Status and Impacts of Industrial Pollution on the Karnafully River in Bangladesh: A Review

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Abstract
Rapid growth of urbanization and industrialization in Bangladesh has been coupled with increasing environmental pollution. The coastal and estuarine ecosystems of the country are now facing increasing pollution pressures because of the elevated level of waste discharges from various sources. Major sources of pollution include domestic sewage, industrial waste, commercial waste, agricultural waste, institutional waste, street sweepings, construction debris, mining activities and sanitation residues etc. In this review, status and effect of solid waste pollution, heavy metal pollution, organochlorine pesticides pollution and oil pollution along with the Karnafully River Estuary is assessed by a comprehensive review, recorded by researchers especially on water, sediment and aquatic biota. Different study show that metal concentrations in estuarine water relatively higher due to rapid acceleration of industrial sector. Metal concentrations is higher in fish than water and sediment. Elevated level of trace metals is highly detrimental for fish and human mechanism shown by different studies. Oil pollution is responsible for environmental deterioration due to its adverse effects on estuarine biota, fish and shellfishes, phytoplankton and zooplankton. Industrialization is needed for the development of the country. But it should be eco-friendly for the effective and sustainable development and for the protection of the environment (aquatic).

Keywords
Industrial pollution; Impacts; Biota; Development; Karnafully River

Introduction
Bangladesh is blessed with an extensive coastline of about 710 km which is mostly covered by a complex estuarine ecosystem (Pramanik, 1988). This estuarine ecosystem is enriched with the huge amount of living resources such as aquatic macrophytes (i.e. Tropical moist forest, salt marshes, seagrasses and seaweeds), fisheries, avian fauna, animals and coral reefs (Kamal and Khan, 2009). In Bangladesh, the estuarine system is comprised mainly of the Brahmaputra - Megna (Gangetic delta), Karnafully, Matamuhuri, Bakkhali and Naf rivers etc.

However, the Karnafully estuary (Figure 1) originating from the Lushai hills of Asam in India ultimately finds its way into the Bay of Bengal through the south-eastern coast of Bangladesh (O’ Mallery, 1908). This estuary is an important for many aspects including navigation, transportation, fishing activities, docking yards, the industrial utility of river water (Siddique and Akter, 2012). Moreover, it is used for port activities, fishing and industries (cooling and processing purposes) (Sarkar, 1998). But pollution is rapidly increasing and crossing safe limit day by day in the Karnafully River Estuary hampering coastal fisheries and people (Forkan, 2003). Water pollution occurs when foreign materials, either from natural or other sources mixes with water, contaminate water supplies and may be harmful to life because of their toxicity and the reduction of the normal O2 level of water as well as they also have aesthetically unpalatable effects which are responsible for the spread of epidemic diseases (Pandey, 1997). This river receives a lot of canals, tributaries and small river, which has been played a dominant role on the hydrobiology of the Karnafully River, contributing large amount of contaminated water, solid wastes, sewage (Hossain et al., 2006). The latest addition to the fertilizer industry is a modern installation with a proper stream, but Hossain (1992) reported that the Karnafully estuary is, nevertheless, being polluted by its effluents. About 800 industrial units are located on and adjacent to the banks of the Karnafully in different industrial areas such as Kalurghat, Nashirabad, Sagarica and Anawara industrial zone as well as oil refinery, oil companies depot, ship...
breaking activities, etc. (ADB, 2004). It is obvious that huge amounts of toxic pollutants in its rivers and in the Bay of Bengal are threatening aquatic life, particularly fish. Many cases of localized but severe environmental problems, like fish kills, have been registered by the DOE, other institutions and by fisher folk (Bhuyain, 1983). The invertebrate’s fauna is affected by the elimination of certain species, taxa which are universally affected by metal mining and associated activities. Mollusks, crustacean, Platyhelminthes, oligochaetes and some groups appear to behave inconsistently in response to metal pollution (Tyler and Buckney, 1973; Bhuyan et al., 2016; Islam et al., 2016). Consequently, any form of critical investigation on estuarine living resources and their environment can be considered as an important research in Bangladesh. As part of the estuarine study, this paper review the living estuarine resources with their usefulness and their depletion due to pollution.

Figure 1 Map showing the study site (Map created by ArcGIS v.10.3)

1 Status of the Water Quality
1.1 Physico-chemical parameters of the Karnafully River

Industrialization increases the unsuitability of surface water and create pressure on ground water which have negative impacts on human and aquatic organisms (Bhuyan et al., 2017). Physico-chemical parameters fluctuated seasonally in the estuarine area (Khan and Mahmood, 1976; Quader, 1978; Paul, 1981; Hussain et al., 1988a; Hussain et al., 1988b; Hussain, 1992; Islam, 1993; Uddin, 1993; Ahammad, 1995). The ranges of measured parameters of water samples were 26.5-32°C, 0.0-5.0‰, 7.5-7.9 and 2.28-2.91 mg/L for temperature, salinity, pH and DO (Alam and Zafar, 2012) (Table 1).

Table 1 Physico-chemical parameters of the Karnafully river water (Source: Sarwar et al., 2010)

| Sample id                 | Color            | Odor          | Tem. (°C) | TSS (mg/L) | TDS (mg/L) | TS (mg/L) | Turb (FTU) | DO (mg/L) | pH   | EC (µs/cm) | BOD (mg/L) | COD (mg/L) | Salinity (mg/L) |
|---------------------------|------------------|---------------|-----------|-----------|-----------|-----------|------------|-----------|------|-----------|------------|-----------|-----------------|
| Patenga Sea Beach         | Nearly colorless | Odorless      | 21        | 590       | 13200     | 13990     | 42.00      | 3.0-2.6   | 7.0  | 19920     | 163        | 390       | 6.20            |
| Patenga Nevay Academy     | Nearly colorless | Odorless      | 21        | 560       | 17500     | 18300     | 50.10      | 2.7-2.9   | 6.9  | 31340     | 178        | 380       | 6.50            |
| Nevay Academy 15 no ghat, | Nearly colorless | Odorless      | 22        | 610       | 16100     | 16850     | 49.45      | 2.5       | 6.9  | 29900     | 195        | 420       | 9.20            |
| opposite of the KAFCO     |                  |               |           |           |           |           |            |           |      |           |            |           |                 |
| Dry Dock                  | Nearly colorless | Odorless      | 23.5      | 360       | 15000     | 15490     | 38.54      | 0.70      | 6.9  | 29200     | 195        | 423       | 9.90            |
| Shipping Corporation      | Nearly colorless | Odorless      | 23.5      | 490       | 12590     | 13193     | 45.00      | 0.20      | 6.8  | 20700     | 200        | 425       | 6.70            |
### Continued Table 1

