

Environmental Consequences of Industrial Waste Discharge on the Pasur River

Chandan Dey

Northern University of Business and Technology Khulna

Prottay Mazumder

Khulna University of Engineering & Technology (KUET)

Sadib Bin Kabir

`sadib.kabir@monash.edu`

Monash University

Research Article

Keywords: Industrial effluent discharge, Water quality indices, Geographical Information System, Pasur River pollution, Spatial analysis of contaminants

Posted Date: October 13th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11312195/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

1 **Environmental Consequences of Industrial Waste Discharge on the Pasur River**

2 Chandan Dey, Prottay Mazumder, Sadib Bin Kabir*

3

4 **Chandan Dey**

5 Lecturer, Northern University of Business and Technology, Khulna, Bangladesh, Department of
6 Civil Engineering, Khulna 9100, Bangladesh, Contact Number: +8801826813297, email:
7 chandance15@gmail.com

8 Postgraduate student, Department of Civil Engineering, Khulna University of Engineering &
9 Technology (KUET), Khulna 9203, Bangladesh

10 **Prottay Mazumder**

11 Postgraduate student, Department of Civil Engineering, Khulna University of Engineering &
12 Technology (KUET), Khulna 9203, Bangladesh, email: prottaypm106@gmail.com

13 *** Sadib Bin Kabir (Corresponding Author)**

14 PhD Student, Monash University, Department of Civil and Environmental Engineering, 16 and 18
15 Alliance Lane, Clayton, VIC 3800, Australia. Telephone: +61 0 487966883; Email:
16 sadib.kabir@monash.edu; ORCID iD: 0000-0002-8823-4295.

17

18 **Abstract**

19 Industrial effluent discharge is degrading the Pasur River, the principal channel of the Sundarbans
20 mangrove region in southwestern Bangladesh. This study assesses the impact of discharge from
21 nine industrial facilities (cement, LPG, and ceramic plants) at Mongla Port using water samples
22 collected at each discharge point, laboratory analyses of physicochemical parameters and metals,
23 and GIS-based spatial analysis. We evaluated water quality using the Water Quality Index (WQI),
24 Comprehensive Pollution Index (CPI), Metal Index (MI), and irrigation indices, and identified
25 sources using principal component and cluster analysis. Mean total dissolved solids (1976.4 mg/L)
26 and magnesium (63.3 mg/L) exceeded the Bangladesh health-based guideline values at all stations.
27 WQI ranged from 69.9 to 127.4, with six of nine stations above 100, the threshold for water unfit
28 for use. Average Metal Index (8.31) exceeded the severe-impact threshold at every station.
29 Irrigation indices indicate restricted agricultural use without treatment. Principal component
30 analysis explained 51.9% of the variance, and cluster analysis grouped the stations by effluent
31 type: cement and LPG discharges drove high organic and metal loads.

32 In contrast, ceramic and LPG discharges drove high dissolved-solids loads. Spatial mapping
33 identified a shoreline hotspot of five adjacent facilities. The results provide a practical workflow
34 for regulators: screen compliance using WQI, CPI, and MI; target additional monitoring at the
35 hotspot; and prioritize treatment by effluent cluster. The framework uses routine monitoring data
36 and can be applied to other rapidly industrializing river systems. These findings support enforcing
37 effluent limits, treating heavy metals and domestic wastewater, and sustaining monitoring to
38 protect the river's ecology and public health.

39 **Keywords:** *Industrial effluent discharge, Water quality indices, Geographical Information*
40 *System, Pasur River pollution, Spatial analysis of contaminants.*

1. Introduction

Water resources are crucial for maintaining environmental sustainability, supporting economic development, and safeguarding public health. However, water resources are continuously contaminated with industrial waste discharged in an unplanned way, particularly in developing countries with often inadequate regulatory frameworks. Bangladesh, being a developing agrarian country, uses river water for agricultural and fishery purposes. River water contamination negatively impacts both the fish culture rate and agricultural activities by degrading water quality, disrupting aquatic ecosystems, and posing risks to both biodiversity and human health, leading to the economic downfall of a nation. The impact of industrial pollution on river water should be assessed through continuous monitoring of surface water quality near the industrial zones, and providing adequate regulatory frameworks (Choudhury et al., 2021).

