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Status of Heavy Metals in Water and Sediment of the Meghna River, Bangladesh

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Abstract: The pollution of river water and sediments by heavy metals has assumed serious problems due to their toxicity and accumulative behavior. The present study has been undertaken to assess the levels of heavy metals and the extent of pollution in the surface water and sediments from the Meghna river. Water and sediment samples were collected by the Standard Methods and, processed and analyzed for heavy metals using Flame Atomic Absorption Spectrophotometer (FAAS). The mean concentrations of heavy metal found in the river water were in the order of: Fe (1.0224 mg L^{-1}) > Zn (0.0364 mg L^{-1}) > Cr (0.0346 mg L^{-1}) > Mn (0.0088 mg L^{-1}) > Cd (0.003 mg L^{-1}) and in the sediments in the order of: Fe (1281.416 mg kg^{-1}) > Mn (442.596 mg kg^{-1}) > Zn (79.021 mg kg^{-1}) > Ni (76.116 mg kg^{-1}) > Cr (31.739 mg kg^{-1}) > Pb (9.4702 mg kg^{-1}) > Cd (0.230 mg kg^{-1}). Pb and Ni were found below detection limit in river water. Based on the findings, the Meghna river water can be considered as unpolluted with respect to Cd, Cr, Mn and Zn, whereas concentration of Fe was above the standard value according to recommended standard guidelines. According to Sediment Quality Guideline (USEPA, 1989), sediments were not polluted for Cd, Pb and Zn; moderately polluted for Cr and Mn and heavily polluted for Ni. The sediment geo-accumulation index (I_{geo}) values showed no pollution for most of sampling sites for all studied heavy metals. Pollution Load Index (PLI) values showed that all the studied sampling sites were not polluted and on the other hand mean Contamination Factor (CF) values showed low pollution for all measured heavy metals except Ni which indicated moderate pollution. This study can be used as reference to monitor the quality of water and sediments of the Meghna river.

Keywords: Contamination Factor, Geo-Accumulation Index, Pollution Load Index, Sediment Quality, Water Quality

Introduction

Rapid urbanization and industrial development during last decade have provoked some serious concerns in environment. Heavy metal contamination in river is one of the major quality issues in developing countries (Silambarasan *et al.*, 2012). rivers are a dominant pathway for metals transport (Mohiuddin *et al.*, 2010) and metals enter these aquatic systems mainly through natural inputs such as weathering and erosion of rocks and anthropogenic sources including urban, industrial and agricultural activities, terrestrial runoff and sewage disposal (Barakat *et al.*, 2012). As industrial activities, domestic wastes, urbanization and land development all contribute to the heavy metal pollution of rivers. The identification and quantification of the heavy metal in water and sediments are important environmental issues (Manoj *et al.*, 2012). Contamination of aquatic ecosystems with heavy metals has received much attention due to their toxicity, abundance and persistence in the environment and subsequent accumulation in aquatic habitats (Arnason and Fletcher, 2003). Heavy metals entering natural water become part of the water-sediment system and their distribution processes are controlled by a dynamic set of physical-chemical equilibria. The metal solubility is principally controlled by pH, concentration and type of ligands and chelating agents, oxidation-state of mineral components and the redox environment of the system. Since each form may have different bioavailability and toxicity, the environmentalists are rightly concerned about the exact forms of metal present in the aquatic environment. Thus distribution of heavy metals in water and sediments play a key role in detecting sources of heavy metal pollution in aquatic ecosystem (Singh *et al*., 2012). Their accumulation and distribution in sediments, water and environment are increasing at an alarming rate causing deposition and sedimentation in water reservoirs and affecting aquatic organisms as well (Mohiuddin *et al.*, 2011). The contamination of surface water by heavy metals is a serious ecological problem as some of them are toxic even at low concentrations, are non-degradable and can bio-accumulate through food chain (Abdullah, 2013). Heavy metals undergo a global ecological cycle in which natural water are the main pathways (Saha and Hossain, 2011). Sediments act as sink of heavy metals can become immediate source of metal pollution of the water bodies (Manoj *et al.*, 2012). Data from sediments can provide information on the impact of distant human activity on the wider ecosystem. The composition of sediment sequences provides the best natural archives of recent environmental changes. It acts as both carrier and potential sources of contaminants in an aquatic environment and can serve as a pool that can retain or release contaminants to the water column by various processes of remobilization (Ogbeibu *et al.*, 2014). Heavy metals accumulate in the sediments through complex physical and chemical adsorption mechanisms depending on the nature of the sediment matrix and the properties of the adsorbed compounds (Rabee *et al.*, 2011). Exposure to heavy metals has linked to several human diseases such as development retardation or malformation, kidney damage, cancer, abortion, effect on intelligence and behavior and even death in some cases of exposure to very high concentrations. The most toxic heavy metals Cr, Ni, Pb, Cd and As. Cr (VI), Ni and Cd are carcinogenic; As and Cd are teratogenic and the health effects of Pb include neurological impairment and malfunctioning of the central nervous system. Although some heavy metals such as Fe, Mn, Co, Cu and Zn are essential micronutrients for fauna and flora, they are dangerous at high levels (Saha and Hossain, 2011; Moore *et al.*, 2009).