| Sample id                          | Color         | Odor         | Tem. (°C) | TSS (mg/L) | TDS (mg/L) | TS (mg/L) | Turb (FTU) | DO (mg/L) | pH | EC (µs/cm) | BOD (mg/L) | COD (mg/L) | Salinity (mg/L) |
|-----------------------------------|---------------|--------------|-----------|------------|------------|-----------|------------|-----------|----|-----------|------------|------------|-----------------|
| Chaktai New Bridge               | Muddy         | Pungent      | 22        | 480        | 510        | 1120      | 40.50      | 2.10      | 6.7| 820        | 290        | 635        | 0.40             |
| Karnafuly River in front of Chaktai Khal | Turbid color | High pungent | 22.5      | 190        | 421        | 695       | 16.20      | 0.35      | 6.6| 820        | 397        | 865        | 0.40             |
| Chaktai Khal (Chawkbazar)        | Turbid color  | High pungent | 23        | 120        | 292        | 472       | 14.00      | 0.65      | 6.6| 552        | 198        | 510        | 1.50             |
| Firingibazar Khal (at outfall to Karnafuly River) | Light green | High pungent | 24       | 230        | 999        | 1320      | 19.71      | 0.40      | 6.4| 1806       | 370        | 755        | 5.20             |
| Firingibazar Khal (Upstream)     | Oily & Black  | High pungent | 24.5      | 380        | 6920       | 1320      | 19.71      | 0.40      | 6.4| 1806       | 370        | 755        | 5.20             |
| Monohar Khal (Low tide starting, east of Sadarghat) | Turbid color | Odorless     | 24        | 175        | 910        | 1167      | 18.45      | 0.10      | 6.4| 1712       | 273        | 600        | 1.40             |
| Monohar Khal (at outfall to Karnafuly River) | Nearly colorless | Odorless   | 24       | 305        | 7510       | 7932      | 22.00      | 1.20      | 6.5| 12880      | 243        | 590        | 5.10             |
| Mazhirghat (Main drain)          | Light green   | Shortly pungent | 23.5    | 210        | 3500       | 3910      | 19.50      | 4.5-8     | 6.4| 6190       | 310        | 743        | 2.70             |
| Mazhirghat (Outfall to Karnafuly River) | Turbid color | Shortly pungent | 23.5    | 275        | 6300       | 6685      | 26.10      | 6.5       | 10450      | 255        | 695        | 4.70             |

At the waste disposal area, DO varied between (3.3-6.2) mg/L, BOD (1.83-4.82) mg/L and pH (6.3-7.8) (Hossain et al., 1988). Islam et al. (2015) recorded the mean concentrations of pH (7.1-8.5), DO (0.1-0.55 mg/L), TA (47.6-65.9 mg/L), TDS (631.8-653.6 mg/L), TSS (280-300.3 mg/L), SO₄²⁻S (1-2.3 mg/L), NH₃ (0.6-1.1 mg/L), NO₃⁻N (0.2-0.3 mg/L) and PO₄³⁻P (0.1-0.5 mg/L). Ahmed et al. (2010) also studied on the Karnafuly river water quality (Table 2).

### Table 2 Water quality of the Karnafuly River

| Parameters | WHO Standard | Present Study | Previous Study |
|------------|--------------|---------------|----------------|
| Ambient temp (°C) | - | 18.25-35.00 | ND |
| Water temp (°C) | - | 19.50-34.30 | ND |
| pH | NYS | 6.36-9.86 | 7.01-8.24 |
| EC (S/cm) | 800-1000 | 90.00-45600.00 | 100-26150 |
| TDS (mg/L) | - | 45.00-20000.00 | ND |
| TSS (mg/L) | - | 14.40-5100.00 | ND |
| TS (mg/L⁻¹) | - | 46.00-27700.00 | ND |
| DO (mg/L) | 4-6 | 0.00-7.91 | 3.20-7.20 |
| Transparency (cm) | - | 1.50-150.00 | ND |
| Acidity (mg/L) | - | 1.60-52.25 | ND |
| CO₂ (mg/L) | 6 | 1.41-49.98 | ND |
| P.alkalinity (mg/L) | - | 0.00 | ND |
The total Biological Oxygen Demand (BOD) load was estimated at about 3.5 MT every day (Ali, 1997). Uddin (2006) recorded the value of DO (4.9-5.21) mg/L, TDS (115-550) mg/L, BOD (1.14-2.99) mg/L, COD (10.8-32.1) mg/L (Uddin, 2006). Akter (2012) found following values from KPM effluent (Table 3).

Table 3: Experimented value from laboratory analysis of KPM effluent

| Parameters                  | Banshghat (Control) | KPM discharge point | Dhubashi Bazar | Average | Standard |
|-----------------------------|---------------------|---------------------|----------------|---------|----------|
| pH                          |                     |                     |                |         |
| Dry season                  | 8.19                | 8.10                | 8.90           | 8.66    | 7.52     | 8.51    | 6-9      |
| Wet season                  | 8.10                | 8.90                | 8.98           | 7.52    | 8.51     | 6-9      |
| TDS (mg/L)                  | 80                  | 102                 | 520            | 210     | 180      | 327.5   | 2100     |
| TSS (mg/L)                  | 110                 | 170                 | 220            | 122     | 280      | 310.5   | 150      |
| DO (mg/L)                   | 4.5                 | 4.2                 | 0.8            | 3.25    | 3.12     | 1.99    | 4.5-8    |
| BOD (mg/L)                  | 10                  | 12                  | 24             | 18      | 9        | 16.75   | 50       |
| COD (mg/L)                  | 150                 | 170                 | 780            | 320     | 280      | 500     | 200      |
| SO4²⁻ (mg/L)                | 0.14                | 0.9                 | 12             | 22.0    | 17.0     | 5.98    | 0.40     |
| Cl⁻ (mg/L)                  | 15                  | 17                  | 28             | 12      | 14       | 19.25   | 600      |
| NO3⁻ (mg/L)                 | 0.9                 | 0.3                 | 2.8            | 2.2     | 1.2      | 2.25    | 10       |

Note: Source: Akter (2012)

Temperature, transparency, pH, DO, BOD and petroleum hydrocarbon concentration in water sample were found to be ranged from 27-29°C, 14-18 cm, 7.9-9.5, 4.5-7.9 mg/L, 33.6-450.3 mg/L (Ahmed, 2006). According to Chowdhury (2005) DO, water temperature, pH, salinity, CO₂, HCO₃, alkalinity, NO₃-N, PO₄-P and SiO₂-Si varied seasonally. Hossain (2004) and Ahmed (2010) also conducted research on the water quality of the arnfully river (Table 4; Table 5).
Table 4 Typical analysis of river water and pollution load in the Karnafully River at different locations, April 1984–March 1985

| Location                                | pH  | E.C. (micromhos/cm) | Chloride (mg/L) | Total alkalinity (mg/L) | S.S. (mg/L) | D.O. (mg/L) | BOD (mg/L) | COD (mg/L) | Remarks     |
|-----------------------------------------|-----|---------------------|-----------------|-------------------------|--------------|-------------|-------------|-------------|-------------|
| Middle of Karnafully River near Bambooghat | 7.7 | 245                 | 18.0            | 55                      | 240          | 6.5         | 38          | 65          | Maximum     |
|                                         | 6.8 | 134                 | 6.2             | 34                      | 59           | 5           | 4.2         | 49          | Average     |
|                                         | 6.0 | 100                 | 2.0             | 16                      | 101.0        | 4.0         | 0.4         | 30          | Minimum     |
| Side of Karnafully                      | 8.5 | 750                 | 100.0           | 460                     | 42.5         | 5.9         | 22.0        | 68          | Maximum     |
|                                         | 7.3 | 218                 | 15.5            | 36.8                    | 11.0         | 4.4         | 3.8         | 45.1        | Average     |
|                                         | 7.0 | 120                 | 3.1             | 18                      | 46           | 0.1         | 1.0         | 30          | Minimum     |
| River near Dovashi bazaar               | 7.6 | 250                 | 28              | 60                      | 31           | 5.6         | 3.2         | 55          | Maximum     |
|                                         | 7.2 | 150                 | 7.4             | 36                      | 12           | 5.0         | 2.0         | 42.2        | Average     |
|                                         | 6.7 | 120                 | 2.5             | 18                      | 58           | 3.8         | 0.7         | 26          | Minimum     |
| Middle of Karnafully                    | 8.4 | -                   | -               | -                       | 48.5         | 7.4         | 2.9         | 104         | Maximum     |
| River near Dobshi bazaar                | 7.9 | -                   | -               | -                       | 23.0         | 7.0         | 2.2         | 78.9        | Average     |
|                                         | 7.6 | -                   | -               | -                       | ≧ 50         | 6.5         | 1.6         | 39.5        | Minimum     |
| Side of Karnafully river near Patenga   | 7.7 | 245                 | 18.0            | 55                      | 240          | 6.5         | 38          | 65          | Maximum     |
|                                         | 6.8 | 134                 | 6.2             | 34                      | 59           | 5           | 4.2         | 49          | Average     |
|                                         | 6.0 | 100                 | 2.0             | 16                      | 101.0        | 4.0         | 0.4         | 30          | Minimum     |
| Acceptable value of the parameters in the case of use of the river for fishing | 6.5-8.5 | -                   | -               | -                       | ≧ 7.0        | ≧ 5         |