The Pasur River is a vital waterway supporting ecological diversity and local livelihoods, leading to the formation of the industrial zone of the Khulna division of Bangladesh. In this industrial zone, shipbuilding, shrimp farming, and textile industries discharge waste in an unplanned manner along the riverbed, which raises significant concerns about water quality (Lipy et al., 2025). The nearby rural people use river water for a variety of purposes, including industrial use, home activities, bathing, agricultural irrigation, and food preparation. In some circumstances, during the dry season, rural residents boil river water for drinking purposes, resulting in significant risks of health hazards (Tikadar et al., 2024)

The industrial waste in this area typically contains a complex mix of chemical and organic pollutants, including heavy metal carcinogens like lead, cadmium, and mercury, as well as hydrocarbons and nutrients such as nitrates and phosphates. The effect of these contaminants has severe consequences; for instance, heavy metals that accumulate in sediments cause long-term

health risks to humans and wildlife entering through the food chain (Md. K. Hasan et al., 2019). Nutrient overload can lead to eutrophication, marked by algal blooms that reduce oxygen levels and disrupt aquatic life. Additionally, untreated effluents from shrimp farms add organic waste and chemicals to the water, further reducing oxygen levels and harming aquatic habitats. The cement and petroleum industry's discharge also contributes by introducing raw effluents and metals that increase sediment toxicity and render the river unsuitable for critical uses such as drinking, irrigation, and recreation (Ali et al., 2018).

