EFFECTS OF INDUSTRIAL EFFLUENTS ON THE WATER QUALITY OF KARNAPHULI RIVER, BANGLADESH

Swaranjit Roy[1], Sayanti Kanungo[2] and Md. Mehedi Hasan Masum*[2]

[1] *Graduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* swaranjitroy08@gmail.com
[2] *Graduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail:* tannikanungo@gmail.com
[2] *Assistant Professor (Research), Institute of River, Harbor and Environmental Science (IRHES), Chittagong University of Engineering and Technology, Bangladesh, e-mail:* mehedi.ce@cuet.ac.bd

***Corresponding Author**

ABSTRACT

The rising problem of river pollution is a critical issue for developing countries like Bangladesh, driven by rapid urbanization, industrialization, and uncontrolled urban discharges. The Karnafuli River, one of the major rivers in Bangladesh, serves as one of the two rivers supplying drinking water to over 3 million people of Chattogram city. Additionally, the aquatic system of the river is the home to more than 140 different fish species. The main objective of this study is to evaluate the effects of industrial effluents on the pollution levels of the Karnafuli River. Water samples were collected from seventeen (17) selected nearby location of industrial discharge points and also fifteen various stations spanning the upstream to downstream sections of the Karnaphuli River during the period from March to May 2023. A total of eight (08) physio-chemical parameters of water, including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride (Cl), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Turbidity and four heavy metals including Pb, Mn, Fe and Cu were investigated for the evaluation of the impacts on Karnaphuli River. The pollution status of the Karnaphuli River was accessed using both the water quality index (WQI) and heavy metal pollution index (HPI), with an additional evaluation of the spatial distribution of water quality parameters. The investigation indicated a substantial decline in water quality in the downstream section of the river as compared with the upstream section. Furthermore, the water quality standards recommended by the BECR guidelines were also found to be significantly exceeded in the downstream section. Twelve locations in the Karnaphuli River were located in the downstream zone areas where the Heavy Metal Pollution Index (HPI) was more than 100. This was mostly attributed to the direct release of wastewater into the river from a variety of industries, most of which were situated downstream. The study recommends treating industrial effluents before releasing them into the Karnaphuli River and stresses ongoing water quality monitoring in the downstream section, near industrial discharge points, to mitigate health risks and protect aquatic ecology.

Keywords: *Industrial Effluents, Karnaphuli River, Spatial Analysis, Water Quality.*

1. INTRODUCTION

Surface water, specifically river water, serves as a crucial source of drinking water, providing sufficient quantity and quality of drinking water for maintaining a healthy lifestyle (Hossen et al., 2019, Kumar Roy & Kulsum Navera, 2018). Maintaining the water quality in rivers is essential for a green ecosystem and the overall health of aquatic environments in river systems. Bangladesh has experienced rapid urbanization, transitioning from a developing to a middle-income country. Bangladesh, known as a riverine country, boasts approximately 700 rivers that predominantly flow in a southerly direction toward the Bay of Bengal (Alam et al., 2022). However, the rivers of Bangladesh face threats and declining water quality due to various factors such as industrial discharges, sewage, solid waste disposal, encroachment, point and non-point sources, oil spills, and sedimentation (Ahmed et al., 2010, Almeida et al., 2007, Chowdhury et al., 2012, Uddin et al., 2021). Moreover, heavy metals pose a significant threat to human and environmental health, originating from sources like mining operations, volcanic eruptions, and various industrial sectors, including brick manufacturing, oil refineries, and battery production (Edet & Offiong, 2002). The substantial expansion of industries in Bangladesh is having a notable impact on the water quality of the adjacent waterbodies. Effluent contaminants from different industries are characterized by intense color, high temperature, elevated pH, concentrated salts, alkalinity, high BOD and COD, TOC, suspended solids (SS), low dissolved oxygen (DO), and the presence of toxicants, surfactants, fibers, turbidity, and concentrated heavy metals and ions (e.g., Fe, Cu, Zn, Cr, Cd, Mn, Pd, As, K^+, Mg^{2+}, Cl^-, HCO^{3-}, SO_4^{2-}, NO^{3-}, PO_4^{2-}) (Paul et al. 2012; Uwidia and Ejeomo 2013; Bashaye 2015). Water Quality Index (WQI) and Heavy-metal Pollution Index (HPI) are two methods used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts (Wang et al., 2016, Chowdhury et al., 2012). WQI and HPI can be calculated using different parameters and different methods (Chowdhury et al., 2012; Uddin et al., 2021). The most widely used method for the calculation of WQI is weighted arithmetic mean method introduced by Horton in 1965 (Uddin et al., 2021). Karnaphuli is located in Chittagong and is the nearest river to the Bay of Bengal. Chittagong is a port city and due to its strategic location as the busiest seaport in the region has made it a major economic hub attracting strong inflows of foreign investment into the production of apparel, ship breaking and oil refinery activities (Mia et al., 2015). Most industries on the banks of the river do not have the facilities to dispose of waste (Wang et al., 2016). They drain liquid and semi-liquid drainage into adjacent rivers, lakes, canals, ponds, swamps, lands, etc. (K, S. R et al., 2010). This pollution was not so bad, but after the early 1950s, it started worsening, and now the situation is alarming (Ahmed, 2010.) Around 5,000 tons of household wastes are going to the River Karnaphuli every day through 36 canals of the Chattogram city (Uddin et al., 2020). The burnt oil from the boats plying in the river is also contributing to the pollution (Dey et al., 2017). The fertilizer plants discharge 145 cubic meters of polluted water, 35 tons of China soil, four tons of cellulose and sodium hydroxide per day in the river (Hossain Tasin et al., 2020).