Note: Source: Hossain (2004)

Table 5 Seasonal variation of the Karnafully river water quality

| Parameters         | Seasons       | Karnafully Min. | Karnafully Max. |
|--------------------|---------------|-----------------|-----------------|
| pH                 | Pre-monsoon   | 7.15            | 8.12            |
|                    | Monsoon       | 6.36            | 9.86            |
|                    | Post-monsoon  | 7.20            | 8.40            |
| EC                 | Pre-monsoon   | 90.00           | 36325.00        |
|                    | Monsoon       | 99.00           | 25300.00        |
|                    | Post-monsoon  | 93.00           | 45600.00        |
| DO                 | Pre-monsoon   | .00             | 6.33            |
|                    | Monsoon       | 2.15            | 6.50            |
|                    | Post-monsoon  | 3.25            | 7.91            |
|                    | Pre-monsoon   | 1.41            | 13.31           |
| Carbon dioxide     | Monsoon       | 4.47            | 13.40           |
|                    | Post-monsoon  | 3.12            | 49.98           |
|                    | Pre-monsoon   | 5.64            | 119.00          |
| Total alkalinity   | Monsoon       | 16.29           | 104.00          |
|                    | Post-monsoon  | 24.00           | 121.00          |
|                    | Pre-monsoon   | 16.00           | 4000.00         |
| Total hardness     | Monsoon       | 10.00           | 2380.00         |
|                    | Post-monsoon  | 22.00           | 4500.00         |
| Chloride           | Pre-monsoon   | 2.09            | 13147.70        |
|                    | Monsoon       | 3.21            | 10125.94        |
|                    | Post-monsoon  | 7.00            | 12120.20        |
Continued Table 5

| Parameters | Seasons            | Karnafullly |       |       |
|------------|--------------------|-------------|-------|-------|
|            |                    | Min.        | Max.  |       |
| BOD        | Pre-monsoon        | 0.22        | 9.17  |       |
|            | Monsoon            | 0.21        | 6.22  |       |
|            | Post-monsoon       | 11.39       | 122.46|       |
| Nitrite-N  | Pre-monsoon        | 1.01        | 3.89  |       |
|            | Monsoon            | 0.00        | 5.18  |       |
|            | Post-monsoon       | 1.60        | 14.60 |       |
|            | Pre-monsoon        | 2.00        | 3.37  |       |
| Phosphate-P| Monsoon            | 0.12        | 4.94  |       |
|            | Post-monsoon       | 9.26        | 212.81|       |
| Sulphate-S | Pre-monsoon        | 152.08      | 974.10|       |
|            | Monsoon            | 28.55       | 977.08|       |
|            | Post-monsoon       | 9.26        | 32.87 |       |
| Fe         | Pre-monsoon        | 0.06        | 2.30  |       |
|            | Monsoon            | 0.40        | 2.72  |       |
|            | Post-monsoon       | 0.23        | 3.24  |       |
| Mn         | Pre-monsoon        | 0.01        | 0.92  |       |
|            | Monsoon            | 0.22        | 0.45  |       |
|            | Post-monsoon       | 0.01        | 0.24  |       |

Note: Source: Ahmed (2010)

2.2 Sediment
The overlying deposits of the Karnafully river is consist of successive layers of mud and sand (Rizvi, 1971). During rainy season, a large amount of sand and mud particles run down into the river water increasing turbidity and decreasing navigability of the river by siltation (Hossain, 1992). Chowdhury (2005) conducted a comprehensive study on the soil of the Karnafully river (Table 6).

Table 6 Organic carbon, organic matter and soil texture of sediment at three stations during post-monsoon (January, 2005)

| Parameters       | Amanat Shah Bridge | Sadar Ghat  | Jetty no. 15 |
|------------------|--------------------|-------------|--------------|
| Organic carbon   | 0.200              | 0.230       | 0.430        |
| Organic matter   | 0.344              | 0.396       | 0.740        |
| Soil texture     |                    |             |              |
| Sand (%)         | 82.36              | 84.25       | 78.87        |
| Silt (%)         | 7.82               | 6.90        | 11.52        |
| Clay (%)         | 9.82               | 8.85        | 9.61         |

Note: Source: Chowdhury (2005)

2.3 Macro benthos
Macro benthos distribution vary spatially and temporally (Sharif et al., 2017). According to Chowdhury (2005) maximum population density 148583 indiv/m² was recorded during pre-monsoon at Amanat Shah Bridge and minimum population density 1333.33 indiv/m² was recorded at Jetty no.15 during monsoon. Sharif et al. (2017) recorded 25 major taxa of zooplankton from the Karnafully River of which 23 taxa during monsoon, 20 taxa during post monsoon and 20 taxa during pre-monsoon. Species richness, diversity and evenness were very low in the mouth of the Chaktai canal where majority of sewage materials of Chittagong city falls into the Karnafully estuary in comparison with the Goverment Fish landing station and Eastern side of the third Karnafully Bridge (Molla et al., 2014). Oligochaetes, the most common that constitute the largest assebly of benthic form during pre-monsoon and lowest during monsoon (Kamruzzaman, 2003) (Table 7).

2.4 Bacteria
Health hazard bacteria are *Escherichia coli*, Fecal *Streptococci* sp. and *Staphylococcus*. Occurrence of *Salmonella* sp. and *Vibrio cholerae* were also found (Alam, 2005). In compare with bacterial load between water and sediment,
sediment sample carry higher bacteria than water sample in the Karnafully River (Alam, 2005). The available DO consumed by bacterial activity and thus the presence of such materials quickly leads to a depletion of DO (Islam, 1998). Hossain et al. (1988) recorded as many as 18000 coliforms/100 mL in the Karnafully River Estuary near sewage disposal areas which is higher than safer level (0/100 mL) for drinking water and greater than 200 cells/100 mL for bathing recommended by WHO (1984) (Table 8).