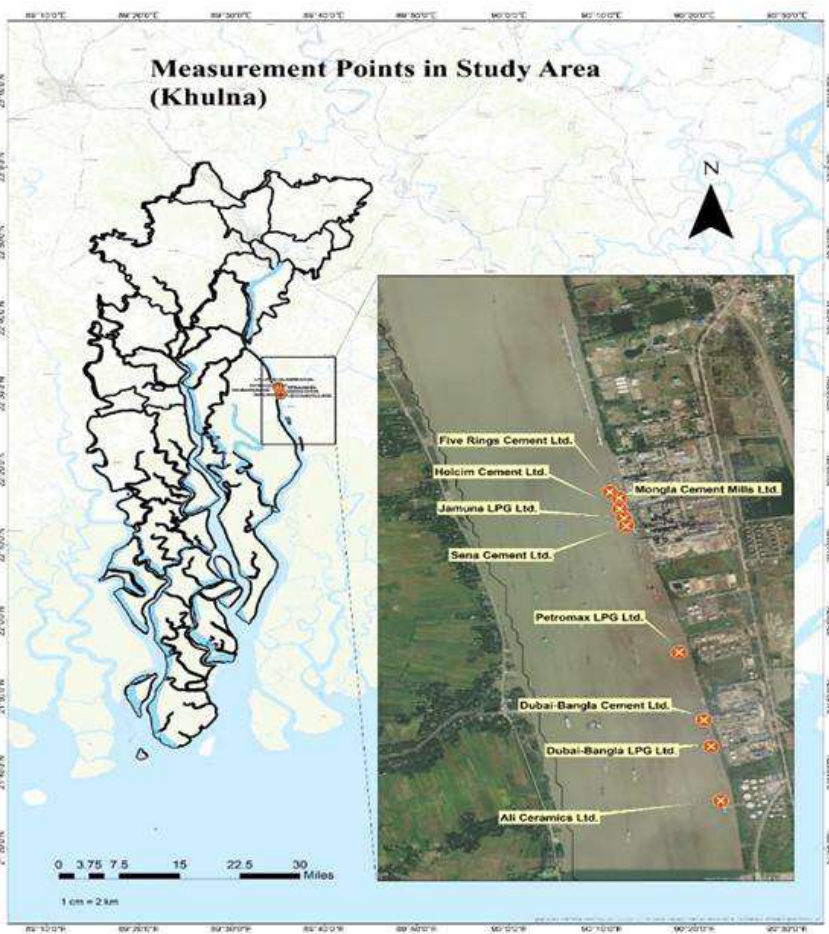
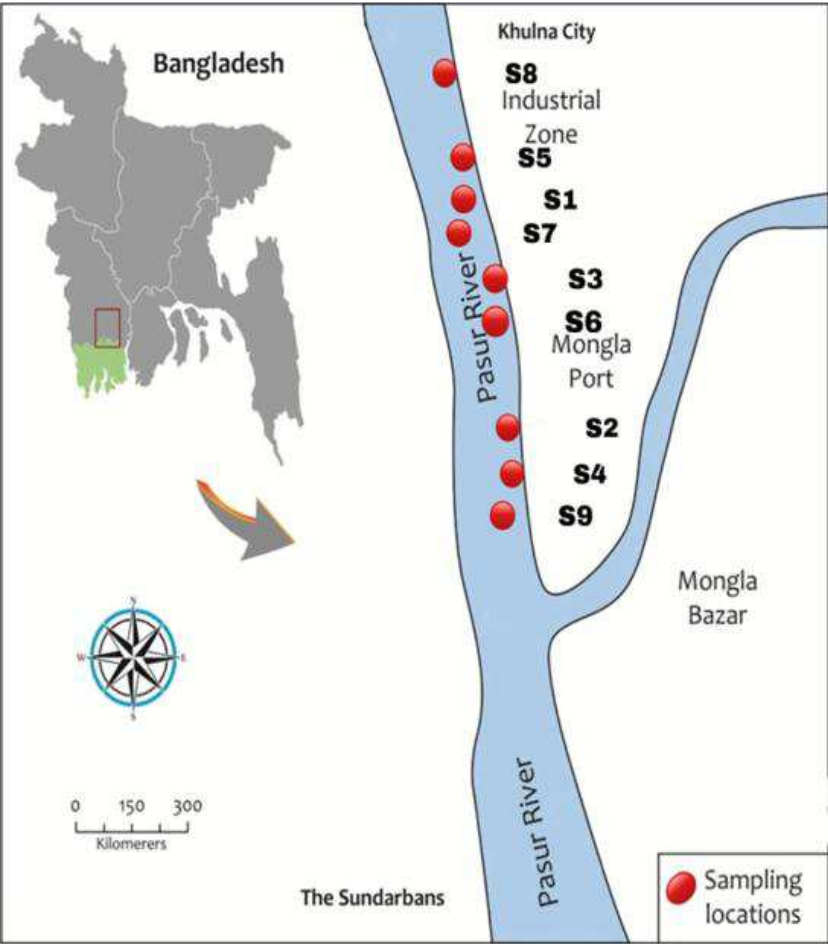
Previous studies on the Pasur River limited their scope of work to seasonal fluctuations of physicochemical properties, toxic metal pollution in river sediment, and identification of the contamination point sources (M. R. Hasan et al., 2023; Jewel et al., 2024; Roy et al., 2025). This study focused on this research gap and modeled the trend of contamination spreading along the river to help develop targeted strategies for managing industrial waste and protecting river ecosystems, thereby supporting sustainable resource management in the region. By applying spatial analysis using GIS, the metal concentrations were pinpointed, and other parameter distributions from the sources of pollution were identified, revealing clear patterns tied to industrial discharges. This work not only fills a crucial knowledge gap but also provides a foundation for better protecting and managing the Pasur River—a lifeline for so many in the region.

2. Study area

The Pasur River, which is the principal channel of the Sundarbans mangrove region (89°30' E, 21°45' N), flows through Mongla Port Municipality in Bagerhat District, Khulna, Bangladesh. This area is located about 55 km south of Khulna City and 131 km north of the Bay of Bengal, hosts the nation's second-largest seaport, an export processing zone, and active fishing industries. The land use in this area is dominated by industrial, agricultural, forested, and urban zones. The

geology is mainly composed of tidal deltaic deposits, with marsh clay and peat in the north and west, mangrove swamp sediments in the south, and deltaic silt in the northeast.(Islam et al., 2022).

On October 27, 2024, water samples were collected from the Pasur River in Mongla, Bagerhat district, focusing on nine locations near the industrial wastewater discharge points of major establishments, including Mongla Cement Mills Ltd., Petromax LPG Ltd., Five Rings Cement Ltd., Holcim Cement Ltd., Jamuna LPG Ltd., Sena Cement Ltd., Dubai-Bangla LPG Ltd., Dubai-Bangla Cement Ltd., and Ali Ceramics Ltd (Fig 1 and Table 1). These sampling stations were selected through a detailed reconnaissance survey to capture the impact of industrial effluents on the river. Samples were collected midstream using an engine boat at 2m depth from the top surface, following standard guidelines (Saha & Paul, 2019). Separate 1000 ml PET bottles were used for cationic and anionic analyses, and the samples were immediately transported to the laboratory for testing to ensure reliable and accurate results.