While various studies have explored the water quality of the Karnaphuli River, none have undertaken a comprehensive assessment covering its entire length. Furthermore, there is a noticeable gap in research that incorporates a holistic approach involving spatial analysis, Water Quality Index (WQI), and Heavy-metal Pollution Index (HPI). Therefore, this study aims to assess the impact of industrial effluents on the Karnaphuli River's water quality, establishing a link between industrial discharge and pollution by integrating these methodologies. The study also seeks to identify critical zones of pollution in the river, examine the impact of tidal variations on pollution levels, and propose essential measures for mitigating environmental degradation. This comprehensive approach aims to facilitate the implementation of effective strategies to counteract the escalating pollution in the river.

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2. METHODS AND MATERIALS

2.1 Study Area and Sampling Stations

The Chattogram Hill Tracts and Chattogram's largest and most significant river is the Karnaphuli (Ali et al., 2016). It is a 667-metre (2,188 ft) wide river in the south-eastern part of Bangladesh with Latitude: 22° 12' 60.00" N and Longitude: 91° 47' 59.99" E. It rises in Mizoram, India's Saithah village and flows 270 kilometres (170 mi) southwest through Chattogram Hill Tracts and Chattogram into the Bay of Bengal (Babel et al., 2023). The study as seen in Figure 1, covered a total of 50 km longitudinal distance. The river is divided into two sections, upstream and downstream based on their average elevation from mean sea-level (Wang et al., 2016) from a geological standpoint. The river's first 20 km were considered downstream, and the remaining length of the river were considered as upstream with an average elevation of 1.5 meters and 3.5 meters above mean sea level, respectively (Sirajul et al., 2023). Most of the industries are located in the downstream end within the first 25 km (Alam et al., 2022).

