate and deficiency to minimal enrichment, respectively.

The implications of these findings can be used as baseline information to monitor and assess the degree of sediment pollution in lentic wetlands. However, the species *N. pubescens*, a commonly occurring rooted attached hydrophyte of the seasonal wetland S, could be considered a pollution indicator, as it grows profusely in heavy-metal-rich soils of aquatic ecosystem. The rooted attached hydrophyte *N. pubescens* grew only in this wetland, where other rooted attached species grew in smaller numbers. Its mechanism of metal tolerance, whether by exclusion or accumulation, still needs further investigation.

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