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ENVIRONMENTAL CHEMISTRY, POLLUTION & WASTE MANAGEMENT | RESEARCH ARTICLE

Heavy metals distribution and contamination in surface water of the Bay of Bengal coast

M.R. Hasan¹S, M.Z.H. Khan¹S*, M. Khan², S. Aktar², M. Rahman², F. Hossain² and A.S.M.M. Hasan³

Abstract: In this study, we measured the distribution of heavy metals (Pb, Ni, Fe, Mn, Cd, Cu) in the surface water of Bengal Coast at the southern part of Bangladesh. We also examined the common water quality parameters to discuss the impacts of pollution. It was revealed that the majority of the heavy metals have been introduced into the Bengal marine from the riverine inflows that are also affected by the impact of industrial, ship breaking yard, gas production plant and urban wastes. The concentration of heavy metals was measured using atomic absorption spectroscopy (AAS) instrument. Heavy metals concentrations were found to decrease in sequence of Fe > Mn > Pb > Cu > Cd > Ni. Results showed that heavy metal concentrations in the marine surface water generally exceed the criteria of international marine water quality. Moreover, both the contamination factor (CF) and pollution load index (PLI) values suggested the elevation of heavy metals concentration in the region. Constant monitoring of the Bengal coast water quality is needed to record with a view to minimize the risk of health of the population and the detrimental impacts on the aquatic ecosystem.

Subjects: Environmental Change & Pollution; Environmental Management; Marine & Aquatic Science

Keywords: Bengal coast; surface water; heavy metals; water parameters; environment

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PUBLIC INTEREST STATEMENT

Southern part of Bangladesh is situated at the coast of Bay of Bengal. World's greatest mangrove forest is situated at this part. Chittagong is the biggest port city and also the coastal city of the country, where the pollution problem is acute due to the stress caused by domestic and industrial effluents. Point sources of pollution are mainly from gas production plants, ship breaking yard, port activities, other nearby industries and untreated urban wastes from metropolitan. It seems very important to assess the water pollution in this coastal area. The authors tried their best to evaluate water pollution from different samples in this area.

1. Introduction

In recent years, the pollution of the aquatic environment with heavy metals has become a world-wide problem. Toxic pollutants, such as heavy metals originating from direct atmospheric deposition, geologic weathering, or through the discharge of industrial waste products deposited in marine sediments as a sink. Due to their potential toxic effect and ability to bioaccumulation in aquatic ecosystems (Rainbow, 2007; Wang & Rainbow, 2008), the investigation of distribution and pollution degree of heavy metals in coastal area has attracted more public concerns recently (Christophoridis, Dedepsidis, & Fytianos, 2009; Feng et al., 2011; Gao & Chen, 2012; Larrose et al., 2010; Liu et al., 2011; Sundaray, Nayak, Lin, & Bhatta, 2011; Varol, 2011; Yang et al., 2012).

The potential sources of heavy metal pollution in the aquatic environment are industrial wastes and mining (Gümgüm, Ünlü, Tez, & Gülsün, 1994). To shorten the discharge of trace metals into aquatic system, a number of preventive actions are being applied, but existence of these metals in water system are even found nowadays (Dural & Bickici, 2010; Kumar, Rita, & Mukherjee, 2011; Kumar, Senthilkumar, Priya, Mukhopadhyaya, & Saha, 2010; Paller & Littrell, 2007). Heavy metals including both essential and non-essential elements have ecotoxicological effect to the living organism (Storelli et al., 2015). Although metabolic activities in organisms necessitates some metals like iron, copper, manganese, zinc etc. but lead, nickel, cadmium, mercury, chromium, arsenic are marked as hazardous due to their toxic nature to the environment (E.C., 2001; USFDA, 1993). Concentrations of heavy metals in the aquatic ecosystems are generally monitored by analyzing their accumulation in water, sediments, and associated biota (Camusso, Vigano, & Balestrini, 1995). Usually level of accumulated metals in water are found considerably lower than sediment and biota (Namminga & Wilhm, 1976). Marine fishes of the polluted area are acting as a pathway to carry away heavy metals to human beings. However, it is important to assess and track the abundance of these heavy metals in coastal ecosystem (Namminga & Wilhm, 1976).

