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Heavy Metal Concentration in Water, Sediments, Freshwater Mussels and Fishes of the River Shitalakhya, Bangladesh

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Abstract: This study was undertaken to study the concentration of some heavy metals in the water and sediment samples and their bioaccumulations in freshwater fish and mussels of the Shitalakhya River. In water samples, concentration of Ni ranged from 4.31 to 7.83 µg/L, Pb 41.24 to 63.15 µg/L, Cd 7.12 to 10.11 µg/L, Cr 192.18 to 234.32 µg/L, and Cu 156.38 to 254.07 µg/L at different sampling stations during pre-monsoon, monsoon and post-monsoon. In sediment samples, Ni ranged from 120.96 to 131.94 mg/kg, Pb 54.52 to 65.90 mg/kg, Cd 1.71 to 2.17 mg/kg, Cr 60.09 to 91.02 mg/kg, and Cu 56.07 to 91.51 mg/kg in dry weight basis at different stations during different seasons. In *Puntius sophore*, Ni ranged from 9.07 to 13.01 mg/kg, Pb 8.01 to 10.09 mg/kg, Cd 0.85 to 1.13 mg/kg, Cr 2.94 to 4.01 mg/kg, and Cu 4.92 to 5.27 mg/kg in dry weight basis during different seasons. In *Glossogobius giuris*, Ni ranged from 10.53 to 11.32 mg/kg, Pb 7.17 to 9.17 mg/kg, Cd 0.81 to 1.07 mg/kg, Cr 3.13 to 3.37 mg/kg, and Cu 5.19 to 6.03 mg/kg in dry weight basis during different seasons. In the muscles of the freshwater mussels (*Lamellidens marginalis*), Ni ranged from 8.19 to 9.07 mg/kg, Pb 9.16 to 13.09 mg/kg, Cd 1.09 to 1.21 mg/kg, Cr 8.12 to 9.07 mg/kg, and Cu 5.47 to 8.19 mg/kg in dry weight basis during different seasons. These variations of metal concentrations in fish and freshwater mussels in our study are likely to be due to the different sampling locations, seasons, weight and age of the organisms. The present study found much higher concentration of heavy metals in water, sediment and aquatic animals than standard value of WHO and EQS.

Key words: Heavy metals, bio-accumulation, freshwater mussel, Shitalakhya river.

Introduction

The Shitalakhya river originates from the old Brahmaputra and bifurcates into two courses at Toke in Gazipur district. One of the courses named the banar flows southwest and at Lakpur is renamed as the Shitalakshya. It then flows east of Narayanganj town. The Shitalakshya falls into the Dhaleswari near Kalagachhiya. The length of the river is about 110 km and the width near Narayanganj is about 300 m but reduces to about 100 m in the upper reach. Its highest discharge has been measured at 2600 cumec at Demra. The river is navigable throughout the year and shows little erosional tendency. In the past, the famous muslin industry of the country flourished along the Shitalakhya. At present, a number of heavy industries including Adamjee Jute Mill (now closed) stand on the banks of this river. There are three thermal powerhouses located

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at Palash, north of Ghorashal, and one at Siddhirganj, on the bank of the river. The important riverport of Narayanganj is also situated on its bank. The river was once famous for its clear and cool water. The river goes under tidal effect for about five months of the year but normally does not overflow its banks.

The continuous development of agriculture, industrial and urban activities has given rise to a number of environmental problems. Heavy metal contamination in aquatic environment is of critical concern due to toxicity of metals and their accumulation in aquatic habitats. Trace metals in contrast to most pollutants are not bio-degradable, and they undergo a global ecological cycle in which natural waters are the main pathways. Metals introduced into the aquatic environment from domestic wastes, industrial effluents, ship breaking activities, urban run off, atmospheric deposition and mining activities are absorbed on to deposit and are incorporated into sediments. A large part of the trace metal input ultimately accumulates in the river zone.

However, fishes, shellfishes and other aquatic organisms inhabiting in the rivers, canals, etc. are not free from contaminants coming from industries and other sources. Although no study on the industrial waste management of the country is available till date, but it is true that every year huge amount of untreated toxic chemical waste products from several chemical and other industries of the country are released into the rivers, canals and drains. The heavy metals which are not utilized in the synthesis of new substances useful to the organisms lie in their ability to be stored up in enzymes and displace chemically similar elements. In this way vital bio-chemical reactions are blocked. Such an accumulation of heavy metals can harm the organism itself or can be transmitted to the food chain, where a similar toxic process can be involved into the adjacent water bodies and are carried downstream through the river waters (Casper, 1975). Indiscriminate use of these potentially toxic chemicals ultimately risks the stability of biota itself and also results in the disruption of the biogeochemical cycles of the ecosystem. The problem may be exacerbated due to increased concentrations of toxicants during summer paddy cultivation when rivers have low discharge (Karim, 1994). Heavy metals that are introduced into the aquatic environment are ultimately incorporated into the aquatic sediments and organisms living in the sediments (Bryan and Hummerstone, 1977). The sensitivity of macro-benthos to trace metal pollution may vary with the history, behaviour, and environmental factors other than trace metal levels. The availability of metals may vary widely depending on sediment characteristics, water chemistry and biological factors, and simple relationship between water of sediment levels and concentrations in aquatic organisms is seldom shown in field studies. Generally, macro-benthic fauna of metals polluted systems shows a reduction in total abundance, species richness and changes in the proportion abundance of different groups in contrast to non-impacted system. Gastropods, bivalves and crustaceans are regarded as being more sensitive to metal pollution than insects, and may-flies are often the least tolerant insects followed by chironomids (Mance, 1987).

Bio-accumulation of pollutants in aquatic organisms is an important aspect of toxicological research since pollutants can impose no effect unless they enter the tissues of living organisms. Consequently, much effort has been put into the monitoring of pollutant levels in the tissues of living organisms from natural populations, partly from the point of view of the control and monitoring of pollution and partly because of the possible public health implications. Thus a considerable volume of information has been acquired on the levels of pollutants in the tissues of species in the Shitalakhya river. However, it is important to establish the relationship between measured pollutant levels in plant and animal tissues and the existence of toxic effects, which have ecological significance. Potentially useful approaches to this question include several areas of investigation. Long-term studies on the population dynamics of species in polluted and unpolluted areas of the Shitalakhya river need to be established since populations inhabiting polluted areas are being ecologically affected by prevailing level of pollution.

Heavy metals in aquatic ecosystem eventually get accumulated in sediments where they may adversely affect the benthic biota, become a source of contamination in the water column, accumulate in biological tissues, and enter pelagic and human food chain. Contaminated sediments now appear to be the main source of toxicity in many bays, lakes and rivers. In terms of quality, the river water of the Shitalakhya is vulnerable to pollution from untreated industrial effluents and municipal wastewater, runoff from chemical fertilizers and pesticides, and oil and lube spillage in and around the operation of river ports (Alam et al., 2003). The risks of pollution impact are rising upwards sequentially (WARPO, 2000). The wastes, effluents and agrochemicals contain heavy metals, toxic substances, germs and nitrogen containing toxic substances. They pollute the natural system of Shitalakhya river, which actually act as a sink. They thereby create serious environmental hazards, endanger human health and cause problems to aquatic lives (Ahmed and Reazuddin, 2000).

As a riverine country 230 rivers have created an intricate river system in Bangladesh. However, limited data are available on the impact of agriculture, domestic and industrial pollution especially of heavy metals on aquatic environment. In Bangladesh the concentration of heavy metals in aquatic animals, water and sediment are studied by Ahmed et al. (2002, 2003, 2009a,b), Haque et al. (2003a,b, 2004, 2005, 2006, 2007), Chowdhury (1994), Hossain (1996), Khan et al. (1998), Ahmed (2000), Holmgren (1994), Biswas et al. (1998) and Sharif et al. (1991, 1992a,b, 1993a,b). Their study covered mostly coastal area, parts of GBM river system and some rivers of central parts. However, till date no systematic study yet has been carried out for heavy metal concentration in Shitalakhya river.

The objectives of the study were to determine the concentration of heavy metals, that is, nickel (Ni), copper (Cu), chromium (Cr), cadmium (Cd) and lead (Pb) from water, sediments, fish and different parts of freshwater mussel from Shitalakhya river, Bangladesh.