Table 7 Major taxa of macro benthos and their total number (indiv/m²) among Amanat Shah Bridge, Sadar Ghat, Jetty no. 15 during post-monsoon (December-2004)

| Major taxa    | Amanat Shah Bridge | Sadar Ghat | Jetty no. 15 |
|---------------|-------------------|------------|-------------|
| Polychaeta    | 1083.333          | 1166.667  | 500.000     |
| Oligochaeta   | 625.00            | 750.000    | 583.333     |
| Gastropoda    | 83.3333           | 0.00000    | 208.3333    |
| Bivalvia      | 166.6667          | 83.3333    | 0.000000    |
| Crab larvae   | 41.6666           | 0.00000    | 0.000000    |
| Amphipoda     | 83.3333           | 41.6666    | 41.6666     |
| Urchin        | 0.00000           | 41.6666    | 0.000000    |
| Megalopa      | 41.6666           | 41.6666    | 0.000000    |
| Nematoda      | 83.3333           | 83.3333    | 83.3333     |
| Isopoda       | 41.6666           | 0.00000    | 41.6666     |
| Insecta       | 83.3333           | 125.000    | 0.000000    |
| Unidentified  | 375.00            | 208.333    | 291.6667    |
| Total         | 2708.33           | 2541.667   | 1750.00     |

Note: Source: Chowdhury (2005)

Bacteriological study showed that coliform bacteria and faecal streptococci occurred in greater frequency in the polluted area of the Karnafully River rather than pristine area. Polluted stations (Sadarghat and Majhirghat) were dominant in respect of quantitative distribution of Oligochaetes and Polychaetes and occasionally Molluscs (Hossain, 1983) (Table 9).

Table 8 Seasonal variations of different group of organisms/m² at polluted and unpolluted area of the Karnafully River Estuary

| Months & Years | Oligochaeta (Ind/m²) | Polychaeta (Ind/m²) | Mollusca (Ind/m²) | Miscellaneous group (Crab larvae, Mysids, Amphipod, Shrimp larvae, Dipteran larvae) (Ind/m²) | Total organisms (Ind/m²) |
|---------------|---------------------|--------------------|------------------|---------------------------------------------------------------------------------------------|--------------------------|
|               | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted | Polluted | Unpolluted |
| April’82      | 67203    | 83        | 1042    | 63        | 125      | 104       | -       | 21        | 68375    | 271       |
| May’82        | 7667     | 83        | 333     | 63        | 313      | 63        | 42      | -         | 8355     | 209       |
| June’82       | 2167     | 63        | 792     | 42        | 417      | 73        | 62      | 73        | 3438     | 251       |
| July’82       | 77488    | 292       | 21      | -         | 146      | -         | 21      | 77509     | 459      |
| Aug’82        | 22417    | 42        | 542     | 105       | 167      | 83        | 42      | 21        | 23168    | 251       |
| Sept’82       | 83       | -         | -       | -         | -        | -         | -       | -         | 83       | -         |
| Oct’82        | 1500     | 21        | 250     | 73        | -        | -         | -       | -         | 1750     | 198       |
| Nov’82        | 646      | -         | 146     | 73        | -        | 83        | -       | -         | 792      | 136       |
| Dec’82        | 21       | -         | 188     | -         | -        | -         | 42      | -         | 251      | -         |
| Jan’82        | 417      | -         | 833     | -         | -        | -         | -       | -         | 1250     | -         |
| Feb’82        | 988      | -         | 563     | 42        | -        | -         | -       | -         | 1521     | 42        |
| Mar’82        | 8188     | 63        | 396     | 104       | -        | 21        | 63      | 73        | 8667     | 261       |
| Total (Ind/m²)| 188760   | 647       | 5106    | 565       | 1022     | 553       | 271     | 313       | 195159   |

Bacteriological study showed that coliform bacteria and faecal streptococci occurred in greater frequency in the polluted area of the Karnafully River rather than pristine area. Polluted stations (Sadarghat and Majhirghat) were dominant in respect of quantitative distribution of Oligochaetes and Polychaetes and occasionally Molluscs (Hossain, 1983) (Table 9).
Table 9 Health hazard indicating bacterial load in water and sediment of the three sampling sites of the Karnafully River Estuary

| Month | Sample | Site                          | TBC($\times 10^2$) | E. coli | Streptococci sp. | Staphylococci sp. |
|-------|--------|-------------------------------|---------------------|---------|-----------------|------------------|
| March | Water  | Near Shah Amanat Bridge       | 4.03                | 30.67   | 172.33          | 11.0             |
|       |        | Near Sadar Ghat               | 3.95                | 22.67   | 126.67          | 5.00             |
|       |        | Near Jetty No. 15             | 3.94                | 24.67   | 148.33          | 7.00             |
|       | Sediment| Near Shah Amanat Bridge       | 6.32                | 100.67  | 203.00          | 20.33            |
|       |        | Near Sadar Ghat               | 5.86                | 44.67   | 177.67          | 9.33             |
|       |        | Near Jetty No. 15             | 5.71                | 79.00   | 162.0           | 6.67             |
| April | Water  | Near Shah Amanat Bridge       | 3.81                | 30.33   | 185.67          | 10.33            |
|       |        | Near Sadar Ghat               | 4.45                | 34.67   | 134.67          | 6.33             |
|       |        | Near Jetty No. 15             | 3.97                | 22.33   | 188.33          | 8.33             |
|       | Sediment| Near Shah Amanat Bridge       | 5.96                | 129.67  | 266.33          | 16.67            |
|       |        | Near Sadar Ghat               | 6.13                | 64.67   | 226.33          | 16.67            |
|       |        | Near Jetty No. 15             | 5.94                | 76.67   | 164.0           | 11.67            |
| June  | Water  | Near Shah Amanat Bridge       | 4.20                | 33.00   | 200.67          | 14.00            |
|       |        | Near Sadar Ghat               | 3.99                | 29.00   | 166.33          | 12.33            |
|       |        | Near Jetty No. 15             | 3.88                | 16.67   | 118.33          | 5.33             |
|       | Sediment| Near Shah Amanat Bridge       | 6.37                | 108.67  | 269.0           | 14.33            |
|       |        | Near Sadar Ghat               | 6.22                | 93.67   | 215.67          | 18.33            |
|       |        | Near Jetty No. 15             | 5.76                | 54.00   | 108.0           | 17.00            |
| July  | Water  | Near Shah Amanat Bridge       | 4.19                | 22.00   | 145.33          | 9.33             |
|       |        | Near Sadar Ghat               | 4.27                | 39.00   | 164.33          | 7.33             |
|       |        | Near Jetty No. 15             | 3.83                | 15.33   | 134.0           | 10.33            |
|       | Sediment| Near Shah Amanat Bridge       | 6.16                | 42.67   | 189.33          | 10.67            |
|       |        | Near Sadar Ghat               | 6.23                | 54.00   | 175.67          | 20.00            |
|       |        | Near Jetty No. 15             | 6.12                | 68.67   | 144.67          | 13.33            |

Note: Source: Alam (2005)

2.5 Fish diversity
Total 30806 numbers of species were found and the range of species number was from 397 to 1296 with a mean of 855.72±202.58 (Habib, 2011). According to Khan (2005) there are about 51 species under 23 families were found in the Karnafully River Estuary. Among seventy four (74) fish species have been reported by Bhuiyan and Gafur (1977). Twenty eight (28) have neither obtained in sample nor interviewing to fishermen revealed to exit which showed in Kamal (1992) observation. This is probably due to huge pollutant discharges from various sources into the estuary. Pollution status and its hazardous effects in the Karnafully River Estuary have been reported by Khan and Talukder (1993) and Mahmood et al. (1992). Diversity of ichthyofauna is closely related with physico-chemical parameters. Species distribution also vary temporal and spatial basis. In the monsoon, species diversity was found than that of the any other seasons (Khan, 2005). The combination of diverse fluctuating parameters are responsible for distribution and occurrence of ichthyofauna in the estuarine waters (Zafar, 1986).