Bangladesh is constituted by a large delta at the confluence of three major rivers of the world, the Ganges, the Brahmaputra and the Meghna (Alam, 2003). The Meghna river is polluting at different sites from industries which situated on the banks of this river or very close to the river system. One of the most polluted sites of the Meghna river is the Meghna Ghat and its adjacent area. The dominant industries in this area are shipyard, cement, paper, jute, super board, oil, sugar, food processing, salt and chemical industries. The river receives industrial wastes water directly from industries and also domestic and agro-chemical wastes which contribute heavy metal pollution in water and sediment. But no significant studies have been undertaken to investigate the pollution of the Meghna river. So it is necessary to assess the state of the water and sediment quality of the Meghna river. The objective of the present study is to assess the level of heavy metal concentrations in water and sediment that will focus on the pollution status of the Meghna river.

Materials and Methods

Study Area

The Ganges-Brahmaputra-Meghna (G-B-M) drainage basin occupies the total Bengal Basin, which is one of the unique basins of the world (Datta and Subramanian, 1998). These three river basins cover about 1.75×10^6 km^2 across five different countries-China, Nepal, India, Bhutan and Bangladesh (Mirza *et al*., 1998). The Meghna river is the main outlet of the Ganges-Brahmaputra river system collecting water from a vast catchments area of these countries. The total catchment area of the Meghna river is 82000 km^2 and 13 million tons of sediment is being transported per year (Rahman, 2013). The precipitation, evaporation and discharge of water at different seasons of the Meghnariver are given in Table 1. The Meghna Ghat and adjacent area in Narayangonj and Munshigonj districts had been chosen in order to assess the surface water and sediment samples on both banks of the river. A total of eleven sampling sites were selected depending upon the presumed water and sediment quality and extent of pollution by visiting the study area before sample collection (Fig. 1).

Table 1. Precipitation, evaporation and discharge of water at different seasons of the Meghna river (Uddin *et al.*, 2014)

	Pre-monsoon 10^6 m^3/day	Monsoon 10^6 m^3/day	Post-monsoon 10^6 m^3/day
Precipitation	83.524	230.755	16.736
Evaporation	34.261	44.688	52.774
Discharge	6.472	4399.357	1556.367

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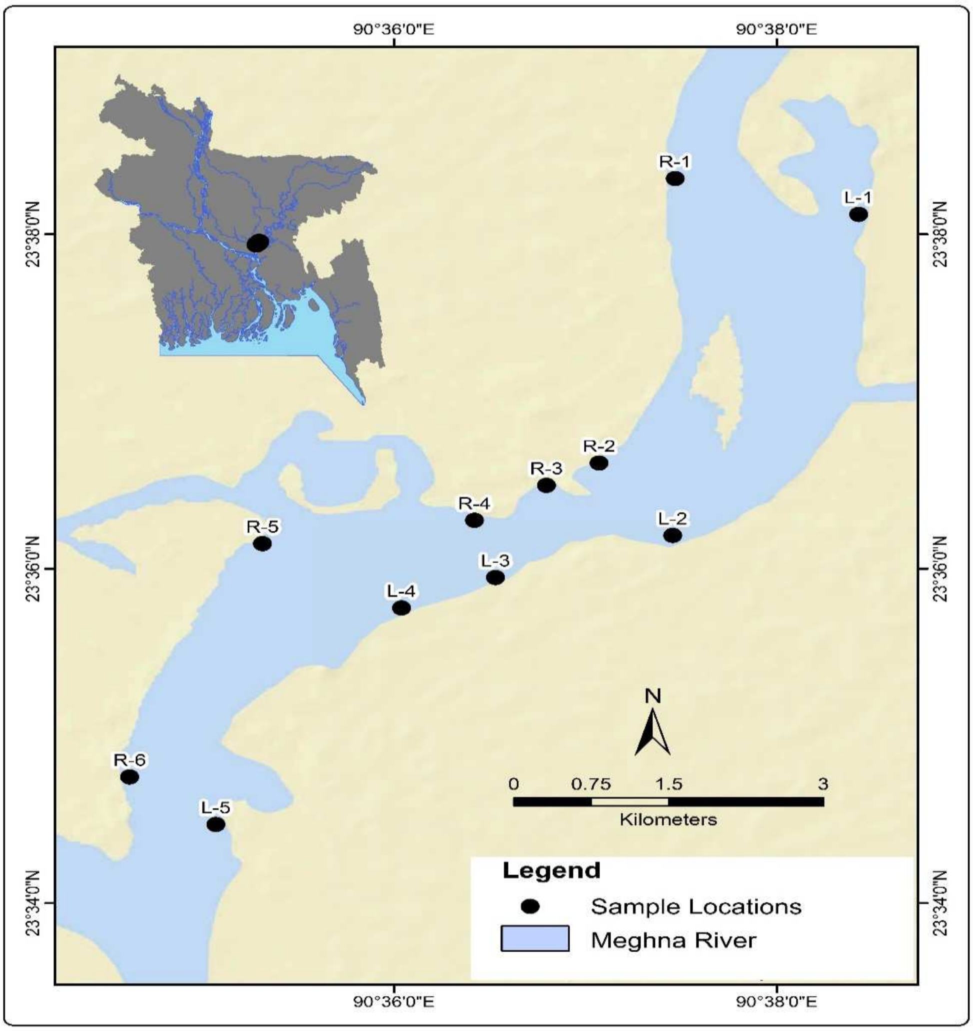

Fig. 1. Study area and sampling sites (Right and Left bank denoted as R and L, respectively)