Materials and Methods

During pre-monsoon, monsoon and post-monsoon the samples of water, sediment, two species of adult fish *Trypauchen vagina* (Bloch & Schneider, 1801) locally called cheua and *Glossogobius giuris* (Hamilton, 1822) locally called bila and one species of adult bivalve mollusc (freshwater pearl mussel; *Lamellidens marginalis*) were collected from three stations of Shitalakhya river, namely Sation-1 (locally called Shilo), Station-2 (locally called Narayanganj launch ghat) and Station-3 (locally called Kalakaicha) (Figure 1).

Both *Trypauchen vagina* (cheua) and *Glossogobius giuris* (bila) are under the same family (Gobiidae) of order Perciformes. Cheua is demersal, occurs along the bottom in tidal rivers and estuaries and stays close to a self-dug burrow, while bila is benthopelagic, found in clear to turbid streams with rock, gravel or sand bottoms, feeds on small insects, crustaceans and small fish.

The water samples were collected with the help of one litre plastic bottles, which were previously soaked with a mixture of distilled water (975 ml), 2% HNO_3 (20 ml) and H_2SO_4 (5 ml) for about 24 hours. On the next day these bottles were scrupulously washed several times with distilled water, rinsed with double distilled water and then kept in an oven (60-70°C). The bottles were then ready for sample collection. The sediment samples were collected by vertical corer and Ekman grab sampler. The water and sediment samples were acidified

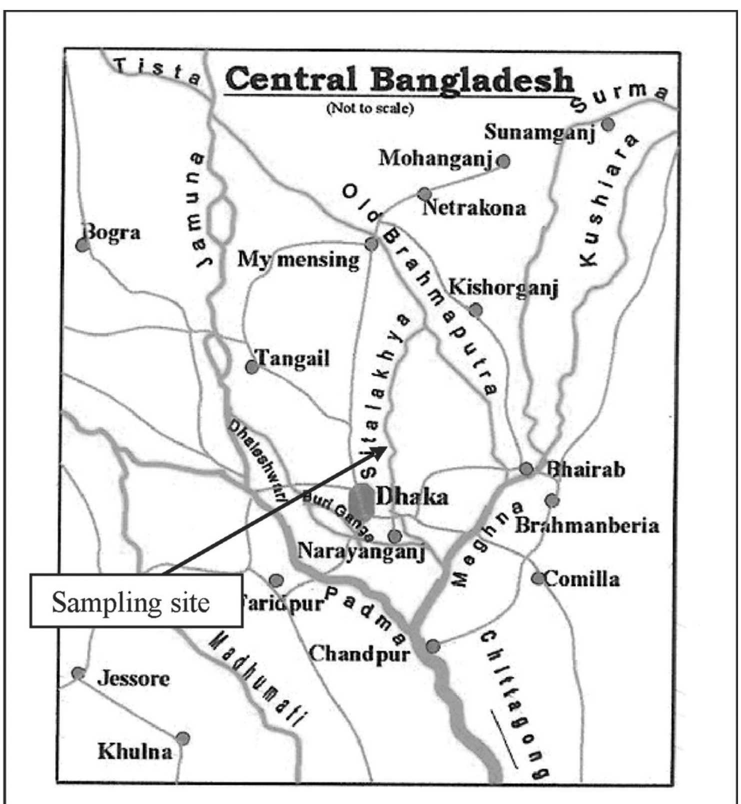

Figure 1: Location map of the Shitalakhya River in central Bangladesh.

immediately with 2 ml of HNO_3 per litre of water and preserved in refrigerator at 4°C for laboratory analysis. The local fishermen supplied the fish, which they collected by netting. All samples were taken in different polythene bags.

The mollusc samples were collected with an Ekman grab sampler, stake net (locally called Behundi net) and by hand. After collection of samples, fouling organisms were removed by washing with fresh water at the sampling site and the samples were kept overnight in fresh water for defecation. The molluscs were then cut open with the aid of teflon coated stainless steel knife and then dried to room temperature and weighed. The soft flesh was dried in an oven at 90°C to an anhydrous state until a constant weight (dry weight) was obtained. While, after collection the sediment and fish samples were washed, weighed and dried in an oven at 105°C until gaining constant weight. After cooling in a dessicator, all the samples were grinded by carbide mortar and pastel to make powder and homogenised. The powdered sediment and fish and mussel samples were finally stored in a pre-cleaned dry plastic bottle and preserved in dessicator for further analysis.

For the quantitative analyses of Ni, Cu, Cr, Cd and Pb, the samples were digested. Dried (0.5 gm) powder was taken in a long test tube. Then 1.0 ml 70% $HClO_4$, 4 ml concentrated HNO_3 and 1.5 ml concentrated H_2SO_4 were added into the test tube. The samples were then heated gently in an oil bath (~100°C) until the solid mass was dissolved. If sample was not clear, 4 ml of HNO_3 was added into the test tube and repeated until the solution was clear. Finally, the mixture was boiled at about 210°C in order to drive off the acids except H_2SO_4 and then it was cooled down at room temperature. Blank digestion was also performed to quantify possible contamination during sample preparation and analysis. The standard solution of the elements Ni, Cu, Cr, Cd and Pb were prepared by pipetting the required amount of the solution from the stock solution, manufactured by Fisher Scientific Company, USA. The standard solution was prepared before every analysis of the current work. The samples were analyzed by using air acetylene flame with combination, as well as single element hollow cathode lamps into an atomic absorption spectrophotometer (Shimadzu, AAS–6800). The analytical quality of the work was checked by analysis of standard reference materials NBS-SRM-1573, Tomato leaves and NBS-SRM-1566, Oyster tissue, prepared by the National Bureau of Standards, Washington DC, USA. The analytical procedures were also calibrated against the above standard reference materials. The average recovery ranged between 94 and 107%.

Statistical software SPSS version 12 was used at $P<0.05$ to analyse the data using ANOVA followed by LSD post-hoc for multiple comparison. The correlation matrix was carried out by Microsoft XL.

Results and Discussion

Concentration of Heavy Metals in Water

The concentration of heavy metals in water varied in all the stations during pre-monsoon, monsoon and post-monsoon (Table-1). The Pb, Cd, Ni, Cu and Cr in water were not different significantly ($P>0.05$) in pre-monsoon, monsoon and post-monsoon. The correlation matrix shows both positive and negative significant correlations among heavy metals (Table 2).

The highest concentration of Ni was 7.83 µg/L at station-1 in post-monsoon and the lowest was 4.31 µg/L

Table 2: Correlation matrix of heavy metals in Shitalakhya river water

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	-0.6995*	1			
Ni	0.9829*	-0.5558*	1		
Cu	-0.0392	0.7415*	0.1456	1	
Cr	-0.9993*	0.7257*	-0.9753*	0.0765	1

* Values >0.5 or < - 0.5 are significantly correlated.

Table 1: Heavy metal concentration (µg/L) in water of Shitalakhya river

Heavy metals	*Station-1*			*Station-2*			*Station-3*			*Average ±SD*
	Pre-monsoon	*Monsoon*	*Post-monsoon*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	
Ni	5.08	5.42	7.83	4.91	6.56	5.04	4.31	5.96	6.71	5.76±1.11
Pb	51.07	63.15	52.35	56.28	48.07	49.71	41.24	45.29	61.59	52.08±7.22
Cd	8.37	7.12	9.02	9.15	10.11	7.68	8.47	9.17	8.06	8.57±0.90
Cr	234.02	234.32	210.13	225.11	200.52	209.45	192.18	198.03	194.37	210.90±16.53
Cu	163.18	201.09	207.01	195.23	254.07	156.38	197.05	193.32	185.07	194.71±28.02

at station-3 in pre-monsoon. The average concentration of Ni was 5.76±1.11 µg/L. In water samples the highest concentration of Pb was 63.15 µg/L at station-1 in monsoon and the lowest was 41.24 µg/L at station-3 in pre-monsoon season. The average concentration of Pb was found to be 52.08±7.22 µg/L. The concentration of Pb in the present study is similar to the results of the study conducted by Abdullah and Royle (1974), and Khan and Talukder (1995). In the water of Ganges Brahmaputra Meghna Estuary, Khan et al. (1998) found the concentration of Pb ranges from 0.012 to 0.431 µg/ml, which is much lower than the current study.