Lakshmanasenthil et al. (2013) have measured the concentration of metals in the sediment and fishes from Bay of Bengal and reported of exceeding the permissible limit for Cd, Cr, Ni, and Mn concentrations. Recently Rashid, Hoque, and Akter (2015) reported that the concentrations of Cd, Fe, Pb, and Cu in Bengal sea water are found to be relatively higher than the standard concentration. Several researchers have conducted studies on water pollution in rivers of Bangladesh. Das, Khan, and Sarker (2002) conducted a study on Karnaphuli River estuary for the determination of some trace metals concentrations in water and reported that the estuary has been polluted from domestic sewage, land washout, river run-off, and shipping activities. Other studies reported on marine sediment pollution of the Bay of Bengal (Jayaraju, Sundara Raja Reddy, Reddy, & Reddy, 2009; Saha, Mitra, Bhattacharyya, & Choudhury, 2001).

Southern part of Bangladesh is situated at the coast of Bay of Bengal. World's greatest mangrove forest is situated at this part. Chittagong is the biggest port city and also the coastal city of the country, where the pollution problem is acute due to the stress caused by domestic and industrial effluents. Point sources of pollution are mainly from gas production plants, ship breaking yard, port activities, other nearby industries, and untreated urban wastes from metropolitan. The nearby industries are discharging waste water directly to the sea without any treatment which is causing serious damage to marine ecology and aquatic lives along with the health of coastal peoples who are exposed to this environment for a long term. Their effect is more evident from the abnormal values of a set of physical and chemical parameters. Assessment of heavy metals pollution at the Bengal marine coastal area is of considerable interest for both scientific and regulatory communities. So far, there are limited or no work focused on heavy metals investigation near this coastal area.

The objective of this study was to determine the heavy metals concentrations and distribution in the water from the southern part of Bengal coastal area. It was aimed to evaluate the contamination status of metals using different metal assessment indices such as contamination factor (CF) and pollution load index (PLI). The general water quality parameters were also examined and explained with relation to water pollution.

2. Materials and methods

2.1. Description of study area

For surface water sampling, 10 sampling points were chosen at the coast of marine bay shown in Figure 1. The sampling points were located at Salimpur Union, just 10 km from Chittagong city which is the second largest city of Bangladesh. These sites were chosen, because they receive considerable amounts of waste water from industrial areas as well as from ship breaking yard and Sangu gas production plant. The details of longitude and latitude values of sampling points are shown in Table 1.

2.2. Surface water sampling, preparation, and measurement

Ten surface water samples were collected during winter closure period. Sampling bottles were pre-conditioned with 5% nitric acid and later rinsed thoroughly with distilled deionized water. At each sampling site, the polythene sampling bottles were rinsed at least three times before sampling was done. Pre-cleaned sampling bottles were immersed about 10 cm below the water surface from the near sea shore using one liter acid-leached polythene bottles. About 0.5 L of water samples were taken from each sampling site. Samples were acidified with 10% HNO₃, placed in an ice bath and brought to the laboratory. The samples were filtered with filter paper and the filtrates were kept at 4°C until analysis. Preparation of liquid samples for AAS analysis was done using EPA Method-3005A. After sample preparation, the element determinations (Fe, Mn, Cu, Ni, Cd, Pb) were performed by means of SHIMADZU AAS-7000 (Flame Atomic Absorption Spectrometer).

Figure 1. Map of water sampling sites along the coast of Bay of Bengal.
Source: Map data ©2015 Google.