101 **Fig 1.** Location showing the study area and sampling points.

102 **Table 1.** Location of the study area with a geographical map.

Location	Site Name	Longitude	Latitude
S1	Mongla Cement Mills Ltd.	89°35'02.3 "E	22°31'02.5 "N
S2	Petromax LPG Ltd.	89°35'13.1"E	22°30'28.6"N
S3	Five Rings Cement Ltd.	89°35'00.6"E	22°31'03.5"N
S4	Holcim Cement Ltd.	89°35'02.4"E	22°31'00.2"N
S5	Jamuna LPG Ltd.	89°35'03.2"E	22°30'58.1"N
S6	Sena Cement Ltd.	89°35'03.6"E	22°30'56.5"N
S7	Dubai-BanglaLPG Ltd.	89°35'18.9"E	22°30'07.8"N
S8	Dubai-Bangla Cement Ltd.	89°35'17.6"E	22°30'13.7"N
S9	Ali Ceramics Ltd.	89°35'20.7"E	22°29'55.3"N

3. Methodology

At each sampling site, three water samples were collected and homogenized to form a composite sample (1.0–1.5 L), which was then divided into 500 mL and 100 mL glass beakers for analysis. Field surveys were conducted simultaneously to document local conditions. The 500 mL samples were preserved with 5 mL of 55% HNO₃ per liter and stored at 4 °C for physicochemical testing, while 100 mL samples were stabilized with 2 mL of 6 N HNO₃ for metal analysis. All containers were pre-cleaned with 10% nitric acid and rinsed with deionized water. For metal determination, samples were digested with concentrated HNO₃ at 130 °C until clear, then filtered through Whatman No. 41 paper using deionized water.(Bhuyan et al., 2019).

3.1 Computed indices

The Water Quality Index (WQI) serves as a comprehensive and reliable tool for assessing the overall condition of water resources and identifying pollution levels in both surface and groundwater systems. By integrating multiple physicochemical parameters into a single numerical score, the WQI effectively simplifies complex datasets and facilitates clear interpretation. This index is extensively used in water quality monitoring to evaluate contamination sources, guide remediation priorities, and support sustainable water management and policy decisions. In this study, the Water Quality Index (WQI) was computed using the weighted arithmetic method originally proposed by Brown et al. (1972). The classification criteria for WQI values, corresponding water quality status, and potential usability are summarized in Table 2. The computational framework for WQI is expressed through Equations (1–4). The unit weight (W_n) of each parameter was determined using Eq. (1), where K denotes the proportionality constant and Sn represents the standard permissible limit of the n^{th} parameter. The summation of all unit weights satisfies the unity condition ($\sum W_n = 1$), ensuring balanced representation of each parameter's

127 significance (Bora & Goswami, 2017). The quality rating (Qn) for each parameter was calculated
128 using Eq. (3), where V_n indicates the measured concentration, S_n denotes the corresponding
129 standard value, and V_o refers to the ideal concentration in pure water—typically zero for most
130 parameters except pH, which assumes a neutral value of 7 at 25 °C.

131
$$W_n = \frac{K}{S_n} \quad (1)$$

132
$$K = \frac{1}{\frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \dots + \frac{1}{S_n}} \quad (2)$$

133
$$Q_n = \frac{(V_n - V_o)}{(S_n - V_o)} \times 100 \quad (3)$$

134
$$WQI = \frac{W_n \times Q_n}{W_n} \quad (4)$$

135 **Table 2.** WQI range, status and possible usage of the water sample (Brown et al. 1972).