3 Pollution Sources and Industries
3.1 Major sources of pollution
Water is the most vital element among the natural resources and is crucial for the survival of all living organisms including humans, for food production and economic development (Shiklomanov, 1993). Surface water of the country is vulnerable to pollution from untreated industrial effluents, municipal wastewater, runoff from chemical fertilizers and pesticides, and oil and lube spillage in the coastal area from the operation of sea and river ports (Hossain, 2001). Water quality depends on effluent types and discharge quantity from different types of industries, types of agrochemicals used in agriculture and seasonal water flow and dilution capability by the river system (DHV, 1998). Industries along the side of the River Karnafuly damp 50 to 60 ton of wastes per day directly into the river (Table 10).
Table 10 Estimated Pollution load as Biodegradable organics in terms of kg BOD/day at Chittagong

| Industrial zone                  | Pollution load (kg/day) |          |          |          |
|----------------------------------|-------------------------|----------|----------|----------|
| Pollution source in Chittagong area | Total          | Textile | Paper | Leather | Others |
| Karnuphuli river                 | -               | -       | 1400   | 110     |
| Kalurghat                        | 2500            | -       | -      | 4100    | 1500   |
| Nasirabad/Sholashahar            | 6400            | 800     | -      | -       | 1800   |
| Patenga                          | 2000            | 200     | -      | -       | 1150   |
| Kaptai (Chandraghona)            | 5800            | 2550    | 2100   | -       |
| Bhatiari                         | 1000            | 600     | -      | -       | 400    |
| Kumira                           | 380             | 380     | -      | -       |
| Barakunda                        | 600             | 600     | -      | -       |
| Fauzdarhat                       | 3200            | 2300    | -      | -       | 900    |
| Domestic waste load from         | 3500            | -       | -      | -       |
| Chittagong city                  |                |         |        |         |

Note: Source: ESCAP (1988)

Moreover, 05 major canals carry domestic and municipal wastes and effluents to the River Karnafully. Urea Fertilizer Factory discharges untreated effluents directly into the River Karnafully. Hg, Pb, Cr, Cd and As from 144 industries, degradable and persistent organic and inorganic compounds from 297 industries and oil, lubricants from (40-50) tankers polluting Karnafully river (MoFL, 2013). From the survey of effluents from different industries, it has been found that the discharge is generally composed of organic and inorganic wastes. The organic wastes are the effluents from the tanneries, fish processing units, degradable wood chips, pulps and untreated municipal and sewage (about 40,000 kg BOD daily) etc. The inorganic wast are chemicals used by the industries such as various acids, bleaching powder, lissapol, hydrogen peroxide, alkali, salts, lime, dyes, pigments, aluminium-sulphate and heavy metals etc. The DDT factory and fertilizer factory disposing of DDT, toxic chemicals and heavy metals to the Karnafully River and ultimately to the Bay of Bengal. Some survey showed about 220 ppm of chromium, 0.3-2.9 of cadmium, 0.05-0.27 ppm of mercury, 0.5-21.8 ppm of lead entering into river and sea water much higher than allowable limits and extremely alarmingly to aquatic flora and fauna and through food chains to human beings (Table 11).

Table 11 Mean load of heavy metals in the coastal water of Chittagong (Tamanna and Hossain, 2010)

| Metals | Mean load of metals (µg/L) with seasonal variation | Standard limit (µg/L) |
|--------|----------------------------------------------------|-----------------------|
|        | Rainy | Dry               | Standard limit (µg/L) |
| As     | 3.746 | 3.981             | 2.60                  |
| Co     | 8.989 | 11.937            | 0.50                  |
| Cr     | 23.346| 25.085            | 50                    |
| Cu     | 57.423| 62.336            | 08                    |
| Fe     | 536.371| 583.042           | 300                   |
| Mn     | 20.349| 23.104            | 100                   |
| Ni     | 7.844 | 12.106            | 01                    |
| Pb     | 23.778| 24.015            | 8.50                  |

Note: Maximum deterioration of the water quality was observed during summer and rainy season due to excessive disposal of wastes and outfall of land washing (Hossain, 1988)

It may be mentioned that Bangladesh obtain table salt from solar drying of sea water and consequently increase pollution of sea water shell create a serious national health hazard situation (IEDS, 2003). The concentration of Pb, Cu, Fe, Ni and Cr were observed higher and concentration of Mn and Cd were found lower than that of the recommended values. It was assumed that from the analytical findings that the estuary has been polluted from domestic sewages, land washout, river runoff and shipping activities (Das et al., 2002). There are some study on the contamination level of heavy metals in water and in sediments along the Karnafully estuary and its adjacent coastal area (Sarker, 1998; Sanjoy, 2007; Tamanna and Hossain, 2010; Hossain, 2010). An ADB study reported...
effluent flux of 150,000 litres/day from tannery Industry at Kalurghat, Chittagong, and discharge of about 0.35 tons of China clay/day from Karnafully Paper Mills (KPM) at Chittagong (MoEF, 2005) that Pollutes river water. According to a government report, in the 1994-1995 fiscal year alone, 2528 metric tonnes of wastes were dumped from shrimp processing units into the Bay of Bengal via the Karnafully River (Hassan, 2006). Human excreta from the city’s 50,000 sanitary and 24,000 service latrines are thrown into the river (Khan et al., 1996). Technical workshops, automobile factories, motor garage, vehicle repairing units, asphalt road constructions, etc. discharge lube oil, grease, diesel, bitumen, and tar, which ultimately contaminate the sediment. The industrial zones, EPZs and city dwellers activities are also responsible for oil contamination in the Karnafully River (Hossain, 2006). Rajakhali Canal, a tributary of the Karnafully River estuary, flowing through Chittagong City (the commercial capital of Bangladesh) receives a huge amount of domestic and industrial wastes and sewages (Islam et al., 2015). In Chittagong region, wastewater from Nasirabad industrial area (mainly chemical, leather, textile and steel re-rolling industries) is discharged into surface drains that ultimately carry it to the Karnafully river (Dey et al., 2015). There are rather few studies published in recent years on pollution sources in the Karnafully River (Hossain et al., 1992; 2001). Annually about 1216 ships and 45-60 oil tankers are handled at the Chittagong port (Ashraf, 2003). As a result, various refuse and disposable materials are discharged and spills from ships, oil tankers and fishing boats get mixed with water and sediments. The high level of Cu in sediments of the Karnafully coast indicates a higher input of deposited organic matter which comes from the industrial and domestic sewages (Siddique, 2012). Nutrient pollution occurred at the Karnafully River to St Martin Island, BoB when concentrations of nitrate, phosphate and silicate vary from 0.16 to 8.98 μg at/1, 0.08 to 2.33 μg at/1 and 0.67 to 6331 μg-at/1 which indicate high productivity (Holmgren, 1994). Running water of the Rivers Karnafully and Padma is heavily contaminated by industrial influents of factories from the river banks (Sarker, 2009) (Table 12).