The concentration of Cd varied from 7.12 µg/L at station-1 in monsoon to 10.11 µg/L at station-2 in monsoon. These variations may be due to different collection spots and seasons. The average concentration of Cd was 8.57±0.90 µg/L. Ahmed (1998) reported the concentration of Cd ranges from 0.018 and 0.007 ppm in water of the Sundarban Reserved Forest. Rao et al. (1985) found the range between 0.9 and 1.3 µg/g in dissolved form and 6.6 and 18 µg/g in particulate form. Values ranging from 0.2 and 0.4 µg/g have been reported from Ostofjorden, Norway and Liverpool Bay, U.K. by Peterson et al. (1972) and Rojahn (1972), respectively. The standard value of Cd for coastal water of Bangladesh is 0.3 µg/g (EQS, 1991). Khan et al. (1998) found the concentration of Cd ranges from 0.001 to 0.107 µg/ml in the water of Ganges-Brahmaputra-Meghna Estuary. All the concentrations are much lower than the present study which indicates the higher level of pollution in Shitalakhya river. The results of present study show more or less similar findings with Khan and Talukder (1995) and Chowdhury (1994).

The highest concentration of Cr was 234.32 µg/L in station-1 at monsoon and the lowest was 192.18 µg/L in station-3 at pre-monsoon season. The average concentration of Cr was 210.90±16.53 µg/L. Khan and Talukder (1995) found similar amount of Cr from the coastal water. Khan et al. (1998) found the concentrations of Cr ranges from 0.015 to 0.491 µg/ml in the water of Ganges-Brahmaputra-Meghna Estuary which are lower than the present study.

The concentration of Cu ranged from 156.38 µg/L in station-2 at post-monsoon season to 254.07 µg/L in station-2 at monsoon. The average concentration of Cu was 194.71±28.02 µg/L. Ahmed (1998) reported the concentration of Cu ranges between 0.11 µg/g and 0.021 µg/g in water of the Sundarban Reserved Forest Area. Rao et al. (1985) found the Cu concentration ranges between 6.8 and 30.6 µg/L in dissolved and 822 and 1801 µg/g in particulate form in Vishakhapattam. The standard for Cu given by Bangladesh Environmental Quality Standard (EQS) is 0.03 µg/g. The present findings differ greatly from above authors, which marks the state of Cu pollution in Shitalakhya river.

Ahmed et al. (2009a) studied the heavy metal concentration in water of the river Dhaleswari, Bangladesh and found the concentrations of Ni, Pb, Cd, Cr and Cu varied seasonally and spatially from 5.47-9.74, 38.25-63.28, 5.29-8.20, 378.87-501.11 and 98.37-188.08 µg/L, respectively, which are more or less similar with present study and the findings of Ahmed (2009c) who investigated the heavy metal concentration in the water of Buriganga river, Bangladesh. Like present study, the authors also mentioned the variations of concentrations likely to be due to different collection spots and seasons.

Concentration of Heavy Metals in Sediment

A wide range of heavy metal concentration was observed in the sediments of the Shitalakhya river (Table 3). The Pb, Cd, Ni, and Cu in sediment were not different significantly ($P>0.05$), whereas Cr differed significantly ($P<0.05$) in pre-monsoon, monsoon and post-monsoon. The correlation matrix shows significant positive correlations among heavy metals (Table 4).

Concentration of Ni varied from 120.96 mg/kg at station-1 in pre-monsoon to 131.94 mg/kg at station-2 in post-monsoon. The average concentration of Ni was observed 126.21±3.70 mg/kg. The highest concentration of Pb was 65.90 mg/kg at station-1 in pre-monsoon and

Table 3: Heavy metal concentration (mg/kg) in sediment in dry weight basis of Shitalakhya river

Heavy metals	*Station-1*			*Station-2*			*Station-3*			*Average ± SD*
	Pre-monsoon	*Monsoon*	*Post-monsoon*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	
Ni	120.96	130.50	127.03	123.17	124.17	131.94	128.91	123.19	126.04	126.21±3.70
Pb	65.90	54.52	59.52	58.25	54.90	56.01	58.51	63.51	61.57	59.19±3.89
Cd	2.15	2.09	2.17	1.71	1.85	1.96	1.93	1.86	1.91	1.96±0.15
Cr	63.46	68.17	91.02	60.09	63.96	86.34	60.09	64.84	84.19	71.35±12.24
Cu	84.5	72.51	91.51	85.13	81.72	74.53	56.07	76.36	86.17	78.72±10.47

Table 4: Correlation matrix of heavy metals in Shitalakhya river sediment

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	-0.1174	1			
Ni	-0.4741	0.9300*	1		
Cu	-0.2537	0.9904*	0.9719*	1	
Cr	-0.2406	0.9922*	0.9687*	0.9999*	1

* Values >0.5 or < - 0.5 are significantly correlated.

lowest was 54.52 mg/kg at station-1 in monsoon. The average concentration of Pb was 59.19±3.89 mg/kg. Khan et al. (1998) reported the Pb concentration ranges from 2.355 to 26.086 mg/kg in sediment which are remarkably similar to Abdullah and Royle (1974), Chowdhury (1994) and Khan and Talukder (1995).

In our study Pb concentrations were not lower than the certified value and therefore it could be harmful for soil and benthic community. The highest concentration of Cd was 2.17 mg/kg at station-1 in post-monsoon and the lowest was 1.71 mg/kg at station-2 in pre-monsoon. The average concentration of Cd was 1.96±0.15 mg/kg. In our study the concentration of Cd did not exceed the standard value and therefore indicated that it was not so harmful for soil and for the benthic organisms within the sediments. The highest concentration of Cr was 91.02 mg/kg at station-1 in post-monsoon and lowest was 60.09 mg/kg at station-2 in pre-monsoon and at station-3 in pre-monsoon. The average concentration of Cr was 71.35±12.24 mg/kg. The amount of Cr found in our study was harmful to soil and the benthic community. The concentration of Cu ranged from 56.07 mg/kg in station-3 at pre-monsoon to 91.51 mg/kg in station-1 at post monsoon. The average concentration of Cu was 78.72±10.47 mg/kg in this study. The concentration of Cu found in our study was harmful for the benthic community.

Sediments are the sources of organic and inorganic matter in the river, estuaries, and oceans. Bottom sediments have the capacity to exchange of cations with the surrounding water medium. Trace elements, especially heavy metals are concentrated in the surface micro-layer by transport of particle-associated bubbles. Despite injection of trace elements by streams, whether natural or artificial, since most of the impute becomes trapped in the sediments and incorporated mainly into organic matter, most of the cationic forms have very little chance of leaving an estuarine and coastal area in solution (Haque et al., 2007). Any contaminant element is normally introduced into the sediments in a physico-chemical form, which permit it to enter the natural cycling of element in the discharge ecosystem (Segar and Pellenberg, 1973).

The bio-availability of heavy metals may widely depend on sediment characteristics, water chemistry, hydrography and biological factors etc. The deposits reflect the biological, chemical and physical condition of water body and become a signature to the state of heavy metal concentration in aqueous system (Ahmed et al., 2002). Many of these metals (for example, cobalt, copper, manganese, molybdenum, nickel and zinc) are essential trace elements for aquatic organisms and are involved in biochemical processes such as enzyme activation. However, although essential in small amounts, many are toxic at only slightly elevated free ion concentrations (Furnas, 1991). Others such as cadmium, lead and mercury have no known biological roles and are detrimental to essential life processes (Burden-Jones and Denton, 1984).

Ahmed et al. (2009a) studied the heavy metal concentration in sediment of the river Dhaleswari, Bangladesh and found the concentrations of Ni, Pb, Cd, Cr and Cu ranges from 135.02-231.44, 58.19-70.26, 2.11-4.14, 95.76-141.27 and 31.53-76.52 mg/kg, respectively in dry weight basis, which are more or less similar with present study and the findings of Ahmed (2009c) who investigated the heavy metal concentration in the sediment of Buriganga river, Bangladesh. Like present study, the authors also mentioned the variations of concentrations likely to be due to different collection spots and seasons.