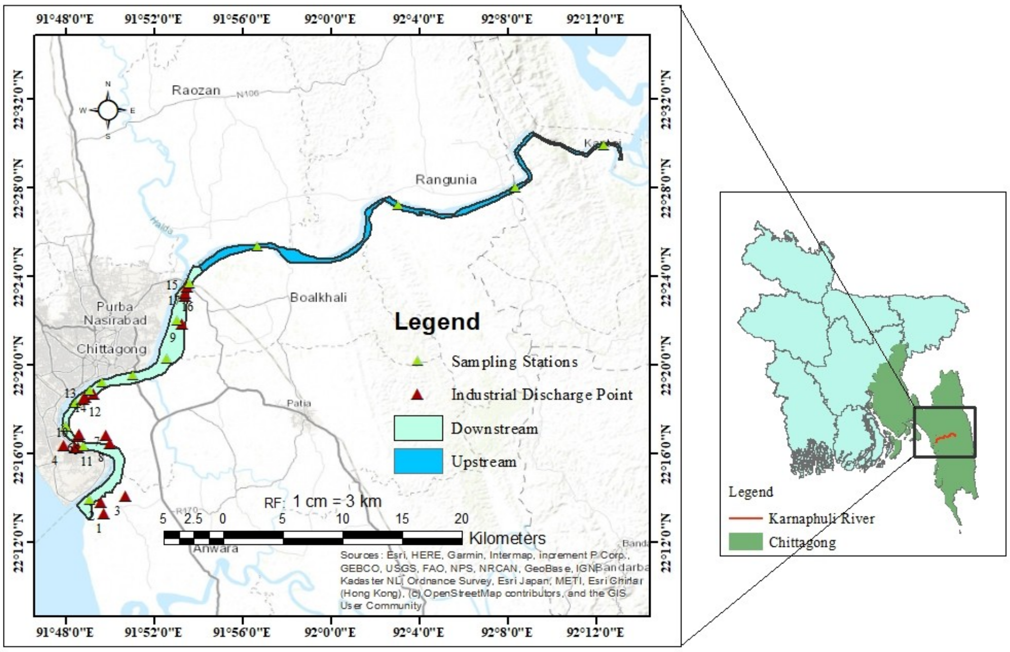


Figure 1: Map showing the geospatial locations of the sampling points in Karnaphuli River.

Water sample was collected directly from the river and the discharge points of the industries. The area between downstream of the river (0-30km) is where the majority of Chittagong's industries are located (Mukut et al., 2023). The river received regular direct discharges of wastewater from more than 50 different industries (Tasin et al., 2020). Based on various earlier studies and recommendations, 17 sampling points nearby industries were chosen. Sampling stations were spaced apart by 2.5 km in the downstream, and by 5 km for the remaining length of the river. Sample was collected from three different points (right, left and mid-point) at each station during tide and ebb period. A total of 96 sample was collected in dark High-Density Polyethylene (HDPE) bottles. The distribution of industrial discharge points is as follows: 3 within 0-5 km, 2 within 5-10 km, 6 within 10-15 km, 2 within 15-20 km, 1 within 20-25 km, and 3 within 25-30 km.

2.2 Data Analysis

Primary data was generated from Laboratory test and secondary data was collected from the Department of Environment, Bangladesh. Box plots were drawn using SPSS to show the overall range and variation of the water quality parameters (Liu et al, 2023). The WQI and HPI were used to evaluate the degree of contamination at each station and discharge points, respectively (Alam et al, 2022; Wang et al, 2016). To determine the spatial distribution of contaminants in the study area, geostatistical models in ArcGIS V10.08 were used.

2.2.1 Water Quality Index (WQI)

Horton first proposed WQI in 1965. The weighted arithmetic water quality index method was developed by Brown et al. in 1970, and Cude multiplied the water parameters using a weighting factor and expressed the results using subsequent equations in 2001(Chowdhury et al., 2012; Dey et al., 2017).

$$W_i = \frac{K}{S_i} \quad (1)$$

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - L_i|}{|S_i - L_i|} \times 100 \quad (2)$$

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (3)$$

Here, Qi, Mi, Li, Si, Wi, K and n, represent the sub index, monitored value, ideal value, standard value, unit weightage, constant and range of ith parameter. The considered WQI range for water quality pollution assessment is 0-25 : Excellent, 26-70 : Good, 51-75: Poor, 76-100 : Very Poor and greater than 100 : Unsuitable for drinking (Alam et al.; 2022).

2.2.2 Heavy Metal Pollution Index

Heavy Metal Pollution Index (HPI) was first proposed by (Mohan et al., 1996), is used to determine overall water quality depending on heavy metal ions, and calculated according to following equations (4), (5) and (6). The idea of HPI has developed throughout time as a useful tool for measuring and evaluating the extent of heavy metal contamination in the environment.

$$W_i = \frac{K}{S_i} \quad (4)$$

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{|S_i - I_i|} \times 100 \quad (5)$$

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (6)$$

Here, Qi, Mi, Ii, Si, Wi, K and n, represent the sub index, monitored value, ideal value and standard value, unit weightage, constant and range of ith parameter. The considered HPI range for water quality pollution assessment is 0-100 : Not Contaminated, greater than 100 : Contaminated (Wang et al.; 2016).