WQI	Water Quality Status	Possible Usage	Health Implications	Common Pollutants	Recommended Actions
0-25	Excellent	Industrial, drinking, and irrigation.	Health risk is lowest.	Lowest Pollutant.	Continuous monitoring and preservation.
26-50	Good	Industrial, drinking, and irrigation.	Little hazard and trace pollutants availability.	Nitrates and phosphate availability.	Regular treatment and supervision.
51-75	Poor	Irrigation and industrial	Potential for gastrointestinal issues	Nitrates, phosphates, and organics	Basic filtration and chemical treatment
76-100	Very Poor	Irrigation	Hazardous health effects.	Heavy metals, pathogens	Advanced treatment and restricted usage
>100	Unfit for use	Need adequate treatment	High health risks (toxicity, disease)	Pathogens, heavy metals, pesticides	Comprehensive treatment before usage

136

A comprehensive pollution index (CPI) is a grading system that evaluates water quality and compares the quality of different bodies of water. It can be used to identify the main pollution parameters in the body of water and to analyze trends in water quality represented in Eqs. (5 - 6). The Comprehensive Pollution Index (CPI) identifies the overall water quality status (Bi et al., 2021).

$$PI = \frac{Ci}{Si} \quad (5)$$

$$CPI = \frac{1}{n} \sum_{i=0}^n PI \quad (6)$$

Where, Pollution Index (PI) for each parameter was calculated as the ratio of its measured concentration (Ci) to the corresponding standard limit (Si), with n representing the total number of parameters. Standard values were adopted from WHO and the Department of Environment (DoE), Bangladesh, guidelines. Following Mekuria et al. (2021), PI serves as a Single Factor Evaluation Index (SFEI), where $PI < 1$ denotes compliance with surface water standards and $PI > 1$ indicates pollution. Based on the Comprehensive Pollution Index (CPI), water quality is classified as clean (0–0.20), sub-clean (0.21–0.40), slightly polluted (0.41–1.00), moderately polluted (1.01–2.00), and heavily polluted (≥ 2.01). (Son et al., 2020).

The metal index (MI) is a water quality index that estimates the overall quality of drinking water by evaluating the potential health risks of heavy metals, using Eq. (7) (Ojekunle et al., 2016).

$$MI = \sum \frac{Ci}{(MAC)_i} \quad (7)$$

Where, Ci denotes the mean concentration of the i -th metal and MAC is its maximum allowable limit. MI value > 1 indicates contamination, while water quality classification based on MI is: < 0.3 (Class I: very pure), 0.3–1.0 (Class II: pure), 1.0–2.0 (Class III: slightly affected), 2.0–4.0 (Class

IV: moderately affected), 4.0–6.0 (Class V: highly affected), and >6.0 (Class VI: severely affected) (Withanachchi et al., 2018).

The total hardness of irrigation water is the sum of the calcium and magnesium concentrations in the water, expressed in parts per million (ppm) of calcium carbonate (CaCO₃). Eq. (8) is used to compute Total Hardness (TH). Based on the concentration of Na, Ca and Mg concentrations, Magnesium Hazard (MH), Kelley's ratio (KR), and sodium adsorption ratio (SAR) was calculated (Eqs. 9 - 11)(Hossain et al., 2024). These water quality parameters suggest the suitability of water for irrigation purposes.

$$TH = 2.497 Ca^{2+} + 4.115 Mg^{2+} \quad (8)$$

$$MH = \frac{Mg^{2+}}{Mg^{2+} + Ca^{2+}} \quad (9)$$

$$KR = \frac{Na^+}{(Mg^{2+} + Ca^{2+})} \quad (10)$$

$$SAR = \frac{Na^+}{\sqrt{\frac{(Mg^{2+} + Ca^{2+})}{2}}} \quad (11)$$

The sustainability of the water samples in the selected area was evaluated by comparing their physicochemical properties to the WHO and BDWS criteria (M. F. Hasan et al., 2021). This comparison offers insights into surface water's long-term viability and suitability for various applications by examining its adherence to established rules and regulations.

3.2 Geo-statistical interpolation method for estimating values

ESRI ArcGIS (10.8) was used with custom-built analysis tools and Satellite Imager to integrate diverse spatial analysis within a GIS platform as custom Arc Tools. Spatial interpolation is a technique applied to raster datasets, transforming discrete sample data into continuous fields. Inverse Distance Weighting (IDW) is a commonly used interpolation method that relies on the distances between measured points to estimate unknown values. Previous research has utilized similar approaches to derive more accurate area estimates from point measurements (Mazumder et al., 2023). IDW predicts unknown values based on neighboring data points, with its accuracy often surpassing that of the Kriging method (Tamara et al., 2019).