Ahmed (1998) found the highest and lowest concentration of Pb as 61.66 and 10.96 mg/kg, Cd as 0.817 µg/g and 0.121 µg/g, Cu as 50.5 µg/g and 6.89 µg/g and Cr as 120.8 µg/g and 20.2 µg/g, in sediment of the Sundarban Reserved Forest. The Cd concentration in the sediments of Baltic Sea ranged between 0.2 and 2.2 µg/g, while the values for the North Sea are below 1 µg/g for 80% of the samples (Nicholson and Moore, 1981). Mehedi (1994) found the concentration of Cd ranged from 0.8 to 0.88 µg/g and Cu ranged from 3.8 µg/g and 60.88 µg/g in ship breaking area of Chittagong. Chester and Stonar (1975) found as high as 2424 µg/g of Cu and 624 µg/g of Cr in sediments of Sorfijord, West Norway. Bryan and Hummerstone (1977) studied on the heavy metal concentration in the Looe estuary and found the highest concentration of Cr as 5 µg/g. According to Legorburu and Canton (1992) the standard values from the analysis of marine sediment (SD-N-1/2), in the IAEA laboratory in Monaco, are 120 mg/kg for Pb, 11 µg/g for Cd, 72 µg/g for Cu and 149 µg/g for Cr. The present investigations show lower concentration of the above heavy metals except Cu. However, the certified value of Pb from USSR state standard reference material No. 2499-83, Soil SDPS-2 is 7±5 µg/g and the present study did not find concentrations of Pb lower than the certified value and therefore harmful for soil and benthic community.

Heavy Metal Concentration in Fish

In *P. sophore* and *G. giuris* heavy metals were found to have a broad range of variation (Table 5). The Pb, Cd, Ni, Cu and Cr were not different significantly (P>0.05) between *Puntius sophore* and *Glossogobius giuris*. The correlation matrix shows both positive and negative significant correlations among heavy metals in both of the two fishes (Tables 6 and 7). In *P. sophore* the highest concentration of Ni was 13.01 mg/kg in monsoon and the lowest was 9.07 mg/kg in post-monsoon. The average concentration of Ni was 11.53±2.14 mg/kg. Khan et al. (1986) found it to vary between 2.70 and 15.2 mg/kg in dry weight basis for different species of fishes. The highest concentration of Pb was observed 10.09 mg/kg in post-monsoon and the lowest was observed 8.01 mg/kg in monsoon. The average concentration of Pb was 9.09±1.04 mg/kg. The highest concentration of Cd was 1.13 mg/kg in post-monsoon and lowest was 0.85 mg/kg in pre-monsoon. The average concentration of Cd was 0.96±0.15 mg/kg. The concentration of Cr ranged from 2.94 mg/kg at post monsoon to 4.01 mg/kg at monsoon. The average concentration of Cr was 3.63±0.60 mg/kg. The highest concentration of Cu was 5.27 mg/kg in monsoon and the lowest was in post-monsoon as 4.92 mg/kg. The average concentration of Cu was observed 5.07±0.18 mg/kg. These variations are likely to be due to the different sampling locations, seasons, weight and age of the fishes. According to WHO (1982) the concentration of all the metals in this species was very high.

In *G. giuris*, the highest concentration of Ni was 11.32 mg/kg in post-monsoon and the lowest was 10.53 mg/kg in pre-monsoon and monsoon. The average concentration of Ni was 10.79±0.46 mg/kg. The result of the present investigation is similar to the findings of the study of Khan et al. (1986). The highest concentration of Pb was 9.17 mg/kg in post-monsoon and the lowest was 7.17 mg/kg in monsoon. The average concentration of Pb was observed 8.24±1.01 mg/kg in this study. The highest concentration of Cd was 1.07 mg/kg during post-monsoon and the lowest was observed in monsoon as 0.81 mg/kg. The average concentration of Cd was observed as 0.97±0.14 mg/kg. The values of Cr concentration varied from 3.13 mg/kg in pre-monsoon to 3.37 mg/kg in monsoon. The average concentration of Cr was 3.25±0.12 mg/kg. The highest concentration of Cu was 6.03 mg/kg during monsoon and the lowest was 5.19 mg/kg during pre-monsoon. The average concentration of Cu was 5.54±0.44 mg/kg which was similar to Khan et al. (1986).

Table 6: Correlation matrix of heavy metals in *Puntius sophore* (dry wt. basis) of Shitalakhya river

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	0.7003*	1			
Ni	-0.8912*	-0.9479*	1		
Cu	-0.9845*	-0.5644*	0.7979*	1	
Cr	-0.8576*	-0.9677*	0.9976*	0.7543*	1

* Values >0.5 or < - 0.5 are significantly correlated.

Table 7: Correlation matrix of heavy metals in *Glossogobius giuris* (dry wt. basis) of Shitalakhya river

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	0.9745*	1			
Ni	0.8029*	0.6486*	1		
Cu	-0.7876*	-0.9058*	-0.2651	1	
Cr	-0.6339*	-0.7914*	-0.0481	0.9758*	1

* Values >0.5 or < - 0.5 are significantly correlated.

Table 5: Heavy metal concentration (mg/kg) in fish in dry weight basis in Shitalakhya river

Heavy metals	*Puntius sophore*				*Glossogobius giuris*			
	Pre-monsoon	*Monsoon*	*Post-monsoon*	*Average ±SD*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Average ±SD*
Ni	12.50	13.01	9.07	11.53±2.14	10.53	10.53	11.32	10.79±0.46
Pb	9.17	8.01	10.09	9.09±1.04	8.37	7.17	9.17	8.24±1.01
Cd	0.85	0.91	1.13	0.96±0.15	1.02	0.81	1.07	0.97±0.14
Cr	3.95	4.01	2.94	3.63±0.60	3.13	3.37	3.24	3.25±0.12
Cu	5.02	5.27	4.92	5.07±0.18	5.19	6.03	5.41	5.54±0.44

The variation of concentrations of different heavy metals of both of these two fish are likely due to the different collection spots, seasons, weight and age of the fish. The much higher concentration are likely due to surrounding water and sediment which are polluted by industrial, agriculture and domestic waste originated from surrounding as well as upstream environment. Aquatic organisms living in the sediment accumulate heavy metal to a varying degree (Bryan and Hummerstone, 1977).

Ahmed et al. (2009a) studied the heavy metal concentration in *Trypauchen vagina* of the river Dhaleswari, Bangladesh and found the concentration of Ni, Pb, Cd, Cr and Cu varied seasonally from 6.35-9.56, 6.14-8.03, 0.51-0.73, 6.92-12.23 and 5.43-9.45 mg/kg, respectively. They also found the concentration of Ni, Pb, Cd, Cr and Cu varied seasonally from 4.75-10.17, 4.25-8.17, 0.61-0.71, 7.15-11.92, and 5.17-7.48 mg/kg, respectively in *G. giuris*, which are more or less similar with present study and the findings of Ahmed (2009c) who investigated the heavy metal concentration in *G. giuris* of Buriganga river, Bangladesh. Like present study, the authors also mentioned the variations of concentrations likely to be due to different collection spots and seasons.

Sharif et al. (1992b) studied the heavy metal concentration in *T. vagina* and found the concentration of Ni, Cu, Pb and Cd as 2.4±0.00, 3.76±0.48, 2.42±0.27 and 0.11±0.00 mg/kg (dry weight basis), which are much lower than the present study. There may have several reasons for this; firstly, unlike the current study where fish were collected from one of the polluted river, auction markets were the sources of fish originated from variable habitat. Secondly, only flesh of fish that contains relatively less amount of heavy metal than other parts of the body (Wright, 1976) was analysed, while on the other hand, whole body was analysed in the current experiment. Moreover, the size was variable (100-500 gm), whereas present study was conducted with adult fish. Sharif et al. (1992a) and Sharif et al. (1993b) found much lower concentrations of Pb and Cd and Cr, respectively in different marine fish of the Bay of Bengal than those of present investigation and well below the permissible levels of human consumption. These variations are likely due to difference of habitat in addition with the reasons mentioned above for Sharif et al. (1992b).

