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Assessment of Heavy Metals Pollution in Bottom Sediment of the Buriganga River, Dhaka, Bangladesh by Multivariate Statistical Analysis

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Abstract

Heavy metals (Pb, As, Zn, Cu, Ni, Co and Cd) concentrations are determined from the Buriganga riverbed sediments to evaluate their levels and the distribution by using X-ray fluorescence spectroscopy (XRF). The average concentrations of heavy metals Pb, As, Zn, Cu, Ni, Co and Cd are 4.00, 34.90, 50.70, 49.80, 64.50, 8.90 and 1.17 mg/kg, respectively in river sediments. The average concentration of As, Cu, Ni, Co and Cd exceeds the threshold effect level of Canadian sediment quality guideline in relation to river sediment. Hence, the high concentration of these heavy metals in river sediments may cause serious threat to the aquatic environment and the public health of adjacent people. The order of heavy metal abundances is Ni > Zn > Cu > As > Co> Pb > Cd in present study. Multivariate statistical analyses such as principal component analysis, cluster analysis and correlation matrix shows significant anthropogenic and geogenic intrusions of Pb, As, Zn, Cu, Ni, Co and Cd in river sediments. Significant positive correlation between Co vs. Ni, Cd vs. Zn and Co vs. As indicates their common origin especially from industrial effluents, municipal wastes and agricultural inputs which are responsible to enrich these variables in river sediments. On the other hand, significant negative correlation between Cu vs. As, Pb vs. As, Co vs. Cd and Co vs. As indicates the anthropogenic and geogenic sources of these variables.

Keywords: River bed sediment, heavy metals, multivariate statistical analysis.

Introduction

The weathered river sediments is a major transporter of heavy metals in the aquatic environment where the physicochemical processes like precipitation, adsorption, chelating etc. are involved in their association[1]. River plays an important role in assimilation or carrying off the municipal and industrial wastewater and runoff from agricultural land. Heavy Metals are natural compounded elements occurring in the environment and different in concentrations along the earth crust. Dissimilar to organic polymerized toxins it can be degraded slowly by biological or chemical processes; therefore heavy metals are considered to be non-degradable pollutants[2]. Although metals are natural constituents of our earth and are present in all environs, but their concentrations are drastically altered by man-made actions. The natural distributions of metals have been distressed in terrestrial and aquatic environment due to industrialization and urbanization in last few decades[3]. Moreover unwanted and undesirable metal levels adversely affect the ecosystems. Sources of these elements in soils mainly include natural occurrence derived from parent materials and anthropogenic activities. Anthropogenic inputs are associated with industrialization and agricultural activates deposition such as atmospheric deposition, waste disposal and waste incineration, emissions from traffic, fertilizer application and long-term application of wastewater in agricultural land[4].

In current decades, the heavy metal accumulation in the soils is a growing concern due to its potential health risks as well as its detrimental effects on soil ecosystems[4]. Heavy metals are non-biodegradable[5] and they can be necessary or beneficial to plants at certain levels but can be toxic when they exceed the specific thresholds level[4]. These toxic heavy metals when released in aquatic environment may enter into the food chain through bio-magnification which may cause various health problems in humans and animals. The objectives of this study are to investigate the levels of heavy metals content in river sediment and to evaluate the sediment quality in terms of heavy metals concentration in the study area.

Material and Methods

Study Area: The study area is lies between 23^0 45′ to 23^0 42′ North latitude and 90^0 19′ to 90^0 22′ East longitude (figure-1). The Buriganga River is feed mainly by the Turag River which receives flows from local rainfall and spill flows from the left bank of the Jamuna River. The lower reaches of the Dhaleswari-Buriganga-Lakhya system are tidal during the dry season when upstream inflows are minimal. The study area encompass places such as Dhanmondi and Mohammadpur which are some of the major populated areas of Dhaka city, while at the same time Hazaribagh next to the Buriganga river is Dhaka city's tannery hub.