2.2.3 Spatial Distribution of Water Quality Data

The Kriging method was used to evaluate the spatial distribution of each parameter. The Kriging geostatistical method determines the target's spatial distribution based on a variogram fitted to the data (Belkhiri et al., 2020; Oliver et al, 1996). A variogram is a mathematical model used to explain the spatial continuity of a variable, according to Li and Heap (2008).

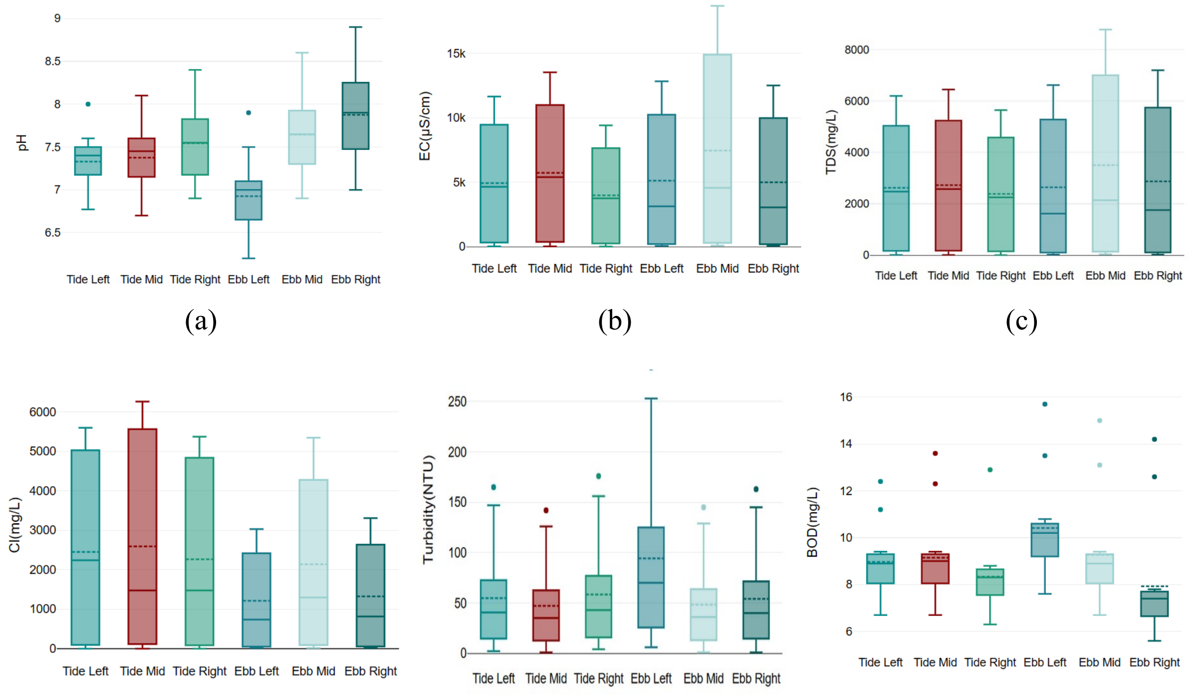
$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} ¿¿¿ \tag{7}$$

where γ (h) is the semi-variance for contaminant z, h is the distance between the measured samples, n is the number of measured samples, and $z(x_i)$ and $z(x_i+h)$ are the measured contaminant concentrations at locations x_i and $x_i + h$. To find the best fit for the data, a number of semi-variogram models including spherical, exponential, and circular models were assessed.

3. RESULTS AND DISCUSSIONS

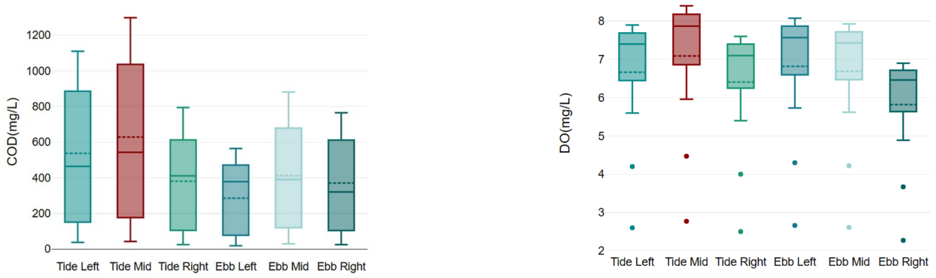
3.1 Variation Ranges and Spatial Distribution of Water Quality Parameters