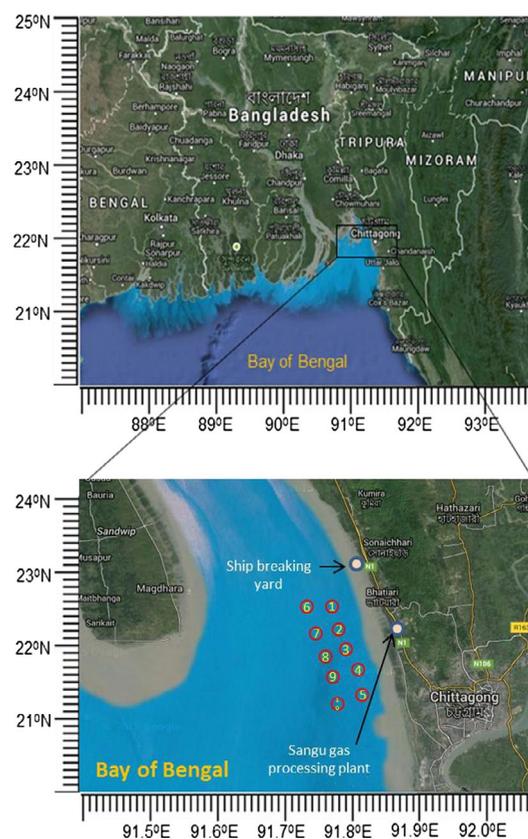


Table 1. Geographical locations of the sample collecting points

Sample ID	Latitude (N)	Longitude (E)
1	22.61'98"	91.81'23"
2	22.31'24"	91.82'01"
3	22.02'91"	91.82'94"
4	21.59'53"	91.83'74"
5	21.36'48"	91.84'67"
6	22.64'11"	91.74'44"
7	22.21'76"	91.75'32"
8	21.96'22"	91.76'64"
9	21.39'68"	91.77'53"
10	22.11'44"	91.79'87"

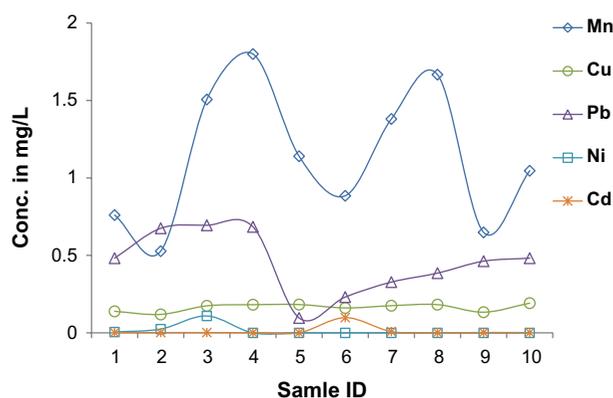
3. Results and discussion

3.1. Determination of heavy metals in sediments

Normally a number process namely biological uptake, scavenging by particulate matter, release from bottom sediments, advection and mixing water masses and Aeolian transport of terrestrial materials etc. regulates the concentration of dissolved metals in the sea water (Jones & Murray, 1984; Moore, 1978; Wangersky, 1986; Yeats & Campbell, 1983). Concentration of heavy metals in the water sample of Bay of Bengal is shown in Figure 2 which reflects the order of metal concentration of the present study as follows: Fe > Mn > Pb > Cu > Cd > Ni. The average concentration of Fe, Mn, Pb, Cu, Cd, and Ni in the water of near shore of Bay of Bengal is shown in Figure 2 which are 23.68 mg/L, 1.136 mg/L, 0.452 mg/L, 0.164 mg/L, 0.012 mg/L, and 0.0066 mg/L, respectively, and actual concentration ranged between 0.1561–60.454 mg/L, 0.52–1.80 mg/L, 0.0964–0.694 mg/L, 0.119–0.192 mg/L, 0.0017–0.098 mg/L and 0.0055–0.1091 mg/L, respectively. Whereas maximum limits of these metals permissible in drinking water recommended by WHO/FEPA are 0.03 µg/L, 0.050 µg/L, 0.16 µg/L, 1.0 µg/L, and 0.003 µg/L, respectively (World Health Organization, 2003). So it can be suggested that water of the study area are not drinkable even after removal of salts due to its contamination.