Sample Collection: Sediment samples were collected from ten (10) different locations by using clean stainless steel (figure-1). The geographical location of each sampling point was determined with the help of a GARMIN handheld GPS receiver. Bottom sediment samples were coded as BR-01, BR-02, BR-03, BR-04, BR-05, BR-06, BR-07, BR-08, BR-09 and BR-10. About 1 kg of sample was taken for each sample from bank of river at the depth of 20 to 100 cm and kept in polythene bags with designated sampling location, date and sample ID.

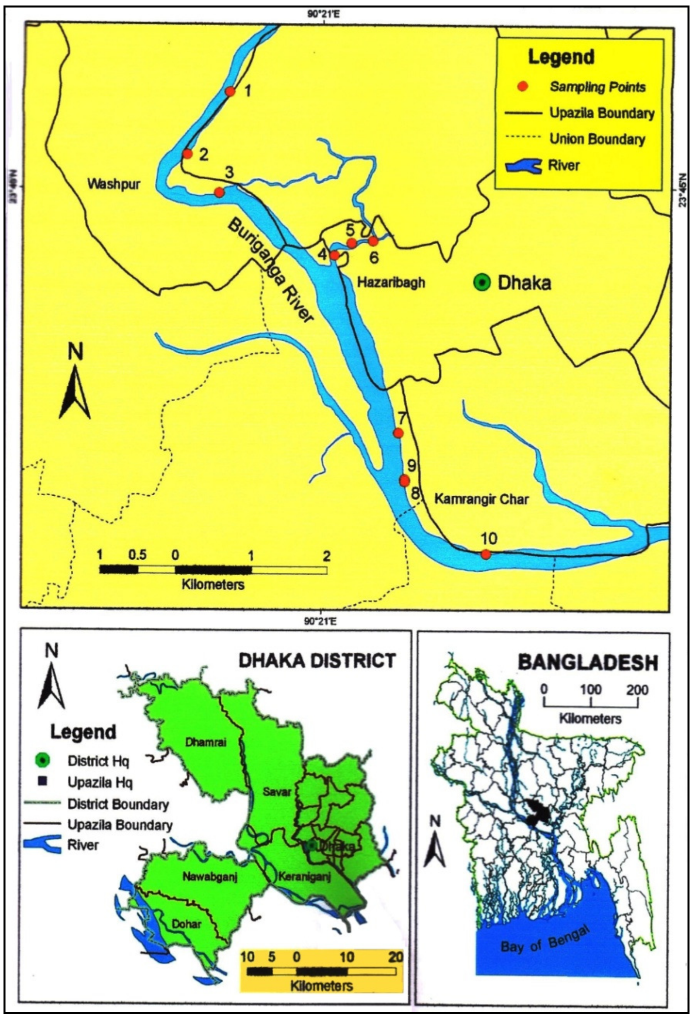

Figure-1
Locations of sampling points in study area

Measurement of Physicochemical Parameters: For the determination of pH, 10 gm of air-dried sample was mixed with 25 mL distilled water (soil: water at a ratio of 1:2.5) then the solution was stirred thoroughly and after 25-30 minutes the reading was taken[6]. For Electrical Conductivity (EC) measurement, 10 gm air dried sample was taken and then mixed with 40 ml of deionized water in a biker (soil: water at a ratio of 1:40) and after stirring of 30 minutes reading was taken[7]. In this study TOC was measured by dry combustion method following the equation 1[8].

$$\mathrm{TOC} = \frac{\text{Final Sample Weight} - \text{Initial Sample Weight}}{\text{Initial Sample Weight}} \times 100\%. \tag{1}$$

Elemental Analysis by XRF: Total concentrations of geochemical chemical variables in soil samples were measured by X-ray fluorescence spectroscopy (XRF) at the Institute of Mining, Mineralogy and Metallurgy, Bangladesh Council of Scientific and Industrial Research (BCSIR), Joypurhat following the procedures outlined by Qishlaqi A. and Farid Moore F.[9] through using Rigaku ZSX Primus XRF machine equipped with an end window 4 kW Rh-anode X-ray tube. The samples were mixed with binder (steric acid: sample at a ratio of 1:10) and pulverized for two minutes. The resulting mixture was spooned into an aluminum cap (30 mm). The cap was sandwiched between two tungsten carbide pellets using a manual hydraulic press with 10 tons/sq.in for 2 minutes and finally pressure was released slowly. Measurements of major and trace elements were carried out using 40 kV voltage and 60 mA current and 30 kV voltage and 100 mA current, respectively. The Geological Survey of Japan (GSJ) stream sediments (JSD) series have been used as a standard in the analyses and the precision is found better than ±5% for all analyzed elements.