Water quality parameters were measured at three sections from each sampling point (Figure 1) in both tide and ebb periods and they were tide left, tide mid, tide right, ebb left, ebb mid and ebb right. Figure 2(a-h) represent the variation of different water quality parameters between tide and ebb, and Figure 3(a-h) display the spatial distribution graph of water quality parameters, including pH, EC, TDS, Cl, Turbidity, BOD, COD, and DO. As seen in Figure 2(a), the pH ranges from 6.2 to 8.9 with a mean of 7.5, with the highest value observed in ebb right and the lowest value in ebb left. The values peak at 7.5 km in the downstream as seen in Figure 3(a) where several industrial discharge points are located (Figure1). Figure 2(b) illustrates that the highest electrical conductivity (EC) value of 18,689 µS/cm is observed in ebb mid, while the lowest value of 18 µS/cm is recorded during tide right.



(a) (b) (c)

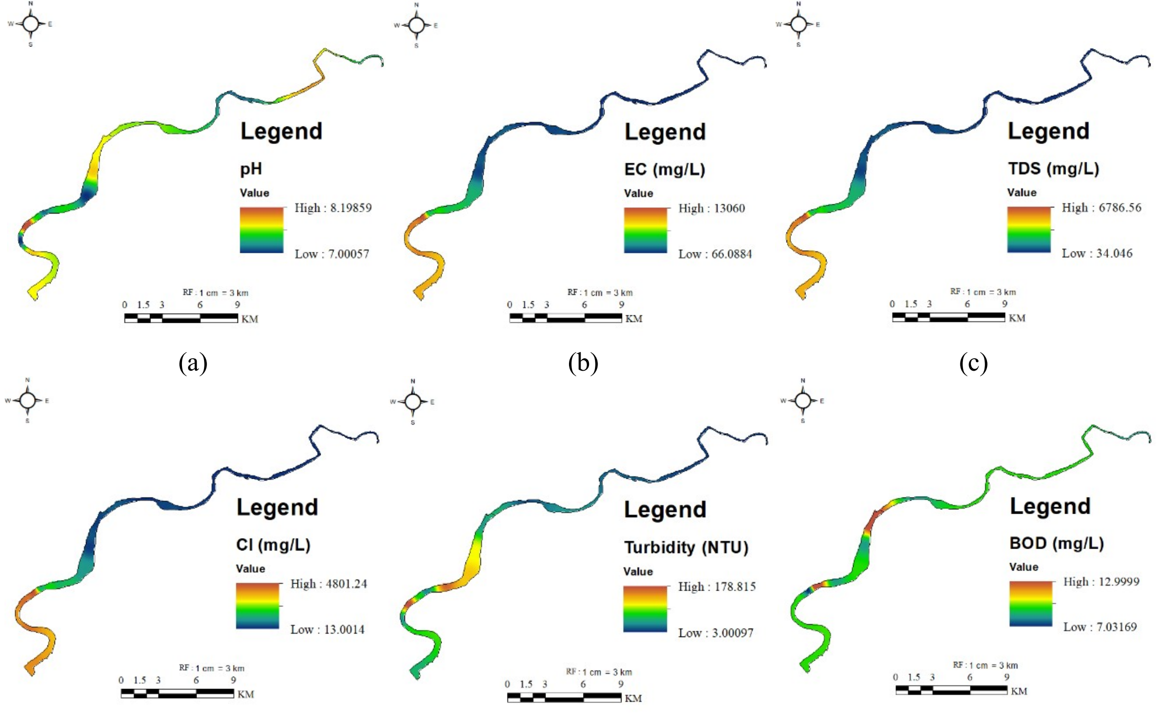
(d) (e) (f)



(g) (h)

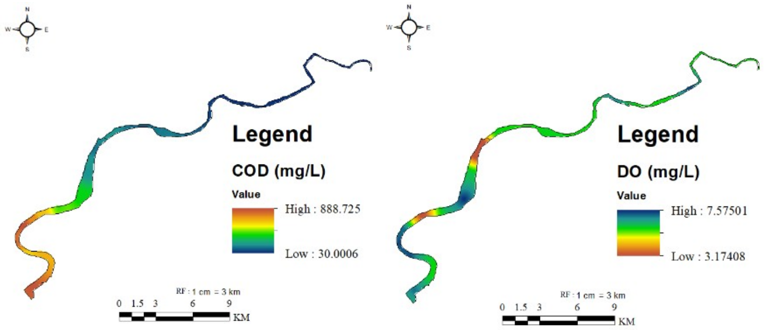
Figure 2: Variations of water quality parameters during ebb and tide in different sections of the Karnaphuli River (a) pH, (b) EC, (c) TDS, (d) Chloride, (e) Turbidity, (f) BOD, (g) COD, (h) DO