Cadmium naturally exists in Soil and rocks of some extend. Besides, anthropogenic activities like unsafe use and handling of Ni–Cd batteries, industrial activities, waste treatment plant, as well as agricultural fertilizer are the source of cadmium load to the sea (HELCOM, 2007). Residual discharge of produce water from gas processing plant, metallurgical activities (Ship breaking) and also other industrial activities are responsible for increase in cadmium in Bay of Bengal coastal water. Average concentration of Cd in the research area was found to be 0.012 mg/L. Although it is in low level, yet it is contaminated.

Figure 2. Measured concentration of heavy metals in different water samples.



Lead is a heavy metal found as metallic lead, inorganic, and organometallic compounds. Tetravalent and divalent, in both forms lead is found in nature where Pb^{2+} is predominant over Pb^{4+} . Pb^{2+} salt with common anion are slightly soluble in water and its high content in aquatic environment is toxic for most forms of life, especially aquatic organisms (Branica & Konrad, 1977). It has no beneficial or nutritional effect, whereas it becomes a matter of concern when released into the air and water at higher concentration and also it is well documented that lead has toxic effect to human. Its concentration was found in the range of 0.0964–0.694 mg/L and average value is about 0.452 mg/L. Highest concentration was found at sample 3, on the other hand lowest one is found at sample 6, whereas its world seawater average concentration is 0.00003 mg/L.

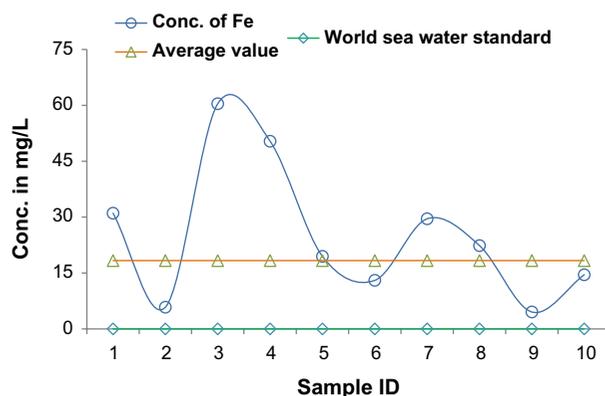
In the environment, copper is all-pervading with the composition of 50 mg/L in the earth crust and 0.25 μ g/L in the ocean water (Caspers, 1981). Living and dead organic material, extraction process of copper, anthropogenic activities, volcanic action, and thermal vent are the main sources of copper in the aquatic environment (Lewis, 1995). An estimation shows that ocean water contains about 0.34 billion metric tons of copper based on a concentration of 0.25 μ g/L (Adopted from MadSci Network, 2015). It is also regarded as an essential micronutrient required for organisms. Its concentration was found in the range of 0.119–0.192 mg/L and average value is about 0.164 mg/L. Lowest concentration was found at sample 2 on the other hand highest values was found at station 10. This is even higher than 0.00025 mg/L. An elevated level of dissolved copper was found in the San Diego Bay area on the based on concentration, 0.0054 mg/L, primarily due to antifouling paints, in the crowded Shelter Island Yacht Basin vs. 0.0015 mg/L in the Bay outside the marina (Dobalian, 2000). Our finding is even higher than these values.

Manganese is naturally ubiquitous in the environment and earth crust contains about 0.1% and so crustal rock is the main source of manganese in the environment. Ocean spray, forest fires, vegetation, and volcanic activity are other major natural atmospheric sources of manganese. Dissolved manganese are released from some important sources like anaerobic environments where particulate manganese oxides are reduced, aerobic environments where the direct reduction of particulate manganese oxides occurs and the natural weathering of Mn(II)-containing minerals, and acidic environments. Aquatic environment contains Manganese basically in the in two main forms: Mn(II) and Mn(IV). Oxidation and reduction reactions conducted by abiotic or microbial medium governs the movement between these two forms. An average concentration of manganese was found 1.136 mg/L though its value is ranged between 0.52 and 1.80 mg/L. Lowest concentration was found at station 2 on the other hand highest value is found at station 4. Its concentration variation is found at different sampling points due to change in water depth and distance from the discharge point, whereas its world seawater average concentration is 0.0004 mg/L (Anthony, 2000).