Statistical Analysis: By following the theories and methodologies stated by Dreher T.[10], Principal Component Analysis (PCA) has been done on the original data set (without any weighting or standardization) where a Varimax normalized rotation is applied to minimize the variances of the factor loadings across the variables for each factor. Cluster Analysis (CA) has been performed on chemical parameters on both data sets using the weight-pair group average based on Pearson coefficient. In this study, cluster analysis has been performed in wards mode by Statistica 7 for the analysis of heavy metals in sediment samples[7]. Pearson's product moment correlation matrix has been used to identify the relationship among the metals to support the results obtained by multivariate analysis[11-12].

Results and Discussion

The physicochemical parameters in selected river sediment samples are presented in table-1. With regards to physical parameters, pH value of sediment samples varies from 5.36 to 7.43 with an average value of 6.65. The average value of pH 6.65 suggests slightly acidic to moderately acidic conditions for all the sediment samples. Electrical conductivity (EC) of river sediment varies from 19.96 to 347 µS/cm with an average value of 143.39 µS/cm. The high values of EC could be the result of high concentration of soluble salts discharging from tannery effluent or chemicals from nearby industries into low land and surface water bodies of the area. TOC content in collected sediment sample varies from 0.16 to 4.50 % with an average value of 0.70%.

Table-1
Physicochemical parameters in Buriganga river sediments

Sample ID	Moisture Content (%)	TOC %	pH	EC (μs/cm)
BR-1	1.13	0.21	7.22	19.96
BR-2	0.61	0.17	7.02	91.7
BR-3	0.92	0.24	6.00	80.5
BR-4	1.98	0.30	7.31	145.4
BR-5	1.58	0.34	7.35	95.6
BR-6	3.25	0.64	7.43	347.0
BR-7	2.38	4.50	7.05	293.0
BR-8	0.61	0.19	6.25	177.7
BR-9	0.08	0.23	5.46	102.3
BR-10	0.09	0.16	5.36	80.7
Max	3.25	4.50	7.43	347.0
Min	0.08	0.16	5.36	19.96
Average	1.263	0.70	6.65	143.39

The analyzed heavy metals concentration in river bed sediment is shown in table 2**.** The concentrations of heavy metals Pb, As, Zn, Cu, Ni, Co and Cd in studied sediments and the worldwide threshold effect level concentration for sediments[13] is presented in table-2 to compare with present average value in this section because of their significance to health and environment in the study area. From comparison it can be said that except Pb and Zn, the average concentration of heavy metals As, Cu, Ni and Cd in this study exceeds the Canadian sediment quality recommended threshold effect level concentration. The average concentrations of heavy metals Pb, As, Zn, Cu, Ni, Co and Cd are 4.00, 34.90, 50.70, 49.80, 64.50, 8.90 and 1.17 mg/kg, respectively and the order of heavy metal abundances is Ni > Zn > Cu > As > Co> Pb > Cd in present study. This elevated concentration of heavy metals in sediment may be harmful for the human health and environment because the investigated metals have been considered as carcinogen and their abundance in soil may directly or indirectly be attributed to food chain contamination[14].