Sample Collection and Preparation

Eleven water and 11 sediments samples were collected on 6 August, 2014 from the selected sampling sites. Surface water samples were collected from 15-30 cm below the river water surface and at distances of 40-80 cm from the bank of the river in pre-labeled sample bottles which was washed with 10% HNO_3 acid and rinsed repeatedly with distilled water. Before the sample collection, sample bottles were rinsed three times with the river water (Tareq *et al*., 2013). For measurement of heavy metal concentration, 65% concentrated HNO_3 acid was added to each sample immediately to bring the pH blow 2 to minimize precipitation and adsorption onto container walls (APHA, 1998). Sediment samples were taken at a depth of 0-10 cm and then immediately transferred into polyethylene bags. Prior to sampling the polyethylene were washed with 10% HNO_3 acid solution and ringed with distilled water (Manoj *et al*., 2012; Rabee *et al*., 2011; Ogbeibu *et al*., 2014). Water and sediments samples were transported using ice box to the laboratory and water samples were properly labeled and preserved in refrigerator at 4°C temperature. Sediment samples were dried in a dry and dust-free place at room temperature, ground into fine powder using pestle and mortar before sieved under 2 mm mesh. The samples were then stored in plastic container (Jumbe and Nandini, 2009).

Physico-chemical Analysis of river Water and Sediment

Eight physico-chemical parameters of water samples were measured by using different instruments and methods. A centigrade thermometer was used for the measurement of temperature. pH, TDS and EC were measured by portable multiparameter meter

(Model: Sense Ion, 156; HACH, USA). Turbidity and DO were measured by portable turbidity meter (Model: 93703; Hanna Instruments, Hungary) and digital DO meter (Model: HQ 30 D; HACH, USA), respectively. BOD was measured by BOD trak apparatus (Model: BODTrakII^{TM}; HACH, USA). COD was determined by titrimetric method according to Huq and Didarul-ul-Alam (2005). For sediment's pH measurement, 20 gm sediment sample was taken into clean glass beaker and added 50 mL distilled water. The mixture was shaken on a shaking plate more than 30 min and then pH measured with portable multiparameter meter (Model: Sense Ion, 156; HACH, USA). Organic Matter (OM) was determined by wet oxidation method of Walkley and Black (1934).

Estimation of Heavy Metals in Water and Sediment

Water samples were digested with concentrated HNO_3 acid as described by APHA (1998) and sediment samples were digested with concentrated HNO_3 acid and concentrated $HClO_4$ acid according to Huq and Didarul-ul-Alam (2005). Then the digested water and sediment samples were analyzed by Flame Atomic Absorption Spectrophotometer (Model: AA-7000; Shimadzu, Japan) for detection of heavy metals like Cr, Cd, Pb, Ni, Fe, Zn and Mn. The instrument was calibrated with chemical standard solutions in accordance with manufacturer's instructions.

Sediment Quality Assessment

Geo-Accumulation Index ($_{Igeo}$)

The geo-accumulation index (I_{geo}) has been widely used in trace metal studies since the late 1960s (Yaqin *et al*., 2008). It has been successfully applied to the measurement of bottom sediments contamination (Loska *et al*., 2003). The I_{geo} enables the assessment of metal contamination in sediments by comparing current concentrations with pre-industrial levels (Qingjie and Jun, 2008). I_{geo} is calculated using the following formula (Müller, 1969):

$$I_{geo} = \log\left(Cn / 1.5 \times Bn\right) \quad (1)$$

where, *Cn* is the measured concentration of the metal (*n*) in the sediment and *Bn* is the geochemical background of the metal (*n*). The factor 1.5 is used for the possible variations of the background data due to lithological variations. Average shale standard for different metals reported by Turekian and Wedepohl (1961) was taken as background concentration throughout the study. Müller (1981) classified I_{geo} values into seven grades or classes (Table 2). The I_{geo} factor is not readily comparable to the other indices of metal enrichment due to the nature of the I_{geo} calculation, which involves a log function and a background multiplication of 1.5 (Abrahim and Parker, 2008).

Contamination Factor (CF)

The Contamination Factor (CF) and Contamination Degree (CD) are used to assess the pollution load of the sediments with respect to heavy metals (Manoj *et al.*, 2012). The CF is the ratio obtained by dividing the concentration of each metal in the sediment by baseline or background value (Varol, 2011). CF for each metal was determined by the following formula (Hakanson, 1980):

$$CF = \frac{Measured\ metal\ concentration}{Background\ concentration\ of\ the\ same\ metal} \quad (2)$$

CD for each site was calculated as sum of all contamination factors (Ahdy and Khaled, 2009). Hakanson (1980) has provided four grade ratings of sediments based on CF values (Table 2).

Table 2. Index classification of sediment quality (Müller, 1981)

I-geo values Müller (1981)	Class	Sediment quality
≤ 0	0	Unpolluted
0-1	1	Unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	Moderately to strongly polluted
3-4	4	Strongly polluted
4-5	5	Strongly to extremely polluted
≥6	6	Extremely polluted
CF values		
Hakanson (1980)	Class	Sediment quality
CF <1	1	Low CF
1≤ CF <3	2	Moderate CF
3≤ CF <6	3	Considerable CF
CF ≥6	4	Very high CF

Pollution Load Index (PLI)

Pollution Load Index (PLI) is used to find out the mutual pollution effect at different stations by the different elements in soils and sediments (El-Sammak and Abdul-Kassim, 1999). The PLI gave an assessment of the overall toxicity status of the each sampling site and also it is a result of the contribution of the measured seven metals. PLI for each site was determinedas the nth root of the multiplications of the contents (CF_{metals}) by the following equation proposed by Tomlinson *et al*. (1980):

$$PLI = \sqrt[n]{\left(CF1 \times CF2 \times CF3 \times \ldots \times CFn\right)} \quad (3)$$

where, *CF* is the contamination factor and n is the number of metals. The *PLI* value of >1 is polluted, whereas <1 indicates no pollution (Harikumar *et al*., 2009). This index is quickly understood by unskilled personal in order to compare the pollution status of different places.