Nickel is omnipresent in nature and is nutrient for the function of many organisms; both anthropogenic release and naturally release responsible for higher concentrations in some areas may be toxic to living organisms (Diagomanolin, Farhang, Ghazi-Khansari, & Jafarzadeh, 2004; Haber et al., 2000; Scott-Fordsmand, 1997). The earth's crust comprise about 0.008% of nickel, the core of the earth contains 8.5%, deep-sea nodules 1.5%; meteorites have been found to (Lyon, International Agency for Research on Cancer, 1990). In nature, nickel is found in several oxidation states, among them divalent state is found to be predominant while trivalent state may be formed by redox reactions in cell (Huang, Frenkel, Klein, & Costa, 1993). The natural background levels of nickel in water are relatively low, in open ocean water 0.228–0.693 ppb (World Health Organization, 1991). In most of the samples in this research, Nickel was below detection limit. Analysis found nickel in Sample 1, 2 and 3 whose values are 0.0055, 0.0245, and 0.1091 mg/L, respectively, whereas its world seawater average concentration is 0.0066 mg/L (Anthony, 2000).

Iron is the fourth most abundant element in the earth's crust and also present in natural waters. In the aquatic environment, the chemical behavior of iron is determined by oxidation–reduction reactions, pH, and the presence of co-existing inorganic and organic complexing agents. Its concentration was found in the range of 0.1561–60.454 mg/L and average value is about 23.68 mg/L (Figure 3).

Figure 3. Concentration of Fe in different samples.



Highest concentration was found at sample 3, on the other hand lowest one is found at sample 10, whereas its world seawater average concentration is 0.0034 mg/L (Anthony, 2000).

3.2. Pollution assessment

Due to consequences of variations in analytical procedures between studies and the presence of an unknown natural background in the water, it is difficult to make an overall assessment of the degree of metal contamination. In this study, three approaches were employed to evaluate the sediment pollution, contamination factor (CF), and pollution load index (PLI).

3.2.1. PLI Factor

The PLI is determined as the n th root of the n contamination factors (CF_n) multiplied together and calculated using the following equation:

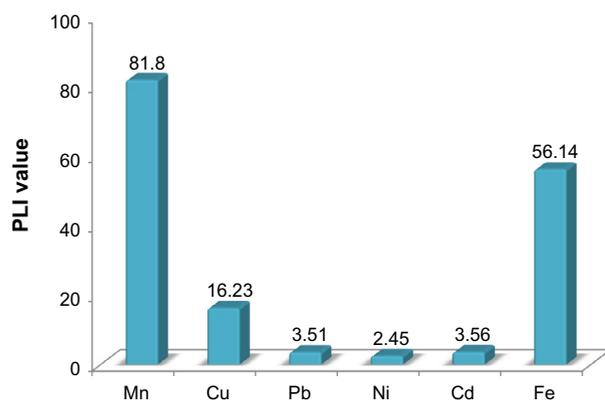
$$PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n}$$

This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution. The PLI value > 1 indicates a polluted condition, while $PLI < 1$ means no metal pollution existing (Tomlinson, Wilson, Harris, & Jeffrey, 1980). PLI values in liquid samples for all metals are much larger than 1 and hence metal pollution existing in the experimental sites. The PLI values observed > 1 for all metals, which means all stations are metal contaminated to some extent. The results of average PLI are as high as 81.8 for Mn and as low as 2.45 for Ni. PLI values in sediment samples for all metals are also found larger than 1 showed in Figure 4.

3.2.2. Contamination factor

Contamination factor (CF) usually used to express the level of contamination. The value was calculated as follows-

Figure 4. PLI values for water samples of the Bengal Marine.



$$CF = (\text{metal content in sample sediment}) / (\text{metal content in natural reference sediment})$$

There are mainly four classifications to express contamination factor; $CF < 1$ refers to the low contamination factor, $1 \leq CF < 3$ refers to the moderate contamination factor, $3 \leq CF < 6$ refers to the considerable contamination factor, and $CF \geq 6$ refers to the very high contamination factor. The values of CF factor are shown in Figure 5. Very high contamination was recorded at all stations for Fe, Mn, and Cu, whereas considerable contamination was observed for Cu and Pb. A linear contamination factor was found for Cu and Pb at all stations.