Table-2
Concentration of heavy metals (mg/kg) in sediment

Sample ID	Pb	As	Zn	Cu	Ni	Co	Cd
BR-01	3	46	60	39	126	13	-
BR-02	2	41	61	16	75	8	2
BR-03	1	44	43	36	96	13	1
BR-04	1	37	8	34	56	8	1
BR-05	1	38	17	38	74	9	1
BR-06	1	35	184	70	12	3	2
BR-07	19	19	62	46	34	9	1
BR-08	9	11	29	111	69	8	1
BR-09	2	45	5	34	21	9	1
BR-10	1	33	38	74	82	9	2
Maximum	19	34.9	184	111	126	13	2
Minimum	1	11	5	16	12	3	1
Average	4.00	34.90	50.70	49.80	64.50	8.90	1.17
TEL	35	5.9	123	35.7	18	-	0.6
(TEL-Threshold Effect Level from Canadian sediment quality guidelines)							

The author terminate that high levels of these metals in sediments may be obtained from indiscriminate disposal of industrial, agricultural and domestic wastes which can move towards main river watercourse through surface runoff and can be settled at the river bed. Besides, adjacent area of river is well cultivated where the use of organometallic chemicals as pesticide is common and the washing of automobiles near the river may also increase the heavy metal concentration in river sediments. Therefore, the heavy metal concentration is so high to damage the river ecosystem and the accumulation of heavy metals in sediments can be a source of water pollution in study area.

Correlation Matrix: In geo-environment, inter-element relationships in sediment matrix provide information on sources and pathways of variables. In general, correlations between heavy metals agreed with the results obtained by PCA and CA which are useful to confirm some new associations between parameters. According to the values of correlation coefficients in river sediment in table-3, a significant positive correlation exists between Co vs. Ni (0.77), Cd vs. Zn (0.42) and Co vs. As (0.33). The strong correlation among these variables indicates their common origin especially from industrial effluents, municipal wastes and agricultural inputs that are responsible to enrich these variables in river sediments. The significant positive correlation of this heavy metal indicates that the variables may derive from similar sources as moving together. On the other hand, significant negative correlations are also found between Cu vs. As (-0.75), Pb vs. As (-0.73), Co vs. Cd (-0.68) and Co vs. As (-0.57) in river sediment, which indicates the anthropogenic and geogenic sources of these variables.

Table-3
Correlation matrix of heavy metals in sediment

	Cu	As	Ni	Zn	Co	Pb	Cd
Cu	1.00						
As	-0.75	1.00					
Ni	-0.11	0.26	1.00				
Zn	0.19	-0.03	-0.32	1.00			
Co	-0.33	0.33	0.77	-0.57	1.00		
Pb	0.24	-0.73	-0.23	0.00	0.01	1.00	
Cd	0.14	-0.10	-0.43	0.42	-0.68	-0.21	1.00

Principal Component Analysis: In PCA analysis Eigen values greater than 0.88 are taken into account. Here, three PCs are extracted by using correlation matrix which reflects the processes influencing the heavy metals composition having 82.52 % of total sample variance (table-4). The total variance explanations of the PCs are 42.22%, 27.73% and 12.57% for PC 1, PC 2 and PC 3 respectively. PC 1 is strongly correlated with Cd, Zn, Cu and PC 2 with Pb. PC 1 is also seen to be negatively correlated with As, Ni and Co and PC 2 with As and Cd. On contrary, PC 3 is mainly precipitated in Cu and Ni in river sediment and negatively precipitated in Pb. The source of PC 1 loading variables can be considered as mixed source from anthropogenic inputs particularly from industrial effluents and agricultural activities in the study area. On the contrary PC 2 and PC 3 can be considered as assorted source from both lithogenic and anthropogenic inputs.

Table-4
Component matrix of three factor model with moderate to strong loadings in river sediment

Parameters	PC 1	PC 2	PC 3
Cu	0.58	0.49	0.60
As	-0.64	-0.74	-0.08
Ni	-0.75	0.20	0.53
Zn	0.59	-0.37	0.14
Co	-0.89	0.34	0.05
Pb	0.33	0.77	-0.44
Cd	0.64	-0.52	0.15
Eigen value	2.96	1.94	0.88
% Total variance	42.22	27.73	12.57
Cumulative %	42.22	69.95	82.52