Table 12 Estimated amount of pollutants entering the water

| Inorganic | Probable quantity discharged directly or indirectly to coastal water of Chittagong | Conc. Level in ground water in Chittagong (ppm) | Conc. Level in surface water and in Bay of Bengal (ppm) | Standard allowable concentration (ppm) |
|-----------|---------------------------------------------------------------------------------|-----------------------------------------------|-------------------------------------------------|-------------------------------------|
| Mercury   | 500kg/year                                                                       | -                                             | 0.05-0.27                                       | 0.01                                |
| Lead      |                                                                                 | -                                             | 0.5-21.8                                        | 0.025                               |
| Chromium  |                                                                                 | -                                             | 220                                             | 0.05                                |
| Arsenic   |                                                                                 | -                                             | +ve                                             | 0.015                               |
| Cadmium   |                                                                                 | -                                             | 0.3-2.9                                         | 0.015                               |
| Si        | 1.9-12.12                                                                        | -                                             | -                                               |                                     |
| Al        | 0.53-32                                                                         | -                                             | -                                               |                                     |
| Fe        | 0.97-42                                                                         | 2.6-5.6                                       | 0.3                                             |                                     |
| Ca        | 3.2-25.2                                                                         | 5.2-23.2                                      | -                                               |                                     |
| Mg        | 0.0-70                                                                          | 6.57-10.36                                    | 125                                             |                                     |

Note: * * means data not available; Source: Department of Environmental Pollution Control, Bangladesh (ESCAP, 1988)

3.2 Major polluting industries

The major polluting industries are 19 tanneries, 26 textile mills, 1 oil refinery, 1 TSP plant, 1 DDT plant, 2 chemical complexes, 5 fish processing units, 1 urea fertilizer factory, 1 asphalt bitumen plant, 1 steel mill, 1 paper mill (solid waste disposal hourly 1450 m³), 1 rayon mill complex, 2 cement factories, 2 pesticide manufacturing plants, 4 paint and dye manufacturing plants, several soap and detergent factories and a number of light industrial units (IEDS, 2003) (Figure 2). According to Islam (1993); Rahman (1994); Ahmed et al. (2002); Kamruzzaman (2003) and Uddin (2006) the polluting industrial units include 19 tanneries, 26 textile mills, 2 chemical industries, 5 fish processing plants, 2 soap factories, 2 pesticide plants, 2 detergent plants, 1 oil refinery, 1 asphalt bitumen plant, 1 TSP plant, Chittagong Steel Mills Ltd., Karnafully Paper Mills, Karnafully Rayon Complex, coca cola factory, 4 paint and dye manufacturing units, Chittagong Urea Fertilizer Ltd. (CUFL), Triple superphosphate (TSP), and Karnafully Fertilizer Company (KAFCO).
3.3 Major pollutants

SO$_2$, CO$_2$, NO$_3$, H$_2$S and lignin vapor from tanning industries; Na$_2$SO$_4$, NaOH, CaCO$_3$, Ca(OH)$_2$, Hg, Na$_2$CO$_3$, Na$_2$SO$_3$, H$_2$SO$_4$, HCl etc. from pulp and paper industries; Cr, Ni, Cd textile industries; NH$_3$, NO$_2$, SO$_2$, H$_2$SO$_4$, Sulphur dust, rock dust and COD from fertilizer industries; Lime components, silica, alumina iron from cement industries; DDT, Caustic soda, HCl, H$_2$SO$_4$, bleaching powder, acids, alkalis, ammonia, chlorine and suspended solid from chemical industries; waste water containing high level of BOD, COD, Phenol, Cyanides and very low value of DO from iron, steel and metal industries; crude oil from oil refinery; baling, jute fibre and dust from jute industries; minerals, organic acids, alkalis, ammonia, suspended solids and various chemicals from pharmaceutical industries; acids, solvents, cyanides, chlorophenolic components, lead, copper, arsenic, suspended solids etc. from pesticides and herbicide manufacturing industries; Zn, Cd and grease from rubber and plastic industries; pigments, resins, solvent, Pb, Sal, Cr, Cd, and Zn from paint manufacturing industries are major pollutants of the Karnafully water pollution (Ahmed et al., 2002). According to Chowdhury (1994) caustic soda, lime stone, lime, salt cake, resin size, china clay, alum, sodium sulphate, sodium sulphide, chlorine gas, calcium hydrochloride, hydrochloride, sulphuric acid and sodium hexameta phosphate are major chemicals used in KPM and KPRC industries.

3.4 Types of pollutants

3.4.1 Organochlorine pesticides

Seasonal variation in organochlorine pesticides was estimated in the Karnafully River (Table 13).

Table 13 Seasonal variation in Organochlorine pesticides

| Name            | Lindane (ng/mL) | Aldrin (ng/mL) | Heptachlor (ng/mL) | P,P’DDT (ng/mL) | P,P’DDE (ng/mL) | P,P’TDE(DDD) (ng/mL) |
|-----------------|----------------|----------------|-------------------|-----------------|----------------|---------------------|
| Surface Water   | 0.321-0.023    | 0.020-0.010    | 2.291-0.053       | 1.851-0.340     | 1.18-.005      | 1.421-0.018          |
| Surface Sediment| 1.321-0.425    | 3.142-0.123    | 3.607-1.224       | 4.560-0.745     | 5.030-0.085    | 2.831-0.531          |
| Fish Muscle     | 132.915-85.212 | 103.215-26.285 | 937.88-124.6      | 702.59-40.0     | 152.35-107.25   | 825.79-112.0         |

Note: Source: Mannan (2006)

3.4.2 Solid wastes

Solid and solid wastes causes serious environmental problems containing urban local government in developing countries. Solid waste generation of the urban areas of Bangladesh is increasing proportionately with the growth of its population that is 5.4% per annum (BBS, 1997). The highest Total Suspended Solid (TSS) was found 405
mg/L at the Karnafully River Estuary (Jetty No.15) and lowest was 169 mg/L (Uddin, 2006). The concentration of TDS was 520 mg/L and TSS was 220 mg/L in dry season and 400 mg/L TDS as well as 620 mg/L was found in wet season at KPM discharge point (Akter, 2012). Akter (2012) showed that solid waste generated from domestic sewage which contributes (53.9%), street sweeping (19.5%), commercial waste (1.4%), industrial waste (8.2%) and clinical waste (1%) in Chittagong city. According to Sarkar (2000) domestic sewage contributes (48.9%), street sweeping (21.5%), commercial waste (18.4%), industrial waste (10.2%) and clinical waste (1%) in Chittagong city.

3.4.3 Domestic sewage
The mixture of water and waste products popularly called sewage (EQS, 1991). Human excreta is only one component of domestic sewage with the wastes of personal washing, household cleaning and home food preparation adding to the dissolved and suspended, organic and inorganic materials in the carrier water (Uddin, 1993) consist of nitrogenous materials, carbohydrates, fats and soaps (EQS, 1991). The Chittagong city has about 50000 sanitary latrines, 24000 service latrines and 3 public toilets whose excreta collected by the municipality are stored in 5 large tanks for 2 months and then discharged into the rivers (Mozumder, 2003). In case of sewage, Chaktai canal contributes 30%, Monoharkhali canal 15%, Majhirghat canal 25% and Firingi-Bazar canal 18% into the Karnafully River (Source: Ahammod, 1995).

3.4.4 Oil pollution
Oil pollution is only one of man's untreated wastes which contributing to the deterioration of the environment (Ahmed, 2006). In the coastal area, it is about 0-2.3 to 0-3.4 ug/kg on the surface of the water. In the tanker routes, it is about 21.7 to 11.2 ug/kg on the surface and the value of the same varies from 23.2 to 13.6 ug/kg at 10 m deep water (Alam, 2004) (Table 14).