These values significantly surpass the Bangladesh Environment Conservation Rules (1997) standard of 1000 µS/cm for EC. Total dissolved solids (TDS) in river water vary according to the study, with an average of 2794.1 mg/L and a range of 11 mg/L to 8774 mg/L (Figure 2(c)). The Ebb mid part has the highest TDS value (8774 mg/L), while the Tide right area has the lowest value (11 mg/L). It is noteworthy that these values greatly exceed the Bangladesh standard for TDS, which is set at 1000 mg/L. In Figure 2(d), chloride values are demonstrated. In some stations, no chloride is found, and in other stations, chloride is found up to 6262mg/L with an average of 1997 mg/L, exceeding the BECR standard of 600 mg/L. High electrical conductivity (EC), total dissolved solids (TDS), and chloride (Cl) levels during high tide are likely due to saltwater intrusion from the nearby Bay of Bengal (Sherin et al., 2020). However, elevated EC and TDS levels, especially during ebb periods, may indicate potential contamination from Textile and Petrochemical Industries, which release chloride-containing effluents (Shukla et al., 2018). The lower water levels during ebb tides can lead to increased ion and dissolved solid concentration in the water. The electrical conductivity (EC), total dissolved solids (TDS), and chloride (Cl) values exhibit a consistent pattern, reaching their peak levels within the 7.5-10 km range in the spatial distribution maps, as depicted in Figure 3(b), (c), and (d). This spatial pattern coincides with the concentration of industrial discharge points shown in Figure 1.



(a) (b) (c)

(d) (e) (f)



(g) (h)

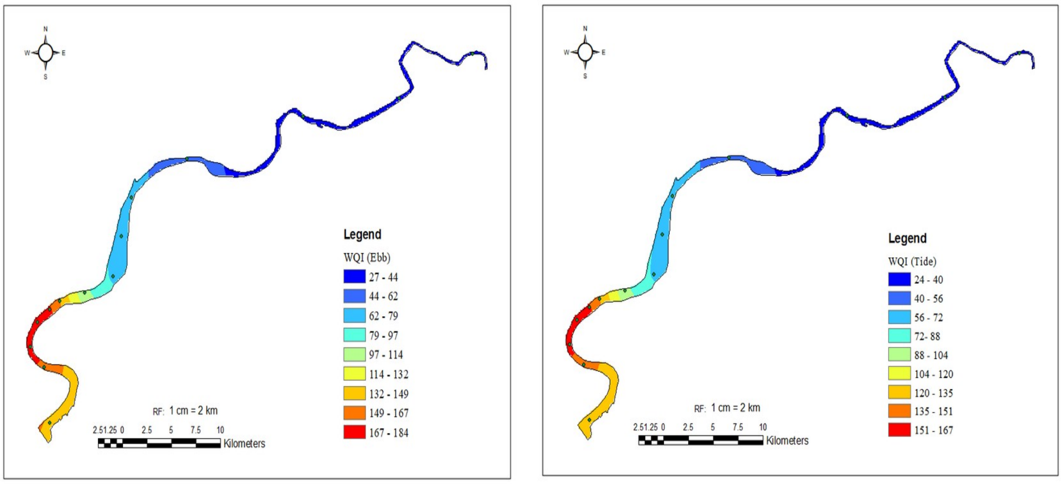
Figure 3: Spatial Variation of water quality parameters in the Karnaphuli River (a) pH, (b) EC, (c) TDS, (d) Chloride, (e) Turbidity, (f) BOD, (g) COD, (h) DO