Results and Discussion

Physico-Chemical Characteristics of river Water and Sediment

The values of physico-chemical parameters measured in the Meghna river water at different sites are given in Table 3. The mean values of temperature, pH, TDS, EC, turbidity, DO, BOD and COD were 25.45°C, 6.85, 43.65 mg L^{-1}, 87.23 µS cm^{-1}, 14.97 FTU, 6.97, 5.3 and 57.31 mg L^{-1} on the Right bank, respectively and 25.15°C, 7.48, 43.68 mg L^{-1}, 87.34 µS cm^{-1}, 11.61 FTU, 7.64, 4.34 and 66.68 mg L^{-1} on the Left bank, respectively. The result showed no significant differences in physico-chemical parameters values between both banks. Physico-chemical parameters play an important role into system restoration maintenance and self-regulation of water quality (Bharti and Singh, 2013). The measured pH values of the Meghna river water were between slightly acidic to moderately alkaline during the study period. The pH has relationship with the solubility and accumulation of heavy metal in river water as well as sediments according to Singh *et al.* (2012). Temperature, pH, DO, TDS and EC of the Meghna river water were within the acceptable limit during the study period but turbidity, BOD and COD values were higher than the acceptable limit of DoE (1997) standard of Bangladesh for drinking water. The physico-chemical parameters values of the present study were compared with other rivers of Bangladesh (Table 4). The measured mean values of pH, DO, TDS, EC and turbidity were lower but BOD and COD were higher than the Ganges and Brahmaputra river recommended by Tareq *et al.* (2013). According to Rahman and Huda (2012), the mean values of temperature, pH, TDS, EC, turbidity, DO were higher but BOD were lower in the Padma river than the present study. The mean values of temperature, pH, TDS, EC were higher but DO, BOD were lower of the present study than the Buriganga river (Hasan *et al*., 2009). Islam *et al.* (2012) investigated that temperature, TDS, EC were higher but pH, DO were lower in Dhaleshwari river than present study. Alam *et al.* (2007) found the mean values of pH, DO, BOD and COD lower in the Surma river than the present study. The mean values of pH, TDS, EC were lower but temperature were higher in the present study than the Shitalakhya, Turag and Bongshi rivers according to Sikder *et al.* (2013).

The range of pH and Organic Matter (OM) in the Meghna river sediment were 6.95-7.56 and 0.2121-5.9189% with mean values of 7.2382 and 1.7216% respectively (Table 5). The mean values of pH and OM were found 7.17 and 2.2631%, respectively on the Right bank sediment and 7.32 and 1.0719%, respectively on the Left bank. The result showed that pH was nearly same on the both bank but OM was higher on the Right bank sediment. The neutral to slightly alkaline pH, probably related to carbonate nature of the sediment (Barakat *et al*., 2012) and the presence of organic matter can influence the accumulation of heavy metals in the sediments (Suthar *et al*., 2009; Mohiuddin *et al*., 2010; Manoj *et al*., 2012). pH mean value in the Buriganga river was lower but in the Shitalakhya river was nearly same and organic matter in the both rivers were lower as reported by Islam *et al.* (2014) than the present study.

Heavy Metals in Water

The heavy metal concentrations for each sampling site found in water in this study and different standard and guidelines are shown in Table 6. The mean heavy metal concentrations were observed in water in decreasing order of Fe > Zn > Cr > Mn > Cd but Pb and Ni were found below detection limit. The mean concentrations of Cd, Cr, Fe, Mn and Zn were 0.0027, 0.0202, 1.0848, 0.0124 and 0.0357 mg L^{-1}, respectively on the Right bank and 0.0033, 0.0520, 0.9475, 0.0045 and 0.0374 mg L^{-1}, respectively on the Left bank. The result showed that Fe and Mn were found higher but Cd, Cr and Zn were lower on the Right bank water than the Left bank. The variation of concentration of heavy metal from locations to locations may be correlated with the flow of the rivers and location of industries and their waste disposal system (Alam, 2003). The average concentration of Cd, Cr, Mn and Zn were found lower but Iron (Fe) was higher in the Meghna river than DoE (1997) standard, WHO (1993) and USEPA (2008) guidelines. The heavy metal concentrations in water of the Meghna river were compared with other rivers of Bangladesh (Table 8). In the Buriganga river, the mean concentrations of Cd, Cr and Zn were investigated higher but Fe was lower than the present study according to Bhuiyan *et al.* (2015). The mean concentrations of Cd and Mn were found higher but Zn was lower as reported by Mokaddes *et al.* (2013) in the Shitalakhya, Turag and Balu river than the present investigation. According to Ahmed *et al.* (2012), the mean concentration of Cd was lower but Cr was higher in the Dhaleshwari river than present investigation.