The influence of measured values diminishes as the distance from the point of measurement increases. IDW operates within a specified radius, limiting the interpolation area and accounting for the distance-dependent variability of the data. This study employed IDW to spatially interpolate point measurements and examine their distribution across various zones. The method provided a visual representation of how additional metal ions and other parameters such as pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), suspended solids (SS), dissolved oxygen (DO), and biochemical oxygen demand (BOD), propagated from their release points into the river. This assessment was used to predict different unknown values near the discharge point, providing a comprehensive understanding of pollution patterns and their correlation with industrial discharge points.

4. Results and discussions

4.1 Water quality guidelines

The water samples were analyzed, and their measured concentrations were compared with the drinking water standards established by the WHO and the Bangladesh Department of Environment. (Rahman et al., 2023). A total of nine sampling stations were considered for the research site. Table 3 shows the laboratory testing of physicochemical factors of the nine samples to ensure their suitability for drinking, irrigation, and other applications.

The pH value is a physical water quality characteristic critical to aquatic life. It is a significant indicator of water quality status because organisms can only exist in a specified range of pH, while the pH value impacts the solubility and availability of nutrients required and used by aquatic species(Kannel et al., 2007). Water pH impacts metal toxicity, chemical reactions, and appropriateness for various uses(Mekuria et al., 2021). The maximum and minimum pH values in the study area were 7.9 and 7.2 in the sampling stations S2 and S3, respectively. The recommended pH by WHO and Bangladesh drinking water guidelines varies from 6.50 to 8.50. The pH values of all the samples were within the standard guideline (Rahman et al., 2023). So, it is crucial to keep the aquatic habitat within that range, as high and low pH can be harmful for aquatic life (Fawaz et al., 2013).

213 **Table 3.** Comparative study of physicochemical parameters of Pasur River water with WHO and BDWS Standards.

Sample No.	pH	EC (µs/cm)	TDS (mg/L)	DO (mg/L)	Na+ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Pb ⁴⁺ (mg/L)	Al ³⁺ (mg/L)	As ³⁻ (mg/L)	Fe ²⁺ (mg/L)	BOD ₅ (mg/L)
S1	7.6	1875	1847	5.9	202	43.527	62	0.05	0.008	0.03	1.13	2.6
S2	7.9	2400	1914	6.6	229	51.341	73	0.04	0.007	0.04	1.13	2.6
S3	7.2	1729	1941	6.3	221	34.101	64	0.05	0.008	0.05	0.91	2.2
S4	7.4	1627	1909	5.6	204	30.12	71	0.04	0.009	0.03	1.12	2.8
S5	7.6	1672	1942	5.9	234	32.18	59	0.04	0.01	0.05	0.63	2.1
S6	7.5	1725	1923	5.4	235	56.23	61	0.05	0.009	0.04	0.45	2.4
S7	7.6	1890	1921	5.5	193	45.25	55	0.04	0.008	0.05	0.71	2.8
S8	7.3	1680	1863	5.2	205	28	58	0.04	0.005	0.03	0.5	2.7
S9	7.8	1752	2528	5.9	210	52	67	0.05	0.009	0.01	1.1	2.5
WHO STD	6.5-8.5	750	1000	-	200	75	50	0.01	-	0.01	-	-
BDWS	6.5-8.5	2000	1000	-	200	75	35	0.05	0.2	0.05	0.3-1.0	0.2

Electrical conductivity (EC) is an important indicator of drinking water quality, reflecting the concentration of dissolved ions and the overall ionic strength of the water.(Ahmed et al., 2020). The maximum and minimum EC values in the study area were 2400 and 1627 $\mu\text{s}/\text{cm}$, respectively. The standard guideline for WHO and Bangladesh drinking water guidelines recommend an EC of 750 to 2000 $\mu\text{s}/\text{cm}$. The standard guideline has been exceeded in sampling station S2, where the value is 2400 $\mu\text{s}/\text{cm}$. The Petromax LPG Ltd. (S2) discharges some residual chemicals, dust, and salt from the station's surface into nearby water bodies through the surface runoff of the rainwater, leading to a higher concentration of dissolved ions in river water. Along with that, poor handling or disposal of LPG residues, cleaning chemicals, or maintenance fluids are responsible for ionic substances entering the river water.