Figure 2(e) depicts turbidity variations between tide and ebb, with the highest turbidity recorded at 284 NTU in ebb left. This value falls outside the standard range, posing potential concerns for both human health and aquatic life (Tornevi et al., 2014). Additionally, Figure 3(e) shows that the initial 20 km of the river exhibits high turbidity, indicating muddy qualities, while the subsequent portion of the river has lower turbidity, suggesting a more stable zone (Yang et al., 2014; Gustavson et al., 1978). The biological oxygen demand (BOD) ranges from 5.6 to 15.7 mg/L, averaging 9.1 mg/L, as depicted in Figure 2(f). The highest BOD, 15.7 mg/L, is found in ebb left, and the lowest, 5.6 mg/L, is in ebb right. These values significantly exceed the drinking water quality standard of 0.2 mg/L set by Bangladesh Environment Conservation Rules (1997). The chemical oxygen demand (COD) of the Karnaphuli River ranges from 19 mg/L to 1298 mg/L, as shown in Figure 2(g). The highest COD is in tide mid, the lowest in ebb left, with an average of 435.7 mg/L, significantly surpassing the 4 mg/L standard set by Bangladesh Environment Conservation Rules. Figures 3(f) and (g) indicate that COD levels are notably high in the first 10 km, whereas BOD levels are much lower in the same region. This disparity suggests that there may be non-biodegradable or slowly biodegradable pollutants present in the water, such as industrial chemicals or complex organic compounds, which contribute to a significant oxygen demand during the COD test but are not fully consumed by the microbial activity measured in the BOD test (Dey et al., 2017; Almeida et al., 2007). The industrial discharge stations concentrated in the first 10 km, as shown in Figure 1, may be contributing to this pollution. Figure 2(h) illustrates dissolved oxygen (DO) fluctuating between 2.27 and 8.4 mg/L, with a mean of 6.57 mg/L, slightly higher than the standard value of 6 mg/L. Low DO levels in rivers can result from industrial pollution, introducing organic matter and pollutants that boost microbial decomposition, leading to oxygen depletion. This poses a threat to aquatic life and water quality (Hossain et al., 2020; Almeida et al., 2007). Figure 3(h) reveals that DO reaches its lowest point at 12.5 km and 25 km, indicating these locations are most critical for aquatic life, with the highest industrial pollution observed in nearby zones.

3.2 WQI and HPI Variations

3.2.1 WQI Variations

Figure 4 depicts the spatial distribution of WQI values obtained from analysing water quality of 90 samples. Significant variability in WQI is evident across the river with the lower portion of the river showing poorer water quality which improves as we move towards the upper portion.



(a) (b)

Figure 4: Spatial Distribution of Water Quality Index in the Karnaphuli River during (a) Ebb and (b) Tide.

The peak Water Quality Index (WQI) range observed during tide ranged from 151 to 167 (Figure 4b), escalating to 167-184 during the ebb (Figure 4a). Conversely, the lowest WQI range during tide was 24-40 (Figure 4b), increasing to 27-44 during ebb conditions (Figure 4a). The higher WQI during ebb is a significant indicator that the concentration of pollutants tends to rise when the water level decreases- a trend consistent with findings from previous research (Dey et al., 2017). This trend is particularly concerning, given the gradual decline in the water level of the Karnaphuli River as documented by Roy et al. in 2020. This suggests a potential exponential increase in pollution levels if the current trajectory continues into the future. The most alarming region identified was the 10-15 km zone, displaying the highest Water Quality Index (WQI) in both tide and ebb conditions. This zone has the highest number of industrial discharge points, totaling six. The observed linkage between water pollution and industrial effluents aligns with findings from prior studies by Roy et al. (2020) and Alam et al. (2022), further emphasizing the 10-15 km zone as having the poorest water quality. The contrasting superior water quality in the upper river segments, devoid of industrial discharge points, underscores the direct impact of these discharges on the water quality of the Karnaphuli River.According to the Water Quality Index (WQI) classification, the downstream water quality of the river falls into the category of "unsuitable for drinking," while upstream is classified as "good." This difference indicates a notable concern, particularly pollution from industrial effluents, in the downstream zone.

3.2.2 HPI Variations

Table 1 displays the concentrations of heavy metals derived from 17 industrial discharge points, with the observed order of the four examined heavy metals being Fe > Mn > Cu > Pb based on their concentrations. The highest concentrations of Fe, Mn, Pb, and Cu in the water were 0.972 mg/L, 0. 365 mg/L, 0. 09 mg/L, and 0. 265 mg/L, respectively, as shown in Table 1. The maximum levels of these metals recommended by Bangladesh Environment Conservation Rules (BECR) are 0.3 mg/L, 0.1 mg/L, 0.05 mg/L, and 1 mg/L, respectively. Except for Cu, which had a substantially lower concentration than the recommended amount, all the heavy metals had concentrations that were higher than the advised norm.