Table 3. The values of physico-chemical parameters of the Meghna river water

Sampling sites	Temperature (°C)	pH	TDS (mg/l)	EC (µS/cm)	Turbidity (FTU)	DO (mg/l)	BOD (mg/l)	COD (mg/l)
R-1	25.100	7.030	30.700	61.300	11.720	7.230	6.100	62.520
R-2	27.300	6.070	91.100	182.200	25.100	4.660	10.100	93.780
R-3	25.400	7.030	36.000	71.900	18.980	7.030	4.900	52.100
R-4	25.100	6.900	34.300	68.600	13.750	7.100	7.100	72.940
R-5	25.000	6.980	35.800	71.500	9.960	8.350	1.200	20.840
R-6	24.800	7.100	34.000	67.900	10.310	7.500	2.400	41.680
L-1	25.000	7.280	34.400	68.800	9.600	8.130	1.800	62.520
L-2	25.000	7.920	34.100	68.200	10.640	7.630	3.400	72.940
L-3	25.800	8.010	80.600	161.200	11.180	7.180	9.700	114.620
L-4	25.100	7.350	35.300	70.500	9.990	8.200	2.300	31.260
L-5	24.900	6.850	34.000	68.000	16.610	7.050	4.500	52.100
Maximum	27.300	8.010	91.100	182.200	25.100	8.350	10.100	114.620
Minimum	24.800	6.070	30.700	61.300	9.600	4.660	1.200	20.840
Mean	25.300	7.230	43.660	87.280	13.440	7.280	4.860	61.570
SD.	0.711	0.392	21.035	42.092	4.912	0.995	3.083	26.953
DoE (1997) standard	20-30	6.5-8.5	1000.000	350.000	10.000	6.000	0.200	4.000

SD- Standard Deviation

Table 4. Comparison of physico-chemical parameters of the Meghnariver with other rivers of Bangladesh

	Mean Values of Physico-chemical Parameters								
river	Temperature (°C)	pH	TDS (mg/l)	EC (µS/cm)	Turbidity (FTU)	DO (mg/l)	BOD (mg/l)	COD (mg/l)	References
Meghna river	25.3	7.23	43.66	87.28	13.44	7.28	4.86	61.57	Present study
Ganges river	-	7.87	260	286	82.78	7.65	2.6	51	Tareq *et al.* (2013)
Brahmaputra river	-	7.66	155	168	64.4	7.52	2.63	41	Tareq *et al.* (2013)
Padma river	27.5	7.67	84.08	162.17	53.37	7.79	4.25	-	Rahman and Huda (2012)
Buriganga river	25.86	7.31	629.33	800.49	-	4.57	3.65	-	Hasan *et al.* (2009)
Dhaleshwari river	29.03	6.15	173.10	319.43	-	6.46	-	-	Islam *et al.* (2012)
Surma river	-	6.11	-	-	-	5.62	0.94	1.43	Alam *et al.* (2007)
Shitalakhya river	25.15	8.1	737	1087.5	-	-	-	120	Sikder *et al.* (2013)
Turag river	21.55	7.45	410.5	579.5	-	-	-	35	Sikder *et al.* (2013)
Bongshi river	20.86	7.43	420.33	594	-	-	-	35	Sikder *et al.* (2013)

Table 5. Values of pH and OM in the Meghna river sediment

Sampling sites	pH	OM (%)
R-1	7.2500	1.4850
R-2	6.9500	5.9189
R-3	7.1600	4.0308
R-4	7.1900	1.3153
R-5	7.2500	0.2121
R-6	7.2200	0.6164
L-1	7.4100	2.1921
L-2	7.4500	0.6577
L-3	7.5600	0.7972
L-4	7.1400	0.6164
L-5	7.0400	1.0962
Maximum	7.5600	5.9189
Minimum	6.9500	0.2121
Mean	7.2382	1.7216
SD.	0.1785	1.7462

SD- Standard Deviation

Table 6. Concentration (mg/l) of heavy metals in the Meghna river water

Sampling sites	Cd	Cr	Fe	Mn	Pb	Ni	Zn
R-1	0.0029	0.02320	1.4640	0.01740	BDL	BDL	0.0283
R-2	0.0032	0.01930	0.4676	0.01530	BDL	BDL	0.0267
R-3	0.0012	0.00920	1.4347	0.01590	BDL	BDL	0.0226
R-4	0.0047	0.00630	1.4064	0.02500	BDL	BDL	0.0781
R-5	0.0032	0.01470	0.9257	0.00050	BDL	BDL	0.0242
R-6	0.0014	0.04840	0.8107	0.00030	BDL	BDL	0.0343
L-1	0.0017	0.04420	0.6014	0.00920	BDL	BDL	0.0109
L-2	0.0026	0.02520	0.5015	0.00860	BDL	BDL	0.0175
L-3	0.0023	0.06950	0.9012	0.00080	BDL	BDL	0.0365
L-4	0.0071	0.07370	1.5987	0.00150	BDL	BDL	0.1122
L-5	0.0029	0.04740	1.1350	0.00230	BDL	BDL	0.0100
Maximum	0.0071	0.07370	1.5987	0.02500			0.1122
Minimum	0.0012	0.00630	0.4676	0.00030			0.0100
Mean	0.0030	0.03460	1.0224	0.00880			0.0364
SD.	0.0016	0.02343	0.4102	0.00854			0.0311
DoE (1997) standard	0.0050	0.05000	0.3-1.0	0.10000	0.05	0.10	5.0000
WHO (1993) guideline	0.0030	0.05000	NA	0.50000	0.01	0.02	3.0000
USEPA (2008) guideline	0.0050	0.10000	0.3000	0.05000	NA	NA	5.0000