3.3. Other water parameters

3.3.1. Density

Density of water is greatly affected by temperature compared to salinity. Average density of sea water was found 1.02 g/mL that is slightly lower than world average value that is 1.025 g/mL (Anthony, 2000), whereas actual density is ranged between 1.014 and 1.024 g/mL that is shown in Figure 6.

3.3.2. Total dissolved solids

Total dissolved solids (TDS) is the measure of extent of solid materials dissolved in water. If the TDS level is high, especially due to dissolved salts, many forms of aquatic life are affected. The salts act to dehydrate the skin of animals. Figure 7 shows that average TDS value of sea water of Bay of Bengal is found to be 0.017 g/mL, whereas world sea water average TDS value is 0.006 g/mL (Anthony, 2000).

Figure 5. CF values for water samples of the Bengal Marine.

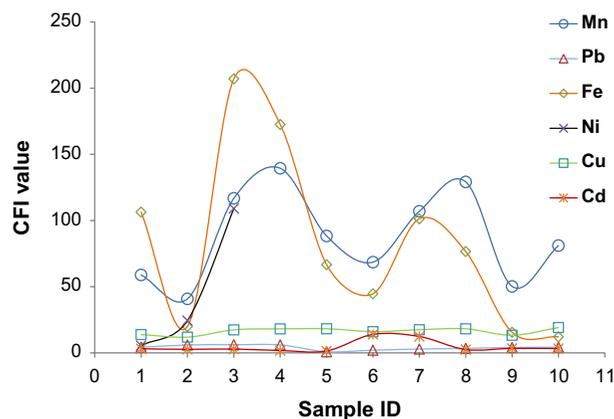


Figure 6. Measured density of coastal water of Bay of Bengal.

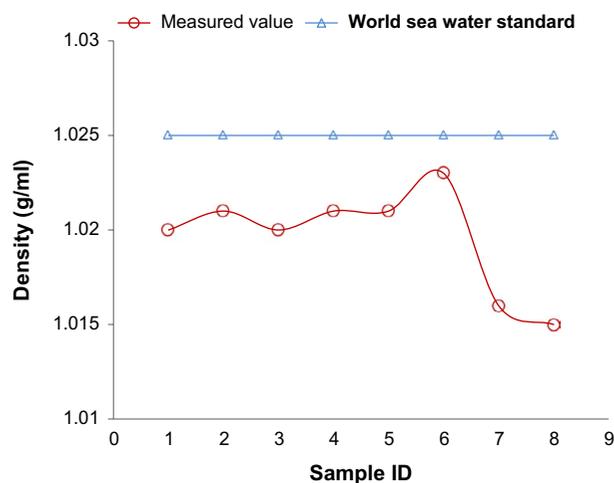
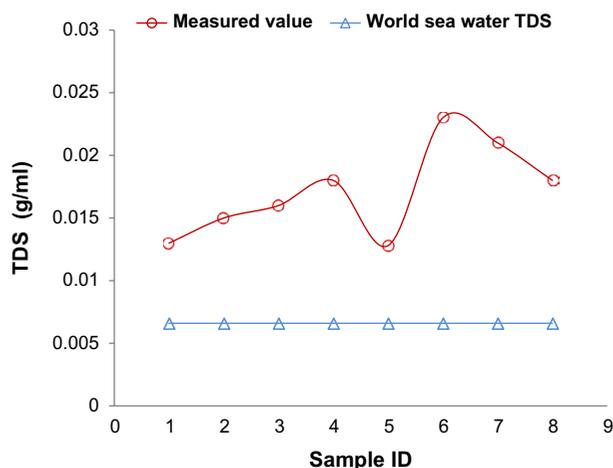


Figure 7. TDS values of different water samples.