Table 1: Heavy-metal Pollution Index near industrial discharge points in the Karnaphuli River

Discharge Points	Parameters				HPI
	Fe(mg/L)	Mn(mg/L)	Pb(mg/L)	Cu(mg/L)	
1	0.43	0.18	0.02	0.12	89
2	0.53	0.14	0.02	0.07	80

3	0.55	0.18	0.02	0.08	95
4	0.64	0.27	0.09	0.15	201
5	0.72	0.32	0.08	0.17	209
6	0.75	0.19	0.06	0.11	145
7	0.97	0.37	0.09	0.27	243
8	0.72	0.33	0.08	0.17	208
9	0.80	0.24	0.07	0.14	178
10	0.71	0.23	0.05	0.13	152
11	0.72	0.22	0.06	0.13	153
12	0.56	0.18	0.02	0.09	95
13	0.56	0.18	0.02	0.09	96
14	0.46	0.17	0.02	0.12	90
15	0.42	0.19	0.02	0.13	89
16	0.55	0.18	0.02	0.11	93
17	0.51	0.19	0.02	0.10	94

The water samples displayed diverse levels of heavy metal contamination, as reflected in the Heavy Metal Pollution Index (HPI) values presented in Table 1, ranging from 80 to 243 with an average value of 136. Significantly, eight out of the seventeen sampling stations situated in close proximity to industrial discharge points reported HPI values surpassing 100, indicating severe heavy metal pollution and categorizing them as "Contaminated." Conversely, the remaining stations recorded values below 100, earning them the classification of "Not Contaminated" according to the criteria established by Wang et al. (2016). The discovery of such high pollution levels in proximity to discharge points 4 to 11, where the HPI exceeded the recommended threshold of 100, raised significant concerns. These stations are all situated within the 10-15 km segment downstream of the river, as illustrated in Figure 1. While heavy metal contamination can result from various sources, such as ship-breaking yards (Aktaruzzaman et al., 2014), textile, petrochemical, and manufacturing industries (Monzer et al., 2012), mining activities (Sirajul et al., 2023), and agricultural runoff (Mohan et al., 1996), the specific contamination within the 10-15 km segment coinciding with the concentration of industrial discharge points strongly suggests that the contamination in this zone primarily stems from industrial effluents. The heavy metal contamination poses a grave threat to aquatic life, potentially leading to fish and aquatic species' poisoning and habitat degradation (Ali et al.; 2013). Additionally, human health may be at risk due to the consumption of contaminated fish and water, potentially causing severe health issues, including heavy metal toxicity (Asuquo et al.; 2019). Therefore, it is recommended that industrial effluents undergo treatment prior to their discharge into the river. Additionally, limiting the number of discharge points to fewer than three within a 5 km radius is advised to mitigate the concentration of heavy metals.

4. CONCLUSIONS

The water quality in the Karnaphuli River is consistently deteriorating, with pollution becoming more pronounced during periods of lower water levels. The heightened concern arises as the river's water level is decreasing over time, exacerbating the pollution levels. Hence, it is advisable to refrain from discharging industrial effluents during ebb conditions, as this significantly and alarmingly affects water quality. The downstream water is categorized as 'unsuitable for drinking,' in stark contrast to the notably better upstream water, classified as 'good.' This difference is primarily attributed to industrial effluent discharge, with a concentration of industries predominantly located in the downstream area, particularly in the 10-15 km zone where numerous industrial discharge points coincide. Regarding heavy metal contamination, eight out of the seventeen industrial discharge points show high levels of contamination, posing a significant concern. It is advised to apply suitable treatment measures to address industrial effluents prior to their discharge into the river. Additionally, the number of discharge points within a 5 km radius should be restricted to a maximum of three.

The research emphasizes the immediate necessity of implementing rigorous standards for industrial effluents and enforcing penalties to efficiently combat water pollution in the Karnaphuli River. This strategy guarantees the preservation of river water quality and protects the well-being of communities that depend on it for various purposes, such as agriculture and drinking water.

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