SD- Standard Deviation, BDL- Below Detection Limit, NA- Not Available

Table 7. Correlation coefficients (r) among heavy metal in water sample

Water/Water	Cd	Cr	Fe	Mn	Zn
Cd	1.00				
Cr	0.244	1.00			
Fe	0.477	0.018	1.00		
Mn	0.021	-0.715*	0.226	1.00	
Zn	0.864**	0.300	0.588	0.066	1.00

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)

Table 8. Comparison of heavy metal concentrations of the Meghna river water and sediment with other rivers of Bangladesh

	Mean Concentrations of Heavy Metal							
river	Cd	Cr	Fe	Mn	Pb	Ni	Zn	References
Water								
Meghna river	0.0030	0.0346	1.0224	0.0088	-	-	0.0364	Present study
Buriganga river	0.0590	0.114	0.612	0.157	0.1119	0.150	0.3320	Bhuiyan *et al.* (2015)
Shitalakhya river	0.0110	-	-	0.0514	0.0011	-	0.0051	Mokaddes *et al.* (2013)
Turag river	0.0136	-	-	0.0555	0.0021	-	0.0191	Mokaddes *et al.* (2013)
Balu river	0.0137	-	-	0.0470	0.0010	-	0.0101	Mokaddes *et al.* (2013)
Dhaleshwari river	0.0010	0.130	-	-	0.201	-	-	Ahmed *et al.* (2012)
Khiru river	0.1275	-	-	0.1672	0.0221	-	0.0065	Rashid *et al.* (2012)
Sediment								
Meghna river	0.2300	31.739	1281.42	442.596	9.4702	76.116	79.021	Present study
Buriganga river	0.8200	101.2	-	-	79.4	-	502.26	Saha and Hossain (2011)
Shitalakhya river	5.0100	63.22	-	-	28.36	39.22	75	Islam *et al.* (2014)
Turag river	0.2800	43.02	-	-	32.78	-	139.48	Banu *et al.* (2013)
Daleshwari river	2.0830	27.393	-	-	15.797	-	-	Ahmed *et al.* (2012)
Bangshi river	0.6100	98.10	-	483.44	59.99	25.67	117.15	Rahman *et al.* (2014)
Korotoa river	1.2000	109	-	-	58	95	-	Islam *et al.* (2015)

Pearson's correlation coefficients of heavy metals studied using statistical software SPSS (version 22.0) in the Meghna river water have been summarized in the Table 7. The relationship between the heavy metals may offer remarkable information on the sources and pathway of heavy metals. Correlation analysis shows significant positive correlation between Zn-Cd (r = 0.864) at p<0.01 level where as Mn is significantly but inversely correlated with Cr (r = -0.715) at p<0.05 level. The high significant correlations between heavy metals may reflect the fact that these heavy metals had similar pollution levels and similar pollution sources (Armah *et al*., 2010). On the other hand the rest of elemental pairs show no significant correlation with each other, suggesting that these metals are not associated with each other and lack of their identical behavior transport in aquatic environment.

Heavy Metals in Sediments

The heavy metal concentrations in the river sediments at all sampling sites and comparison with different Sediment Quality Guidelines (SQG) are given in Table 9. The mean concentrations of analyzed heavy metal were observed in sediment in decreasing order of Fe > Mn > Zn > Ni > Cr > Pb > Cd. Ni was found in all sediment samples but was not found in water samples because Ni is mainly transported in the form of a precipitated coating on particles and in association with organic matter. Ni may also be absorbed on to clay-particles and via uptake by biota. Absorption process may be reversed leading to release of Ni from the sediment (Ahmad *et al.*, 2010). The mean concentrations of Cd, Cr, Fe, Mn, Pb, Ni and Zn in sediments were 0.2808, 35.7464, 1293.85, 411.7323, 12.6384, 74.4498 and 96.6593 mg kg^{-1}, respectively on the Right bank and 0.1698, 26.9322, 1266.496, 479.6334, 5.6684, 78.1162 and 57.8557 mg kg^{-1}, respectively on the Left bank. The result showed that Cd, Cr, Fe, Pb and Zn concentrations were higher but Mn and Ni were lower on the Right bank than the Left bank. Among all sampling sites most all measured heavy metal concentrations were found higher which is situated near a shipyard. High concentration of heavy metals release from base material (e.g., steel, stainless steel, galvanized steel, aluminum, copper-nickel and other copper alloys), abrasive blasting materials (e.g., coal slag, copper slag, nickel slag, glass, steel grit, garnet, silica sand), surface coatings (e.g., pre-construction primers, anticorrosive and antifouling paints) and welding materials in shipyard (Kura *et al.*, 2006; OSHA, 2006) and deposited in river sediment. The mean concentrations of Cd, Pb and Zn in the Meghna river sediments were found lower but Ni was found higher than WHO (2004), USEPA (1999) and CCME (1999) Sediment Quality Guidelines (SQG). Fe and Mn mean concentrations were higher than USEPA (1999) sediment quality guideline and Cr mean concentration was higher than WHO (2004) but lower than CCME (1999) sediment quality guidelines. The heavy metal concentrations in sediment of the Meghna river were compared with other rivers of Bangladesh (Table 8). The mean concentrations of Cd, Cr, Pb and Zn were higher as reported by Saha and Hossain (2011) in the Buriganga river than the present investigation. Cd, Cr, Pb mean concentrations were found higher in Shitalakhya (Islam *et al.*, 2014) and Turag (Banu *et al.*, 2013) rivers than present study but Ni and Zn were found lower in Shitalakhya river. In the Dhaleshwari river, the mean concentrations of Cd and Pb were found higher but Cr was lower as recommended by Ahmed *et al.* (2012) than present measured concentrations. The mean concentrations of Cd, Cr, Mn, Pb and Zn were investigated higher but Ni was lower in the Bangshi river reported by Rahman *et al.* (2014) than this study. According to Islam *et al.* (2015), the mean concentrations of Cd, Cr, Pb and Ni were measured in the Korotoa river than the present study.