In Buriganga river in *Puntius sophore*, Haque et al. (2003b) found seasonal variation of Pb, Cd, Cu and Ni ranges from 1.46-3.07, 0.24-0.41, 3.59-5.66 and 0.94-4.59 mg/kg, respectively in 1999. In the same river they also found seasonal variation of Pb, Cd, Cu and Ni ranges from 1.20-3.41, 0.24-0.58, 3.71-5.69 and 1.17-8.68 mg/kg, respectively in *Mystus vittatus* in 1999. These concentrations are much lower than the present study except Cu. These variations may be due to the species and age of fish, temporal variation of sampling and use of different methods for sample analysis (spectrophotometer).

Haque et al. (2006) studied the seasonal variation of heavy metals concentrations in *Gudusia chapra* inhabiting the Sundarban mangrove forest and found the concentration of Cu, Zn, Fe, Pb, Cd, Cr and Ni seasonally varied from 0.527-3.99, 5.34-25.9, 0.038-0.221, 0-3.396 and 0.176-89.5 µg/g dry weight basis, respectively. The concentrations of these heavy metals are well below the present findings. Like present study, these authors mentioned industrial discharge and pollution from upstream environment as the main reasons. However, they also included upstream discharge from neighbouring countries as sources of pollution.

Holden and Topping (1972) found lead concentrations range from 0.5 to 1.0 mg/kg in wet weight basis of different species of fishes. Khan et al. (1987) found that Ni concentration varies between 2.70 and 15.2 mg/kg in dry weight basis for different species of fishes. Zindge et al. (1979) found the Cu concentration ranges between 2.80 and 12.40 ppm in different fish species. Khan et al. (1987) found Cu varies between 0.65-58.1 mg/kg in dry weight basis for different species of fishes. Roth and Hornung (1977) found Cr varies between 2.8 to 4.9 mg/kg in wet weight basis for different species of fishes.

Heavy Metal Concentration in Freshwater Mussels

Heavy metals were analyzed from a bio-indicator macrobenthos (*Lamellidens marginalis)* collected from the Shitalakhya river. The Pb, Cd, Ni, and Cu were not different significantly (P>0.05) in shell portions, whole body portions and muscles of freshwater mussels, whereas the Cr was different significantly (P<0.05) between whole body portions and muscles. The correlation matrix shows both positive and negative significant correlations among heavy metals in different parts (Tables 8, 9 and 10). The results (Table 11) of different heavy metals in the samples are discussed below.

Lamellidens Marginalis (Shell Portions)

In the shells of *L. marginalis* the highest concentration of Ni was 12.13 mg/kg during post-monsoon and the lowest was observed during monsoon as 8.05 mg/kg. The average concentration of Ni was 9.98 mg/kg. The highest concentration of Pb was 12.36 mg/kg during post-monsoon and the lowest was 9.01 mg/kg during pre-monsoon. The average concentration of Pb was 10.89 mg/kg in this study. The concentration of Cd varied from 0.97 mg/kg during post-monsoon to 1.47 mg/kg at

Table 8: Correlation matrix of heavy metals in shell portions of freshwater mussels (dry wt. basis) of Shitalakhya river

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	0.0953	1			
Ni	0.3971	-0.8758*	1		
Cu	0.2725	0.9837*	-0.7748*	1	
Cr	-0.9995*	-0.0638	-0.4259	-0.2419	1

* Values >0.5 or < - 0.5 are significantly correlated.

Table 9: Correlation matrix of heavy metals in whole body portions of freshwater mussels (dry wt. basis) of Shitalakhya river

	Pb	*Cd*	*Ni*	*Cu*	*Cr*
Pb	1				
Cd	-0.8612*	1			
Ni	0.7139*	-0.9707*	1		
Cu	0.6093*	-0.9277*	0.9902*	1	
Cr	-0.8531*	0.9999*	-0.9744*	-0.9335*	1

* Values >0.5 or < - 0.5 are significantly correlated.

monsoon. The average concentration of Cd was 1.16 mg/kg. The concentration of Cr ranged from 7.93 mg/kg during post-monsoon to 8.16 mg/kg during pre-monsoon. The average concentration of Cr was observed as 8.03 mg/kg. The highest concentration of Cu was 8.19 mg/kg in monsoon and the lowest was 7.04 mg/kg in pre-monsoon season. The average concentration of Cu was 7.45 mg/kg. Ahmed et al. (2009a) studied the heavy metal concentration in the whole body portion of *L. marginalis* of the river Dhaleswari, Bangladesh and found the concentration of Ni, Pb, Cd, Cr and Cu varied seasonally from 6.07-11.32, 7.03-59.21, 0.56-7.23, 9.38-501.11 and 7.55-183.87 mg/kg, respectively, in dry weight basis, which are more or less similar with present study. Like present study, the authors also mentioned the variations of concentrations likely to be due to different collection spots and seasons.

Table 10: Correlation matrix of heavy metals in muscles of freshwater mussels (dry wt. basis) of Shitalakhya river

	Pb	Cd	Ni	Cu	Cr
Pb	1				
Cd	-0.3314	1			
Ni	0.7071*	-0.9015*	1		
Cu	-0.9815*	0.1445	-0.5585*	1	
Cr	-0.5879*	0.9580*	-0.9877*	0.4221	1

* Values >0.5 or < - 0.5 are significantly correlated.

Lamellidens Marginalis (Whole Body Portions)

In the whole body portions of *L. marginalis* the highest concentration of Ni was 9.72 mg/kg in post-monsoon and the lowest was 7.02 mg/kg in monsoon. The average concentration of Ni was 8.42 mg/kg. Sericano et al. (2001) reported the mean concentration of Ni in molluscs (bivalves) from Kara Sea and its adjacent rivers of Russia as 6.4±2.7 µg/g. Bryan and Hummerstone (1977) studied heavy metal concentration in molluscs (*Littorina littorea*) from the Looe estuary and found the concentrations of Ni varied from 2.2 to 4.1 µg/g. Bustamante et al. (2000) reported the mean concentration of Ni in molluscs from New Caledonia as 6.7±3.0 µg/g. Páez-Osuna et al. (1993) found the average concentration of Ni in molluscs from NW Coast Mexico as 3.8 µg/g. Goldberg et al. (1983) found that the average concentration of Ni in molluscs from Gulf Coast, USA as 1741 µg/g. Páez-Osuna and Marmolejo-Rivas (1990) found that the average concentration of Ni in molluscs from Coast of Mazatlan, Sinaloa, Mexico as 424 µg/g.

The highest concentration of Pb was 15.51 mg/kg in pre-monsoon and the lowest was 12.07 mg/kg in monsoon. The average concentration of Pb was 14.0 mg/kg. Sericano et al. (2001) reported the mean concentration of Pb in molluscs (bivalves) from Kara Sea and its adjacent Rivers, Russia as 1.4±0.1 µg/g. Miramand and Bentley (1992) observed the highest concentrations of Pb as 3.75 µg/g and 2.0 µg/g in *Petella* sp and *Fucus serratus*, respectively. The present findings exceeded the

Table 11: Heavy metal concentration (mg/kg) in freshwater mussels *(Lamellidens marginalis)* in dry weight basis in Shitalakhya river

Heavy metals	*Shell portions*				*Whole body portions*				*Muscles*				*Average ±SD*
	Pre-monsoon	*Monsoon*	*Post-monsoon*	*Average*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Average*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Average*	
Ni	9.77	8.05	12.13	9.98	8.51	7.02	9.72	8.42	9.07	8.19	9.05	8.77	9.06±1.44
Pb	9.01	11.29	12.36	10.89	15.51	12.07	14.43	14.00	13.09	9.16	10.14	10.80	11.90±2.25
Cd	1.03	1.47	0.97	1.16	1.15	1.72	0.98	1.28	1.14	1.21	1.09	1.15	1.20±0.25
Cr	8.16	8.01	7.93	8.03	7.36	8.07	7.13	7.52	8.26	9.07	8.12	8.48	8.01±0.55
Cu	7.04	8.19	7.13	7.45	6.31	5.69	7.13	6.38	5.47	8.19	8.04	7.23	7.02±1.03

concentrations observed by Miramand and Bentley. The concentration of Pb observed by Ahmed et al. (2009b) in mud crab as 6.77 µg/g, horseshoe crab 5.28 µg/g, mud skipper 4.99 µg/g, hermit crab 6.5 µg/g and gastropod 4.66 µg/g. Among the five samples, mud crab contained highest value of Pb (6.77 µg/g) and hermit crab contained lowest value of Pb (4.66 µg/g) in their body (Ahmed et al., 2009b). Zorba et al. (1992) observed highest concentration of Pb within a range between 1.23 µg/g and 2.91 µg/g and stated that the variation in concentration was due to the seasonal changes and also with the influence of temperature and salinity.