3.3.3. Temperature

Temperature plays an important role in water. It affects the rate of chemical reactions, the metabolic rates of organisms, as well as the distribution of aquatic organisms throughout aquatic system. The temperatures determine the solubility of dissolved oxygen (DO) in water. There were significant differences in the temperature of water over the study period. The water temperature generally ranged from 22.5 to 30.5°C. Average temperature was 25°C shown in Figure 8.

3.3.4. Dissolved oxygen

Oxygen in water is measured as DO. Oxygen enters the water through photosynthesis in aquatic plants or from the transfer of oxygen between the air and water (waves, turbulence, currents, etc.). Fast-moving water, lower temperature, and lower salinity all result in the availability of more DO. WHO (1993) recommended a concentration of DO of 5 mg/l or above. The DO concentrations in water samples of Bay of Bengal ranged between 3.67 and 7.01 mg/L that is shown in Figure 9.

3.3.5. Electric conductivity

Electric conductivity (EC) is an indication of the amount of salts dissolved in water. It is also defined as the amount of ions (positive and negative) in water, and the water's ability to pass an electrical current. Electrical conductivity is a useful indicator of the salinity, total salt content in a water sample. The values of EC, shown in Figure 10 varied between 3.59 and 20.8 μ S while the average values were 10.178 μ S, on the other hand average seawater in the world's oceans has EC of about 5 μ S (Anthony, 2000).

Figure 8. Temperature of different water samples.

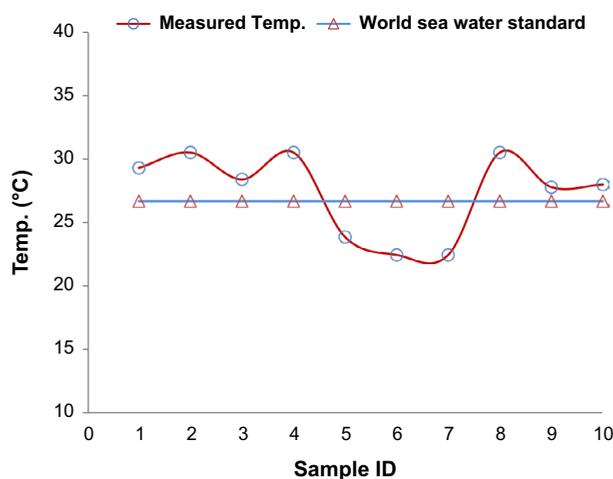


Figure 9. Dissolve oxygen of different water samples.

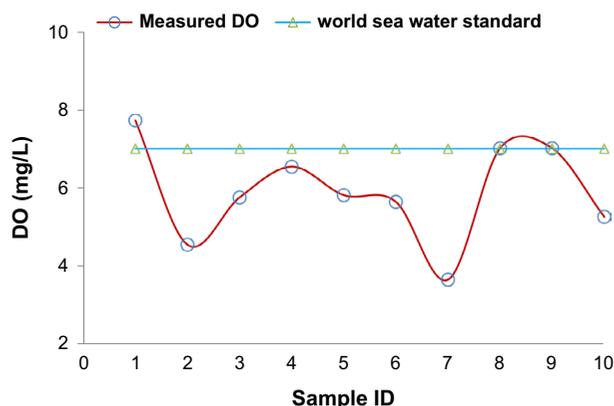


Figure 10. EC of different water samples.