Pearson's correlation analysis shows significant correlation between Zn-Cd (r = 0.894), Zn-Fe (r = 0.736), Ni-Pb (r = 0.930), Pb-Cd (r = 0.977) and Fe-Cr (r = 0.736) at $p<0.01$ level whereas significant correlation between Zn-Ni (r = 0.674) and Ni-Cd (r = 0.679) at $p<0.05$ level (Table 10). These highly significant positive correlations between heavy metals suggest the possibility of common sources of origins which may be anthropogenic (Armah *et al.*, 2010). On the other hand the rest of elemental pairs show no significant correlation with each other in sediments that could be indication of separate source input or sources of pollution.

Table 9. Concentration (mg/kg) of heavy metals in the Meghna river sediments

Sampling sites	Cd	Cr	Fe	Mn	Pb	Ni	Zn
R-1	0.2019	48.1779	1273.560	472.019	7.7426	63.5384	86.9903
R-2	0.3300	56.9500	1324.510	396.600	14.8750	36.4850	121.7500
R-3	0.2100	42.0000	1311.970	616.300	7.1150	57.1650	81.3750
R-4	0.6900	31.0550	1321.490	381.050	44.8550	218.8500	204.7600
R-5	0.1633	23.4505	1270.790	352.525	0.4059	42.4158	49.9158
R-6	0.0900	12.8450	1260.780	251.900	0.8372	28.2450	35.1650
L-1	0.1666	38.4898	1316.170	502.778	8.2525	185.1620	80.8838
L-2	0.1470	42.1078	1294.830	789.510	5.9363	55.2451	73.5245
L-3	0.2079	16.4703	1207.230	230.297	3.3745	47.5643	32.7524
L-4	0.1969	12.6565	1231.620	168.737	6.6139	66.2020	29.4141
L-5	0.1310	24.9368	1282.630	706.845	4.1650	36.4078	72.7038
Maximum	0.6900	56.9500	1324.510	789.510	44.8550	218.8500	204.7600
Minimum	0.0900	12.6560	1207.230	168.737	0.4059	28.2450	29.4140
Mean	0.2300	31.7390	1281.420	442.596	9.4702	76.1160	79.0210
SD	0.1640	14.9460	37.905	198.818	12.3850	63.8010	50.1510
WHO (2004) SQG	6.0000	25.0000	NA	NA	NA	20.0000	123.0000
USEPA (1999) SQG	0.6000	25.0000	30.000	30.000	40.0000	16.0000	110.0000
CCME (1999) SQG	0.6000	37.3000	NA	NA	35.0000	NA	123.0000

SD- Standard Deviation, SQG-Sediment Quality Guideline, NA-Not Available

Assessment of Sediment Heavy Metals Contamination

The heavy metal contaminations in the sediments were evaluated by comparison with the sediment quality guideline proposed by USEPA (1989) (Table 11). The mean concentrations of the present study showed that Meghna river sediments were unpolluted for Cd, Pb and Zn; moderately polluted for Cr and Mn and heavily polluted for Ni.

According to the Müller (1969) formula, the calculated results of I_{geo} values of the sediments are given in Table 12. According to Müller (1981) scale (Table 2), a qualitative scale of pollution intensity (Farkas *et al*., 2007), I_{geo} values indicated that Meghna river sediments are unpolluted ($I_{geo}<0$) for all sampling sites for all metals except R-4 sampling site for Cd, Pb, Ni, Zn and L-1 site for Ni. Sediments in R-4 site for Cd, Pb, Zn and L-1 for Ni are unpolluted to moderately polluted ($0<I_{geo}>1$) but for Ni in R-4 site is moderately polluted ($1<I_{geo}>2$).

Considering calculated Contamination Factor (CF) and degree of contamination (CD) (Table 13), maximum contamination factor was found in R-4 sampling site where the degree of contamination is 10.736. CF>3 (indicating considerable contamination) was found in R-4 sampling site for Ni and CF>1 (indicating moderate contamination) found in R-2 sampling sites for Cd and in R-4 sampling site for Cd, Pb and Zn. Other all the sampling sites have Contamination Factor (CF)>1 (indicating low contamination) for all tested heavy metals. The mean values of the CF were found Cd: 0.767 (low contamination); Cr: 0.352 (low contamination); Fe: 0.026 (low contamination); Mn: 0.52 (low contamination); Pb: 0.473 (low contamination); Ni: 1.119 (moderate contamination) and Zn: 0.831 (low contamination). On the basis of the mean values of CF, sediments are enriched for metals in the following order: Ni > Zn > Cd > Mn > Pb > Cr > Fe.