A Cluster Analysis (CA) is carried out to visualize the groupings in measured variables of river sediment. The result of Cluster Analysis (CA) is shown in figure-2. Here, two distinct clusters which closely relate the group of trace elements are evident: (1) Co, Ni and As and (2) Cd, Zn, Pb and Cu. Each of these clusters is decoupled from one another and the rest of the parameters form their own cluster. Co and Ni form a cluster which further sub-cluster with As. At the same time Cd and Zn form a cluster and sub-clustering with Pb and Cu. The cluster of Co, Ni and As join with Cd, Zn, Pb and Cu in river sediment. Parameters belong to the same clusters or groups are likely to be originated from a common source[7,11].

Conclusion

The results of the study revealed that sediment in Buriganga River are considerably contaminated by heavy metals like As, Cu, Ni, Co and Cd as the concentrations exceeds the threshold average values of Canadian sediment quality guideline which may give rise to various health hazards. The significantly positive correlation of Co vs. Ni, Cd vs. Zn and Co vs. As in river sediment indicates that these variables may be derived from common origin especially from industrial effluents, municipal waste and agricultural inputs. This study demonstrates As, Cu, Ni, Co and Cd as major pollutants due to its high concentration levels while Pb and Zn is appeared as minor pollutants. The PCA results suggest that the studied heavy metals in river sediments are of anthropogenic origin and cluster analysis also confirms the PCA results. PC 1 is loaded with Cd, Zn, Cu; PC 2 with Pb and PC 3 with Cu and Ni in river sediment. The source of PC 1 loading variables can be considered as mixed source of anthropogenic inputs particularly from industrial effluents, municipal waste and agricultural activities in the study area. On the contrary PC 2 and PC 3 can be considered as assorted source from both lithogenic and anthropogenic inputs.

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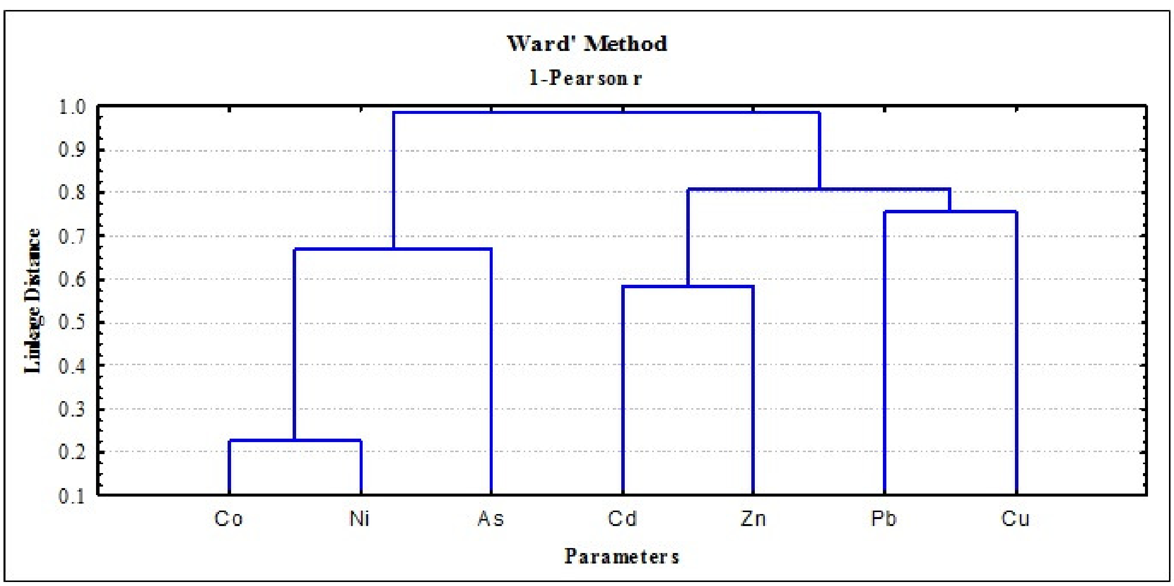

Figure-2
Cluster analysis based on heavy metal concentrations in river sediment

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