Total dissolved solids (TDS) are organic and inorganic substances in the sample water. The increase in level of TDS can decrease the level of palatability(Chandra et al., 2011). The maximum and minimum TDS values in the study area were 2528 and 1847 mg/L, respectively, found in the sampling stations S9 and S1. The recommended maximum concentration for TDS is 1000 mg/L in both WHO and Bangladesh drinking water standards. Ali Ceramics Ltd. (S9) generally uses water during the manufacturing processes, such as clay washing, glazing, and shaping. This wastewater frequently contains high amounts of dissolved salts, minerals, and suspended particles, which, when dumped untreated, increase the TDS levels in Pasur rivers. In addition to this, various kinds of chemical additives are being used in this ceramic production, which enter the river water through washing and other means, increasing the TDS level in the river water.

Dissolved oxygen (DO) levels in water reflect the amount of oxygen gas in the water. DO levels are used to monitor and regulate wastewater discharge, making sure that effluents do not

affect aquatic habitats. They are an essential parameter of water quality. The maximum and minimum DO levels in the study area were 6.6 and 5.2 mg/L, which are found in the sampling stations S2 and S8 respectively.

The biochemical oxygen demand (BOD) test measures the quantity of biodegradable organic material contained in a sample of water. The results are expressed in terms of mg/L of BOD that microorganisms, primarily bacteria, will consume while decomposing these compounds. BOD is the quantity of oxygen required to break down organic materials in water. Greater BOD implies bad water quality, whereas lower BOD suggests good water quality. In the study area, the maximum and minimum BOD levels were 2.8 and 2.1 mg/L, respectively, found in the sampling stations S4 and S5. Holcim Cement Ltd. (S4) discharge effluent includes organic additives utilized during the manufacturing process. These organic compounds become a food supply for microbes, resulting in an increase in BOD level in river water when oxygen is consumed during their decomposition.

The concentration of dissolved cations such as Na^+ , Ca^{2+} , Mg^{2+} , Pb^{4+} , Al^{3+} , and Fe^{2+} varied from 193 to 235, 28 to 56.23, 55 to 73, 0.04 to 0.05, 0.005 to 0.01, 0.45 to 1.13 mg/L, respectively, and the concentration of anion like As^{3-} varied from 0.01 to 0.05 mg/L. The concentration of metal ions is relatively higher due to presence of metals in raw materials such as clay, feldspar, bauxite for ceramic manufacturing, and limestone, fly ash, or slag for the cement industry, respectively. Rainwater runoff from storage heaps or landfills leaches these metals into river water. The average concentration of total dissolved solids (TDS), electric conductivity (EC), and magnesium (Mg) were 1976.4, 1816.7, and 63.3 mg/L, respectively, significantly exceeding the health-based guideline of WHO and Bangladesh standards because of the addition of effluents from the surrounding industries and improper waste management.

4.2 Water quality indices

Water quality indices are widely accepted and effective tools for assessing the overall condition of water resources and quantifying the degree of contamination in both surface and groundwater systems. The water quality indices in the studied region are represented in Table 4, where three water quality indices essential for domestic water use are plotted.

The value of WQI of nine stations is represented in Fig 2, where the fluctuation of values can be clearly identified. The WQI ranged from 69.9 to 127.4 with an average value of 102.842. It exceeded the maximum limit of 100, which denotes a grade 5 pollution status. So, the water in this area contains a huge number of pathogenic organisms like bacteria and other microorganisms, which can be responsible for severe health issues in the local community of that region. All areas have very poor water quality, which indicates that the water is likely unsuitable for drinking. Both S2 and S3 have the maximum value WQI because industries frequently discharge untreated or inadequately treated wastewater, including heavy metals, chemicals, oils, and hazardous compounds into adjacent water bodies, which severely reduces water quality. Also, the elevated WQI in the study area is attributed to contaminations from geogenic sources, municipal wastewater, industrial effluents, fishing boats, agricultural runoff, loading and unloading, and construction. However, the WQI of S6, S8, and S9 shows a comparatively lower value that indicates the water could be used for irrigation and industrial purposes. However, the water is completely unsuitable for drinking and fish culture.