Table 10. Correlation coefficients (r) among heavy metal in sediment sample

Sediment/Sediment	Cd	Cr	Fe	Mn	Pb	Ni	Zn
Cd	1.00						
Cr	0.208	1.00					
Fe	0.415	0.736**	1.00				
Mn	-0.152	0.544	0.557	1.00			
Pb	0.977**	0.236	0.504	-0.043	1.00		
Ni	0.679*	0.115	0.453	-0.007	0.756**	1.00	
Zn	0.894**	0.516	0.736**	0.219	0.930**	0.674*	1.00

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed)

Table 11. Assessment of sediments Heavy Metals Contamination (mg/kg) According to USEPA (1989) guideline

Heavy metals	Not polluted	Moderately polluted	Heavily polluted	Present study
Cd	ND	ND	>6	0.2300
Cr	<25	25-75	>75	31.7390
Fe	ND	ND	ND	1281.4160
Mn	<300	300-500	>500	442.5960
Pb	<40	40-60	>60	9.4702
Ni	<20	20-50	>50	76.1160
Zn	<90	90-200	>200	79.0210

ND-Not Detectable

Table 12. Geo-accumulation Index (I_{geo}) values of heavy metals of the Meghna river sediments

	Geo-accumulation Index (I_{geo})						
Sampling sites	Cd	Cr	Fe	Mn	Pb	Ni	Zn
R-1	-1.156	-1.486	-5.7960	-1.433	-1.954	-0.683	-0.712
R-2	-0.447	-1.245	-5.7400	-1.684	-1.012	-1.483	-0.227
R-3	-1.099	-1.840	-5.7540	-1.048	-2.076	-0.835	-0.808
R-4	0.617	-2.120	-5.7430	-1.742	0.580	1.101	0.522
R-5	-1.462	-2.525	-5.7990	-1.854	-6.207	-1.266	-1.513
R-6	-2.322	-3.394	-5.8110	-2.339	-5.163	-1.852	-2.018
L-1	-1.433	-1.810	-5.7490	-1.342	-1.862	0.860	-0.817
L-2	-1.614	-1.680	-5.7720	-0.691	-2.337	-0.884	-0.954
L-3	-1.114	-3.035	-5.8740	-2.468	-3.152	-1.101	-2.121
L-4	-1.192	-3.415	-5.8451	-2.917	-2.181	-0.624	-2.276
L-5	-1.780	-2.436	-5.7860	-0.851	-2.848	-1.486	-0.971

Table 13. Contamination Factor (CF), Contamination Degree (CD) and Pollution Load Index (PLI) values

Sampling sites	Contamination Factor (CF) Cd	Cr	Fe	Mn	Pb	Ni	Zn	Degree of Contamination (CD)	Pollution Load Index (PLI)
R-1	0.673	0.535	0.026	0.555	0.387	0.934	0.915	4.025	0.403
R-2	1.100	0.632	0.028	0.466	0.744	0.536	1.281	4.787	0.464
R-3	0.700	0.466	0.027	0.725	0.356	0.841	0.856	3.971	0.401
R-4	2.300	0.345	0.028	0.448	2.242	3.218	2.155	10.736	0.765
R-5	0.544	0.260	0.026	0.414	0.020	0.623	0.525	2.412	0.194
R-6	0.300	0.142	0.026	0.296	0.041	0.415	0.370	1.590	0.154
L-1	0.555	0.427	0.027	0.591	0.412	2.723	0.851	5.586	0.449
L-2	0.490	0.467	0.027	0.928	0.296	0.812	0.773	3.793	0.377
L-3	0.693	0.183	0.025	0.271	0.168	0.699	0.344	2.383	0.230
L-4	0.656	0.141	0.026	0.198	0.330	0.973	0.309	2.633	0.241
L-5	0.436	0.277	0.027	0.831	0.208	0.535	0.765	3.079	0.302
Mean	0.767	0.352	0.026	0.520	0.473	1.119	0.831	4.090	

The PLI represents the number of times by which the metal content in the sediment exceeds the background concentration and gives a summative indication of the overall level of heavy metal toxicity in a particular sample (Barakat *et al*., 2012). According to the Tomlinson *et al.* (1980) formula, the calculated PLI values of all sampling sites are shown in Table 13. The PLI ranged from 0.154 to 0.765. The highest PLI value was observed in R-4 sampling site near a shipyard. The present study showed that the PLI values of all sampling sites were lower than 1 that indicating no pollution. The PLI can provide some understanding to the public of the area about the quality of a component of their environment and indicates the trend over time and area (Mohiuddin *et al.*, 2010).

Conclusion

This research reveals that the measured concentrations of Cd, Cr, Mn and Zn in the Meghna river water are lower but Fe is higher than standard guidelines. Pb and Ni are found below detection limit in all sampling sites. According to USEPA (1989) sediment quality guideline, sediment are heavily polluted for Ni. According to geo-accumulation index (I_{geo}), all the sampling sites are unpolluted for all studied heavy metals except R-4 sampling site for Cd, Pb, Ni, Zn and L-1 site for Ni. Pollution Load Index (PLI) values showed that all the sampling sites are unpolluted. According to mean Contamination Factor (CF), all the sampling sites are low polluted for all studied heavy metals except Ni which is moderately polluted. These results clearly indicate the quality of the Meghna river water and sediments to be unpolluted to low polluted. Continuous monitoring and assessment will keep checking the pollution status of the river water and sediment.

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Author's Contributions

Mahmud Hassan: Contributed in sampling, laboratory analysis and writing of the manuscript.

Mirza A.T.M. Tanvir Rahman: Contributed in Research designing, organizing and writing of the manuscript.

Badhan Saha: Contributed in sampling preparation and other laboratory analysis.

Abdul Kadir Ibne Kamal: Contributed in research designing.

Ethics

This article is original and contains unpublished material. The authors have no conflicts of interest in the development and publication of current research.

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