The highest concentration of Cd was observed 1.72 mg/kg in monsoon and the lowest was observed 0.98 mg/kg in post-monsoon. The average concentration of Cd was observed as 1.28 mg/kg. Sericano et al. (2001) reported the mean concentration of Cd in molluscs (bivalves) from Kara Sea and its adjacent rivers, Russia as 2.7±0.42 µg/g. Bryan and Hummerstone (1977) studied on heavy metal concentration in molluscs (*Littorina littorea*) from the Looe estuary and found the concentrations of Cd varied from 0.49 to 2.56 µg/g. Bustamante et al. (2000) reported the mean concentration of Cd in molluscs from New Caledonia as 16±6.5 µg/g. Al Madfa et al. (1998) found the average concentration of Cd in molluscs from Arabian Gulf as 0.49 µg/g. Páez-Osuna and Marmolejo-Rivas (1990) found the average concentration of Cd in molluscs from NW Coast Mexico as 6.0 µg/g. Goldberg et al. (1983) found the average concentrations of Cd in molluscs from Gulf Coast, USA as 5.1 µg/g. Páez-Osuna et al. (1993) found the average concentration of Cd in molluscs from Coast of Mazatlan, Sinaloa, Mexico that was 3.6 µg/g. Watling and Watling (1976) found the average concentration of Cd in molluscs from Langebaan Lagoon, South Africa that was 9 µg/g. Zorba et al. (1992) worked on clams as pollution bio-indicators in Kuwait's marine environment: metal accumulation and deposition and observed highest concentration of Cd within range between 0.18 µg/g and 0.32 µg/g and stated that accumulation of Cd in clam depends on the bio-availability of Cd in sea water and sediment. Miramand and Bentley (1992) observed the highest concentration of Cd within a range between 0.5 µg/g and 1.9 µg/g in*Ficus* sp. and 2.7 µg/g and 7.5 µg/g in *Patella* sp. Segar and Pellenberg (1971) worked on the distribution of the major and some minor elements in marine animals and observed the highest concentration of Cd as 31 µg/g. The findings of Segar were much more higher in comparison with the present findings. Uptake rate increase with temperature in *Crassotrea viginica* (Zaroogian, 1980). These two authors also recorded increased uptake at lowest salinity. Most concentrations of Cd in mollusks may accumulate Cd from littoral algae, and this may be accumulated by carnivorous feeding on these organisms (Davies, 1991). Cadmium is taken up through Ca channels in mammalian cells as well as in fish. Cd uptake in fish is inhibited by high aqueous Ca concentrations. Conversely, Cd has been shown to have an inhibitory effect on Ca uptake in fish. The inhibition of Cd uptake by Ca channel blockers has been reported in excised gills of the bivalves *Anodonta anatina*. Increasing aqueous Ca concentration reduces Cd accumulation in both the shore crab *Carcinus maenas* and the amphipod *Hyalelle azteca* (Haque et al., 2007). Segar et al. (1971) worked on the distribution of the major and some minor elements in marine animals and observed the highest concentration of Cd as 31 µg/g.

The highest concentration of Cr was 8.07 mg/kg in monsoon and the lowest was 7.13 mg/kg in post-monsoon. The average concentration of Cr was 7.52 mg/kg. Sericano et al. (2001) reported the mean concentration of Cr in molluscs (bivalves) from Kara Sea and its adjacent rivers, Russia that was 19±1.2 µg/g. Bryan and Hummerstone (1977) studied heavy metal concentration in molluscs (*Littorina littorea*) from the Looe estuary and found the concentrations of Cr varied from 0.13 to 0.98 µg/g. Bustamante et al. (2000) reported the mean concentration of Cr in molluscs from New Caledonia as 2.6±0.3 µg/g. Bryan (1973) studied seasonal variation of trace metal concentration in molluscs and found that the mean concentration of Cr was 1.3 µg/g. Al Madfa et al. (1998) found the average concentration of Cr in molluscs from Arabian Gulf as 2.79 µg/g. Páez-Osuna et al. (1993) found that the average concentration of Cr in molluscs from NW Coast Mexico was 2.7 µg/g.

The concentration of Cu varied from 5.69 mg/kg in monsoon to 7.13 mg/kg in post-monsoon. The average concentration of Cu was 6.38 mg/kg. Sericano et al. (2001) reported the mean concentration of Cu in molluscs (bivalves) from Kara Sea and its adjacent rivers, Russia was 51±32 µg/g. Bryan and Hummerstone (1977) studied on heavy metal concentration in molluscs (gastropods) from the Looe estuary and found the concentrations of Cu varied from 10 to 194 µg/g. Bustamante et al. (2000) reported the mean concentration of Cu in molluscs from New Caledonia as 73±20 µg/g. Al Madfa et al. (1998) found the average concentration of Cu in molluscs from Arabian Gulf as 7.08 µg/g. Páez-Osuna et al. (1993) found the average concentration (119 µg/g) of Cu in molluscs from NW Coast Mexico. Goldberg et al. (1983) found the average concentration of Cu in molluscs from Gulf Coast, USA as 258 µg/g. Páez-Osuna and

Marmolejo-Rivas (1990) found the average concentration of Cu in molluscs from NW Coast of Mazatlan, Sinaloa, Mexico as 93 µg/g. Watling and Watling (1976) found the average concentration of Cu (12 µg/g) in molluscs from Langebaan Lagoon, South Africa. Zorba et al. (1992) worked on clams as pollution bio-indicators in Kuwait's marine environment and observed highest concentration of Cu (12.5 µg/g) and stated that the concentration of Cu attained in clam by burrowing in sand is their natural occurrence and by their enriched affected pollution from sediments. Miramand and Bentley (1992) worked on heavy metals concentrations in two biological indicators (*Patella vulgata* and *Fucus serratus*) and observed the highest concentration of Cu within the range of 3.0 µg/g to 6.6 µg/g in *Patella* sp. and 0.8 µg/g to 2.0 µg/g in *Fucus* sp. with seasonal fluctuation. He stated that Cu accumulated in both the species due to the industrial activities of nuclear fuel processing plant which deliberate nuclear fuel on its adjacent surrounding biological environment. The present findings substantiated the finding of Miramand and Bentley, but the present investigation, the enrichment of Cu in macrobenthic fauna might be due to the industrial and agrochemicals input of Cu in water and sediments. Cu is intimately related to the aerobic degradation of organic matter (Das and Nolting, 1993).

Lamellidens Marginalis (Muscles)
In the muscles of *L. marginalis* the highest concentration of Ni was 9.07 mg/kg in pre-monsoon and the lowest was 8.19 mg/kg in monsoon. The average concentration of Ni was 8.77 mg/kg. The highest concentration of Pb was 13.09 mg/kg in pre-monsoon and the lowest was 9.16 mg/kg in monsoon. The average concentration of Pb was 10.80 mg/kg. The highest concentration of Cd was 1.21 mg/kg in monsoon and the lowest was 1.09 mg/kg in post-monsoon season. The average concentration of Cd was 1.15 mg/kg. The concentration of Cr ranged from 8.12 mg/kg in post-monsoon to 9.07 mg/kg in monsoon. The average concentration of Cr was 8.48 mg/kg. The range of Cu concentration varied from 5.47 mg/kg in pre-monsoon to 8.19 mg/kg at monsoon. The average concentration of Cu was 7.23 mg/kg. The concentration of heavy metals in oysters in our study does not resemble to the standard value (WHO, 1982).