Table 14 Oil and oily substances in the Chittagong Area

| Oil and oil emulsion source | Estimated source of discharge |
|-----------------------------|-------------------------------|
| Chronic spillage of crude oil during transportation operation in Chittagong port | 6000 metric ton/year |
| Ballast water               | Not known                     |
| Bilge water                 | 2.4 million gallons/year      |
| Leakage loss of fuel oil from mechanized vessels, dry dock, fish harbor etc. | Not known |
| Oil emission from workshop  | Not known                     |
| Crude oil residue process oil and wash water from refinery | 50000 metric ton/year |
| Refuse oil from ship breaking activities from Fauzderhat | 400 kg/year |

Note: Assuming 0.5% transportation loss during crude oil transfer at Chittagong port; Source: ESCAP (1988)

According to Ahmed (2006) about 102-230 mg/L residual oil from surface area, 33.6 mg/L-180 mg/L from 5 m depth and 35.5-230.5 mg/L from 10 m depth were found (Table 15).

Table 15 Probable oil spill points in Chittagong coastal environment

| Oil spill sources      | Kinds of probable spill oil | Remarks                          |
|------------------------|----------------------------|----------------------------------|
| Oil companies terminal | Gasoline, kerosene, diesel oil, fuel oil, lubricating oil | Loading/unloading operation     |
| Dry Dock               | Diesel oil, fuel oil, oil mixed debris | Repairing, painting             |
| Eastern Refinery       | Heavy oil, oil residue     | Crude oil refining               |
| Port operations        | Diesel oil, fuel oil, ballast, bilge | Cargo vessel and oil tanker     |
| Ship breaking activity | Heavy oil, oil debris, ballast, bilge | Dismantling of ships/tankers  |
| Outer anchor           | Bunker oil, gasoline, kerosene, diesel oil, fuel oil | Collision, grounding         |
| Inner anchor           | Bunker oil, gasoline, kerosene, diesel oil, fuel oil | Collision, grounding         |
| Port area              | Bunker oil, Diesel oil, lubricating oil | De-ballasting, De-bilging      |

Note: Merchant vessels and tankers based sources; Source: Hossain (2006)
3.4.5 Heavy metal pollution

Heavy metal concentrations in the water of the river varied temporally and spatially (Bhuyan and Islam, 2017). Heavy metal concentration varied according to seasons in water, sediment and fish (Table 16; Table 17).

Table 16 Seasonal variation of trace metal concentrations (μg/mL) in water sample of the Karnafully River Estuary

| Station | Area     | Season    | Metal concentration (μg/mL) |
|---------|----------|-----------|----------------------------|
|         |          |           | Cr  | Mn   | Zn   | Ni   | Cu   | Pb   | Cd   | Fe   |
| 1       | Mouth    | Premonsoon| 0.573 | 1.174 | 0.541 | 0.493 | 0.390 | 0.563 | 0.139 | 26.316 |
|         |          | Monsoon   | 0.602 | 1.210 | 0.781 | 0.520 | 0.612 | 0.616 | 0.217 | 35.129 |
|         |          | Postmonsoon| 0.421 | 0.686 | 0.625 | 0.356 | 0.391 | 0.405 | 0.119 | 20.025 |
| 2       | Naval base | Premonsoon| 0.741 | 0.662 | 0.682 | 0.516 | 0.372 | 0.542 | 0.093 | 25.012 |
|         |          | Monsoon   | 0.687 | 0.742 | 0.970 | 0.619 | 0.674 | 0.698 | 0.211 | 40.252 |
|         |          | Postmonsoon| 0.429 | 0.498 | 0.472 | 0.510 | 0.449 | 0.437 | 0.129 | 23.168 |
| 3       | Sadarghat | Premonsoon| 0.572 | 1.121 | 0.932 | 0.697 | 0.543 | 0.916 | 0.192 | 31.021 |
|         |          | Monsoon   | 0.925 | 1.173 | 1.186 | 0.865 | 0.918 | 1.195 | 0.210 | 42.203 |
|         |          | Postmonsoon| 0.721 | 0.972 | 0.852 | 0.811 | 0.903 | 0.876 | 0.185 | 22.193 |
| 4       | Kalurghat | Premonsoon| 0.809 | 1.071 | 0.731 | 0.685 | 0.711 | 0.772 | 0.159 | 35.325 |
|         |          | Monsoon   | 0.851 | 1.372 | 0.910 | 0.759 | 0.973 | 0.747 | 0.182 | 36.421 |
|         |          | Postmonsoon| 0.512 | 0.983 | 1.112 | 0.664 | 0.891 | 0.675 | 0.090 | 28.120 |

Note: Source: Sarkar (1998)

Table 17 Seasonal variation of trace metal concentrations (μg/mL) in sediment sample of the Karnafully River Estuary

| Station | Area     | Season    | Metal concentration (μg/mL) |
|---------|----------|-----------|----------------------------|
|         |          |           | Cr  | Mn   | Zn   | Ni   | Cu   | Pb   | Cd   | Fe   |
| 1       | Mouth    | Premonsoon| 65.852 | 60.403 | 31.191 | 28.206 | 34.813 | 40.165 | 0.761 | 3230.69 |
|         |          | Monsoon   | 67.071 | 64.231 | 29.075 | 32.157 | 32.129 | 38.982 | 0.984 | 3425.49 |
|         |          | Postmonsoon| 64.462 | 55.012 | 28.543 | 26.021 | 9.615 | 27.065 | 0.519 | 2910.52 |
| 2       | Naval base | Premonsoon| 56.952 | 62.743 | 38.019 | 56.031 | 35.025 | 35.593 | 1.552 | 3117.71 |
|         |          | Monsoon   | 57.021 | 59.131 | 36.051 | 58.179 | 50.741 | 37.794 | 1.101 | 3009.79 |
|         |          | Postmonsoon| 53.148 | 56.189 | 16.724 | 49.256 | 10.059 | 25.110 | 0.813 | 3349.29 |
| 3       | Sadarghat | Premonsoon| 70.105 | 72.152 | 38.174 | 55.052 | 28.561 | 39.665 | 1.001 | 3649.01 |
|         |          | Monsoon   | 71.243 | 70.210 | 40.051 | 62.916 | 49.718 | 33.891 | 0.803 | 3810.15 |
|         |          | Postmonsoon| 68.183 | 68.421 | 29.215 | 59.421 | 17.252 | 30.571 | 0.795 | 3239.14 |
| 4       | Kalurghat | Premonsoon| 69.631 | 65.321 | 37.145 | 46.021 | 22.192 | 39.158 | 0.625 | 3323.65 |
|         |          | Monsoon   | 67.542 | 68.145 | 40.253 | 39.365 | 37.681 | 40.081 | 0.712 | 3467.05 |
|         |          | Postmonsoon| 63.748 | 61.021 | 38.121 | 44.101 | 24.056 | 34.269 | 0.306 | 3126.42 |

Note: Source: Sarkar (1998)

Most of the dissolved heavy metals were found to be in slightly higher concentrations during winter than that of the rainy season. This trend indicates that during low flow condition of river, the accumulation of the metal concentration increases (Dey et al., 2015) (Table 18).