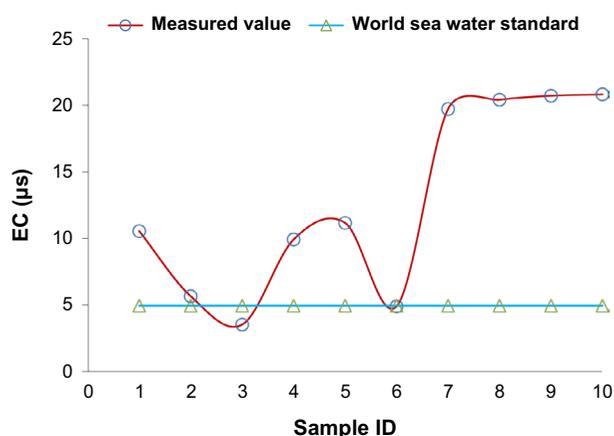
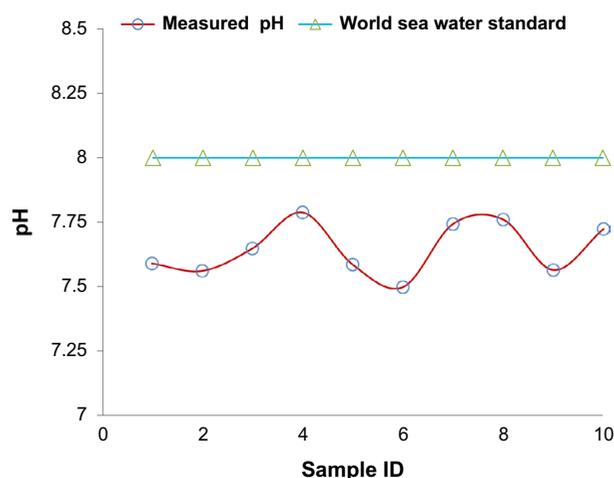


Figure 11. EC of different water samples.

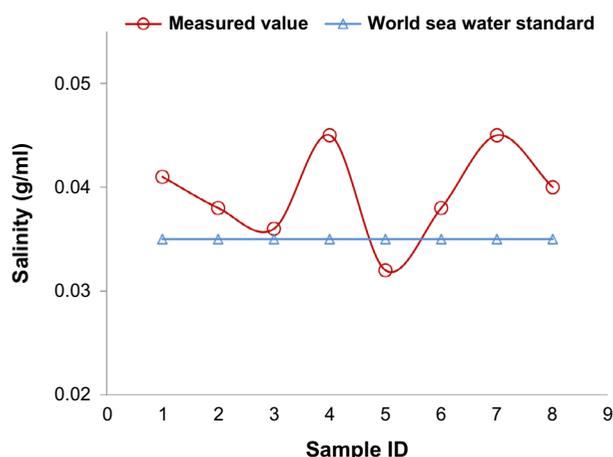


3.3.6. Acidity (pH)

Figure 11 shows the measured pH of different water samples. It is measured on a scale from 1.0 to 14.0. Many chemical and biological processes in the water are affected by lower pH value. A pH reading below 6.5 generally considered as being acidic may cause problems of heavy metal toxicity.

A reading of 6.5–7.5 is considered neutral, suitable for general plant growth, whereas above 7.5 is regarded as basic. The results in Figure 11 indicated that the pH of water was in the range

Figure 12. Salinity of different water samples in g/mL.



7.502–8.045, whereas average pH is 7.7 and considered to be basic so there is a less possibility of heavy metals toxicity. On average, seawater in the world's oceans has acidity of about 8 (Anthony, 2000).

3.3.7. Salinity

On average, seawater in the world's oceans has a salinity of about (0.035 g/mL) (Anthony, 2000). Seawater is not uniformly saline throughout the world, as mixing occurs with fresh water run-off from river mouths or near melting glaciers, as a result seawater can be substantially less saline. Average value of salinity of Bay of Bengal was found to be 0.04 (g/mL), whereas its actual value ranged between 0.032 and 0.045 g/mL, shown in Figure 12, which is slightly higher than world seawater average value and may be due to small volume run-off through different rivers of Bangladesh.

4. Conclusion

From the present study, it was observed that the accumulation of heavy metals is found to be high in the surface water of Bengal Coast mainly due to the land-based activities in general. Most attention should be given to control industrial discharge input into the coastal environment, especially discharge from gas production plant and ship breaking yard plays important role in water quality parameters studied in this research. In the near future, management practices and Government policy should be employed for regulating contamination of Bengal coastal water by controlling effluent discharge from nearby industries which is required to protect the marine ecosystem.

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