These variations of metal concentrations in fish and freshwater mussels in our study are likely to be due to the different sampling locations, seasons, weight and age of the organisms. Molluscs are known to concentrate metals in their body shells in varying proportions depending upon the species, environmental condition, detoxification and inhibitory process (Haque et al., 2007). Simkiss and Taylor (1989) discussed the pathways of metal accumulation by aquatic organisms, and identified six possible types. It is generally accepted that trace elements are taken up by aquatic biota in a passive process, down a concentration gradient into tissues. This can occur despite the presence of much higher concentrations of the elements in the tissues than in the external medium, as the metals in the tissues are bound to a wide range of biochemical sites (Manson et al., 1988). In a few instances, uptake may also occur through ion pumps, and in these cases, an energy dependence exists (Rainbow, 1995; Wright, 1995). It is obvious that heavy metals are bio-accumulated.

Conclusions

Through food chain these heavy metals enter into the human body. These metals are very toxic and can damage red blood cells, kidney tissues and testicular tissues. Exposure to some metals can cause a number of adverse health effects and is suspected for causing mental retardation in exposed children. Obviously it is important to prevent such elements from getting into water. Here the practice of green technology plays an important role. One approach is to strictly forbid the release of heavy metals into water. A much better approach can be possible to use the principles of green chemistry and technology to avoid any possibility of pollutant release. For example, a command-and-control approach to prevent the release of cadmium in electroplating operations would be to strictly control any release. But a green technology approach is to come up with safer substitutes for cadmium in metal treatment so that there is never any cadmium around to be released. Similar approach can be tried with any other water pollutant.

References

Abdullah, M.I. and L.G. Royle (1974). A study of the dissolved and particulate trace elements in Bristol Channel. *J. Mar Biol.*, **54:** 581-597.

Ahmed, F. (1998). Heavy metals in the water and sediment of the Sundarbans Reserved Forest (Undergraduate unpublished thesis). Discipline of Fisheries and Marine Resource Technology, Khulna, University, Khulna, Bangladesh.

Ahmed, M.K. (2000). An Assessment of Trace Metal Pollution in Coastal Areas of Bangladesh. Paper presented at the International Symposium held in Tokyo from 3-10 December 2000 on "Coastal Pollution and Nutrient Cycles" organized by United Nations University.

Ahmed, M.K., Mehedi, M.Y., Hauqe, R. and F. Ahmed (2002). Heavy Metal Concentration in Water and Sediment of Sundarbans Mangrove Forest, Bangladesh. *Asian Jr. of Microbiol. Biotech. Env. Sc.*, **4(2):** 171-179.

Ahmed, M.K., Mehedi, M.Y., Haque, R. and R.K. Ghosh (2003). Concentration of Heavy Metals in two Upstream Rivers Sediment of the Sundarban Mangrove Forest. *Asian Jr. of Microbiol. Biotech. Env. Sc.*, **5(1):** 41-47.

Ahmed, M.K., Ahmed, S., Rahman, S., Haque, M.R. and M.M. Islam (2009a). Heavy metal concentrations in water, sediments and their bio-accumulations in fishes and oyster in Dhaleswari River. *Terrestrial and Aquatic Environmental Toxicology*, **3(1):** 33-41.

Ahmed, M.K., Mehedi, M.Y., Haque, M.R. and P. Mondol (2009b). Heavy Metal Concentrations in Some Selected Macro-benthic Fauna of the Sundarbans Mangrove Forest, Bangladesh. *Environmental Monitoring and Assessment* (*in press*).

Ahmed, M.K., Islam, M.S., Rahman, S., Haque, M.R. and M. M. Islam (2009c). Heavy metals in water, sediment and some pelagic and benthic fishes of Buriganga River, Bangladesh. *International Journal of Environmental Research*, **4(2):** *in press*.

Ahmed, A.U. and M. Reazuddin (2000). Industrial Pollution of Water Systems in Bangladesh. *In:* Rahman, A.A., Huq, S. and Conway, G.R. (ed), Environmental System of Surface Water Systems of Bangladesh, University Press Limited, Dhaka, Bangladesh. pp 175-178.

Alam, A.M.S., Islam, M.A., Rahman, M.A., Siddique, M.N. and M.A. Matin (2003). Comparative study of the toxic metals and non-metal status in the major river system of Bangladesh. *Dhaka Univ. J. Sci.*, **51(2):** 201-208.

Al-Mafda, H., Abdel-Moati, M.A.R. and F.H. Al-Gimaly (1998). *Pinctada radiata* (Pearl Oyster): A Bioindicator for Metal Pollution Monitoring in the Qatari Waters (Arabian Gulf). *Bull. Environm. Contam Toxicol.*, **60:** 245-251.

Biswas, S.K., Sharif, A.K.M., Alamgir, M. and D.A. Choudhury (1998). Mercury level of some marine fishes from the Bay of Bengal. *The Journal of NOAMI*, **15(2):** 1-5.

Bryan, G.W. (1973). The occurrence and seasonal variation of trace metals in the scallops *Pecten maximus* (L) and *Chlamys opercularis* (L). *J. of the Marine Biological Association of the UK.*, **53:** 145-166.

Bryan, G.W. and L.G. Hummerstone (1977). Indicators of heavy metal contamination in the Looe Estuary (Comwall) with particular regard to Silver and Lead. *J. Mar. Biol.*, **57:** 75-92.

Burden-Jones, C. and G.W. Denton (1984). Metals in Marine Organisms from the Great Barrier Reef Province (Final Report, Part 1, Baseline Survey). Department of Marine Biology, James Cook University, Townsville.

Bustamante, P., Grigioni, S., Boucher-Rodoni, R., Caurant, F. and P. Miramand (2000). Bioaccumulation of 12 trace elements in the tissues of Nautilus *Nautilus macromphalus* from New Caledonia. *Marine Pollution Bulletin*, **40(8):** 688-696.

Caspers, H. (1975). Pollution in coastal waters: An Interim Report on Results of a priority programme of the German Research Society (1966-1974).

Chester, R. and J.H. Stoner (1975). Trace Elements in Sediments from the Lower Severn Estuary and Bristol Channel. *Marine Pollution Bulletin*, **6(6):** 92-96.

Chowdury, N.K. (1994). Study on the effects of the effluents discharged from the KPRC on the water quality with the preview of pollution status of the Karnafully River. M.Sc. Thesis. Institute of Marine Science, University of Chittagong, Bangladesh.

Das, J.D. and R.F. Nolting (1993). Distribution of trace metals in sediments and pore waters in the N. W. Mediterranean Sea. NIOZ, EROS-200 Project, 10 p.

Davies, C.A., Tomlinson, K. and T. Stephenson (1991). Heavy metals in River Tees estuary sediments. *Environ. Technol.*, **12:** 961-972.

Environmental Quality Standards (EQS), 1991. Department of Environment, Government of the Peoples' Republic of Bangladesh.

Furnas, M.J. (1991). The behaviour of nutrients in tropical aquatic ecosystems. *In:* Pollution in Tropical Aquatic Ecosystems, Connell, D.W., Hawker, D.W. (Eds.). CRC Press, Boca Raton, Florida.

Goldberg, E.D., Koide, M., Holdge, V., Flegal, A.R. and J. Martin (1983). U.S. mussel watch: 1977-1978 results on trace metals and radionuclides. *Estuar. Coast. Shelf. Sci.*, **16:** 69-93.

Haque, M.R., Ullah, S.M., Ahmed, M.K. and M.S. Azad (2003a). Seasonal variation in physico-chemical parameters of water and sediment in the rivers of Sundarban mangrove forest. *The Journal NOAMI.*, **24(2):** 463-472.

Haque, W., Ahmed, A.T.A., Tarafdar, S.A., Akhter, S. and S. Quraishi (2003). Trace elements in two small fishes, *Puntius sophore* (Hamilton) and *Mystus vittatus* (Bloch) from Buriganga River, Balu River and Ichamati Beel. *Bangladesh Journal of Zoology.*, **31(2):** 247-251.

Haque, M.R., Ahmad, J.U., Chowdhury, M.D.A., Ahmed, M.K. and M.S. Rahman (2004). Seasonal variation of heavy metals concentration in sediments of the rivers and estuaries of Sundarban mangrove forest. *Asian Journal of Microbiology, Biotechnology and Environmental Science*, **6(2):** 175-185.