Table 18 Seasonal variation of trace metal concentrations (μg/mL) in Jew fish (Otolithoides microdon) sample of the Karnafully River Estuary (Sarkar, 1998)

| Representative organs | Season    | Metal concentration (μg/mL) |
|-----------------------|-----------|----------------------------|
|                       |           | Cr  | Mn   | Zn   | Ni   | Cu   | Pb   | Cd   | Fe   |
| Liver                 | Premonsoon| 6.113 | 8.765 | 16.419 | 4.324 | 40.715 | 1.564 | 0.413 | 160.262 |
|                       | Monsoon   | 5.067 | 3.909 | 9.825  | 2.862 | 11.291 | 0.501 | 0.297 | 130.012 |
|                       | Postmonsoon| 6.052 | 5.616 | 10.326 | 3.934 | 17.235 | 1.968 | 0.368 | 140.396 |
| Muscle                | Premonsoon| 5.203 | 11.415 | 25.102 | 2.436 | 9.837 | 1.125 | 0.098 | 98.147 |
|                       | Monsoon   | 3.051 | 5.617 | 41.016 | 1.978 | 8.371 | 1.161 | 0.375 | 39.372 |
|                       | Postmonsoon| 4.690 | 8.168 | 28.132 | 2.156 | 12.192 | 0.160 | 0.105 | 95.261 |
Water is presently contaminated by heavy metals from dyeing industries and oil spills from ship braking industries and ongoing vessels (Sarker, 1991; 1992; 2004; Sarker and Sarker, 1986; 1988).
3.5 Major causes of fish depletion

In Bangladesh, the fish species from the inland and marine water bodies declined gradually due over the last two decades and the catch of fish declined about 40% compared to the past 20 years (DoF, 2002). A number of studies indicated that the major cause of declining fish catch from the river are the increased fishing pressure and habitat destruction (Tsai and Ali, 1987; Siddique, 1990; Hogarth et al., 1999; Graff et al., 2001). Species diversity also declined due to indiscriminate use of gears, over fishing, destruction of spawning ground and trapping of so called white fish (i.e., carps and butterfish) during their downstream migration from floodplains to river (Ali, 1997; Hogarth et al., 1999; Graff et al., 2001). Pollution, soil erosion, siltation, reclamation of land for settlement, reduction of wetland and biodiversity and proper management problem are the probable causes for the declination of the fishery resources (Khan, 2005).

4 Impacts of Pollution

The scientists in a recent research on the Karnafully found traces of radioactivity ‘very close to risk level’ on the soil. If radioactivity of the river soil goes up it will hamper the natural breeding of fish as well as growth of fishes. If the people eat the affected fish it may spread to their body (Amin, 2015). Ahmed and Reazuddin (2000) reported that the availability of the heavy metal in river water directly affects the fish physiology and by the consumption ultimately affects the human health. The presence of heavy metals in the aquatic environment is of major concern because of their heavy toxicity, bio-accumulating tendency in the biota. Pollution by heavy metals is a threat to human life and the entire environment as well as the wetland ecosystem (Islam and Tanaka, 2004; Igwe and Abia, 2006).

Oil pollution responsible for loss of productivity, other resources and exert adverse effects on aquatic environment, sometimes it become carcinogenic to living organisms (Ahmed, 2006). Oil pollution causes severe damage to fishes and crustaceans.

Contaminated water is not suitable for household uses and possibly hazardous to many aquatic animals and human health. Salmonella spp. concentrations found in water and soil samples exceed the standard level both in water and soil that indicates contaminated water is unsuitable for drinking or for even washing without appropriate water treatment for humans (Alam, 2012). Escherichia coli and Staphylococcus causes abdominal cramping, water borne diseases like diarrhea, fever, nausea and vomiting (HACCP, 2000).

Long term consumption of fishes may have a negative impact on human health (Bhuyan et al. 2016). Pathogens (Oligochaetes) are causative agents of different types of diseases of human beings found very high abundance near sewage outfalls areas in the Karnafully River estuary, which indicates localized pollution in the estuary (Hossain, 1987). The major channels which carry domestic wastes and spread into the coastal city areas causing pathogenic microbial pollution and serious health hazards during the rainy season and flood periods severity is more in the Bay (Mahmood et al., 1994). 20,000 fishermen in Raúján, Rangúnia and Anowara thanas previously dependent on the Karnafully river have given up their fishing profession because they do not have enough catches any more (SEHD, 2002). Lower concentrations of methyl mercury may kill aquatic organisms (Hossain, 2004). Paul (1981) also found the minimum phytoplankton population in the oil polluted Karnafully River Estuary. Most species of fish cannot survive in insecticides in concentrations greater than about 1-10 ppb. A sub lethal dose for fish and birds may bring immediate danger (Ali, 1997).

About 23 species of fishes were found in the Karnafully River during 1975-76, which has come down to 6-7 species during 1987-88. Effluents discharged from the large industries have ruined the Hilsha stock of the Karnafully river (Hossain et al., 2006). Presence of heavy metals in the river water causes perilous impact on the aquatic organisms (Dey et al., 2015). The fish catch is diminishing in the river year after year due to depletion of DO (Ali, 1997). The toxic chemical pollutants like Hg, Pb, Cd, COC and DO were found higher than the EQS value which is dangerous for entire aquatic ecosystem and public health (Akter, 2012). Excessive discharge of nitrogen, sulphur and phosphorus compounds in the water system can cause eutrophication (Bhouyain, 1981). The presence of NO₃ in natural water associated with ecological and health hazard, excess NO₃ in human food and
animal feed has adverse impacts, in human health it causes methmoglobinemia cancer (child cancer), respiratory illness. In animal health, causes loss of livestock. Excess NO3− pollute water causing eutrophication (Akter, 2012).

Effects on marine organisms produced by industrial discharged oil studied by Hossain (2011) (Table 21).

### Table 21 Effects of pollutants on marine biota

| Pollutants      | Organisms             | Effects                                                                 |
|-----------------|-----------------------|-------------------------------------------------------------------------|
| Discharged Oil  | Phytoplankton         | Reduced Carbon fixation, cell photosynthesis and finally death.          |
|                 | Zooplankton           | Clogged by the oil and sink to bottom                                    |
|                 | Mangrove vegetation   | Mangrove swamps are highly vulnerable to oiling and oil residue.        |
|                 | Marine Mammals        | Hampered on breeding.                                                   |
|                 | Algae and sea weeds   | Cell division is inhabited at oil concentration of 0.01ppm Sea weeds are clogged and smothered by oil. |
|                 | Eggs and larvae       | At concentration of 0.01 ppm crude oil hatching of fish eggs is irregular, late and deformed At 1 ppm of oil creates abnormal development of young lobsters |
|                 | Fish and shellfish    | Locking of gills of fishes Retardation of growth Reduction by defence |
|                 | Benthos               | Oil residues as tar balls creates acute toxic condition at the bottom Aromatic hydrocarbons cause pronounced mortality to the burrowing organisms |
|                 | Sea birds             | Reduction of flying capacity due to excessive mixing oil with feather Loss of buoyancy of birds Reduction of shell thickness of eggs Loss of breeding capacity |

Note: Source: Hossain (2011)

### 5 Conclusion
From the critical review, it can be concluded that the Karnafully river water is being polluted gradually by haphazard and unplanned industrialization. Polluted water exacerbatin the health problems both in human and fish posing different fatal and chronic diseases. This review also proved that, industrial area are severely polluted than non-industrial area. This review suggested that to protect the aquatic ecosystem by eco-friendly and planned industrial growth.

### Authors' contributions
Md. Simul Bhuyan designed and conducted the review. Md. Shafiqul Islam provided instructions and performed critical review of the manuscript.

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