Haque, M.R., Ahmad, J.U., Chowdhury, M.D.A., Ahmed, M.K. and M.S. Rahman (2005). Seasonal variation of heavy metals concentration in surface water of the rivers and estuaries of Sundarban mangrove forest. *Pollution Research*, **24(2):** 463-472.

Haque, M.R., Ahmed, M.K., Mannaf, M.A. and M.M. Islam (2006). Seasonal variation of heavy metals concentrations in *Gudusia chapra* inhabiting the Sundarban mangrove forest. *The Journal NOAMI*, **23(1):** 1-21.

Haque, M.R., Ahmed, M. K., Ahmad, J.U. and M.D.A. Chowdhury (2006). Seasonal variation of heavy metals in some molluscs of Sundarban mangrove forest, Bangladesh. *Pakistan Journal of Oceanography,* **2(2):** 81-98.

Holden, A.V. and G. Topping (1972). Occurrence of specific pollutants in fish in the Forth and Tay estuaries. *Proc. R. Soc., Edinburgh,* Ser. B., **71:** 189-194.

Holmgren, S. (1994). An environmental assessment of the Bay of Bengal region. BOBP/REP/67. pp.79-112.

Hossain, M.S. (1996). Progress report on bio-accumulation and seasonal variation of tress metals in water, sediment and commercially important fishes and shellfishes of the north eastern Bay of Bengal. Institute of Marine Science, University of Chittagong, Bangladesh. 23 p.

Khan, A.H., Akhter, S., Biswas, S.K. and D.K. Saha (1986). Trace element profile in sweet water and marine fish in Bangladesh. Annual Report. Atomic Energy Centre. Dhaka. BAEC.14, 17-18.

Khan, A.H., Ali, M., Biswas, S.K. and D.A. Hadi (1987). Trace elements in marine fish from the Bay of Bengal. *Sci. Total Environ.*, **61:** 121-130.

Khan, Y.S.A. and A.B.M. Talukder (1995). Accumulation of trace elements, organochlorine pesticides from the sediments of the south coast of Bay of Bengal. M.Sc. dissertation. Institute of Marine Sciences, University of Chittagong, Chittagong, Bangladesh.

Khan, Y.S.A., Hossain, M.S., Hossain, S.M.G.A. and A.H.M. Halimuzzaman (1998). An environment of trace metals in the GBM Estuary. *Journal of Remote Sensing and Environment,* **2:** 103-113.

Lagorburu, I. and L. Canton (1992). Heavy metal concentration in littoral sediments from Guipuzcoa, Spain. *Marine Pollution Bulletin,* **24(9):** 462-464.

Mance, G. (1987). Pollution threat of heavy metals in aquatic environments. Elsevier Applied Science Publishers, London. 363 p.

Manson, A.Z., Jenkins, K.D. and P.A. Sullivan (1988). Mechanisms of trace metal accumulation in the polychaete *Neanthes arenaceodentata*. *J Mar Biol Assoc UK*, **68:** 61-80.

Mehedi, M.Y. (1994). A comparative pen-picture of pollution status of the coastal belt of Bangladesh with special reference to Halisahar and ship breaking area, Chittagong. M.Sc. Thesis. University of Chittagong. 167 p.

Miramand, P. and D. Bentley (1992). Heavy metal concentrations in two biological indicators (*Patella vulgata* and *Fucus serratus*) collected near the French nuclear fuel reprocessing plant of La Hague. *The Science of the Total Environment*, **3:** 135-149.

Nicholson, R.A. and P.J. Moore (1981). The distribution of heavy metals in the superficial sediments of the North Sea. *Rapp. P.-V. Reun. Cons. Int. Explor, Mer.,* **181:** 35-48.

Páez-Osuna, F. and C. Marmolejo-Rivas (1990). Occurrence and seasonal variation of heavy metals in the oysters *Saccrostrea iridescens*. *Bull. Environ. Contam. Toxicol.,* **44:** 129-134.

Páez-Osuna, F., Osuna-López, J.I., Izaguirre-Fierro, G. and H.M. Zazueta-Padilla (1993). Heavy metals in clams from a subtropical coastal lagoon associated with an agricultural drainage basin. *Bull. Environ. Contam. Toxicol.*, **50:** 915-921.

Peterson, A., Jefferies, D.F., Dutton, J.W.R., Harvey, B.R. and A.K. Steele (1972). British Isles coastal waters: the concentration of selected heavy metals in seawater, suspended matter and biological indicators; a pilot survey. *Environ. Pollut.*, **3:** 69-82.

Rainbow, P.S. (1995). Physiology, physicochemistry and metal uptake—a crustacean perspective. *Mar Pollut Bull.*, **31:** 55-59.

Rao, I.M., Saxyarayana, D. and B.R.P. Reddy (1985). Chemical oceanography of harbour and coastal environment of Visakhapatnam (Bay of Bengal): Part 1—Trace metals in water and Particulate matter. *Indian Journal of Marine Science.*, **14:** 139-146.

Rojahn, T. (1972). Determination of copper, lead, cadmium and zinc in estuarine waters by anodic-stripping-alternating-current voltametry on the hanging mercury drop electrode. *Anal. Chim. Acta.*, **62:** 438-441.

Roth, I. and H. Hornung (1977). Heavy metal concentrations in water, sediments and fish from the Mediterranean coastal area. *Israel. Environ. Sci. Technol.*, **11:** 265-269.

Segar, D.A. and R. E. Pellenberg (1973). Trace metals in carbonate and organic rich sediments. *Mar. Poll. Bull.*, **4(9):** 138-142.

Sericano, J., Brooks, J., Champ, M.M.A., Kennicutt II, M.C. and V.V. Makeyev (2001). Trace contaminant concentrations in the Kara Sea and its adjacent Rivers, Russia. *Marine Pollution Bulletin.*, **42(11):** 1017-1030.

Sharif, A.K.M., Mustafa, A.I., Amin, N.M. and S. Shafiullah (1991). Trace metals in tropical marine fish from the Bay of Bengal. *Sci. Total Environ.*, **107:** 135-142.

Sharif, A.K.M., Mustafa, A.I., Hossain, M.A., Amin, M.N. and S. Shafiullah (1992a). Lead and cadmium contents in ten species of tropical marine fish from the Bay of Bengal. *Sci. Total Environ.*, **133:** 193-199.

Sharif, A.K.M., Alamgir, M., Mustafa, A.I., Hossain, M.A. and M.N. Amin (1992b). Trace element concentration in ten species of freshwater fish of Bangladesh. *Sci. Total Environ.*, **138(1-3):** 177-186.

Sharif, A.K.M., Mustafa, A.I., Mirza, A.H. and S. Shafiullah (1993a). Trace element concentrations in tropical marine fish from the Bay of Bengal. *Sci Total Environ.*, **138:** 223-234.

Sharif, A.K.M., Alamgir, M., Krishnamoorthy, K.R. and A.I. Mustafa (1993b). Determination of arsenic, chromium, mercury, selenium and zinc in tropical marine fish by neutron activation. *Journal of Radioanalytical and Nuclear Chemistry*, **170(2):** 299-307.

Simkiss, K. and M.G. Taylor (1989). Metal fluxes across the membranes of aquatic organisms. *Rev Aquat. Sci.*, **1:** 173-188.

WARPO (2000). Environment, National Water Management Plan Project, Ministry of Water Resource, Government of Bangladesh.

Watling, H.R. and R.J. Watling (1976). Trace metals in *Choromytilus meridionalis*. *Mar. Pollut. Bull.*, **7:** 91-94.

WHO (1982). Examination of water for pollution control: A reference hand book, 1 & 2.

Wright, D.A. (1976). Heavy metals in animals from the North East Coast. *Mar. Pollut. Bull.*, **7:** 36-38.

Wright, D.A. (1995). Trace metals and major ion interactions in aquatic animals. *Mar. Pollut. Bull.*, **31:** 8-18.

Zaroogian, G.E. (1980). *Crassostrea virginica* as an indicator of cadmium pollution. *Mar. Biol.*, **58:** 275-284.

Zorba, M.A., Jacob, P.G., Al-Bloushi, A. and R. Al-Nafisi (1992). Clams as pollution bioindicators in Kuwait's marine environment: Metal accumulation and deposition. *Sci. Total. Env.*, **120(3):** 185-204.