Table 4. Water quality index (WQI), Comprehensive Pollution Index (CPI), Metal Index (MI) and pollution status.

Station ID	WQI	CPI	MI	Pollution Level
S1	104.579	2.004	7.960	High
S2	121.427	2.299	9.680	High
S3	127.417	2.023	8.653	High
S4	104.122	2.106	9.387	High
S5	114.626	2.084	7.908	High
S6	89.687	1.975	8.191	High
S7	118.548	2.179	7.775	High
S8	75.265	1.933	7.095	High
S9	69.911	2.041	8.117	High
Average	102.842	2.071	8.307	High

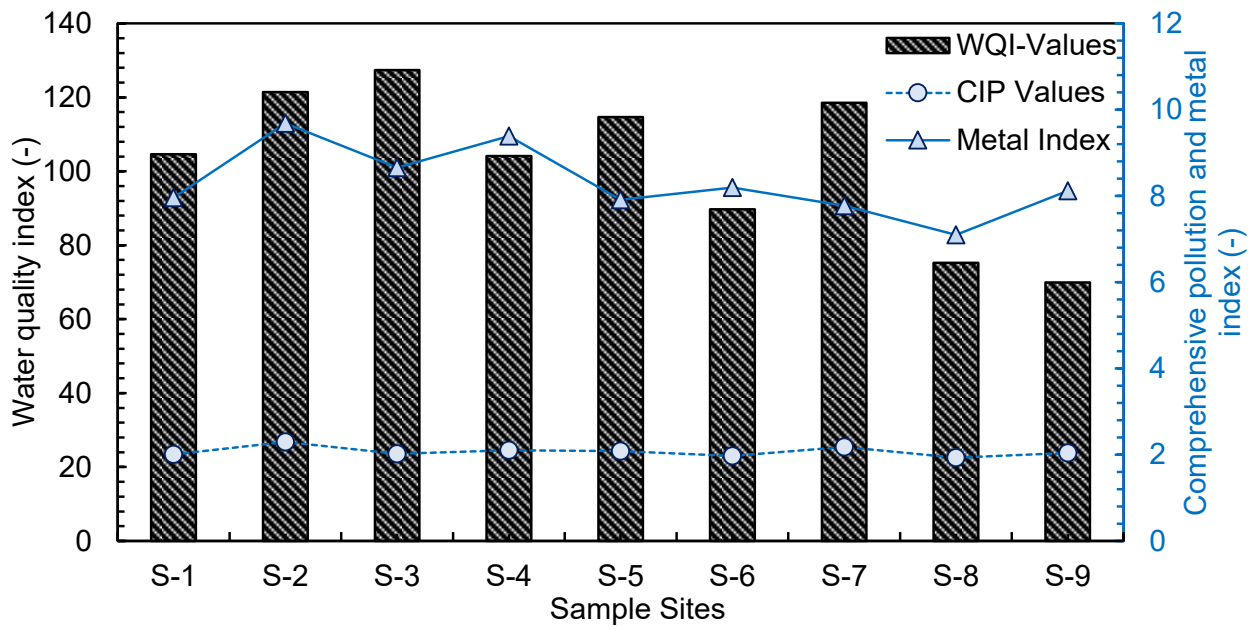


Fig 2. Water Quality Index (WQI), Comprehensive Pollution Index (CPI), Metal Index (MI) values for nine sample locations.

The CPI was used to assess the total level of water pollution in the Pasur River. The value of CPI of nine stations is represented in Fig 2, where the values of all the sampling stations are very close to one another. The value ranged from 1.9 to 2.2, with an average of 2.071 (Table 4), which indicates elevated pollution levels. Most of the stations exceeded the maximum limit of ≥ 2.0 , indicating Category 5 and serious pollution levels. So, the water in this area contains organic matter, toxic substances, and suspended solids. The maximum value of CPI is found in station no 2 because the wastewater from LPG station contains chemicals, detergents, and corrosion inhibitors. Due to the improper discharge of these pollutants and rainwater runoff of these toxic substances in the river water, the value of CPI increases. Also, the discharge of household, sewage, and septic waste from the surrounding municipal area increases the level of pollution. However, the S6 and S8 show comparatively lower values, which denotes a reduced level of pollution. Therefore, the result of CPI illustrates that water in this area is not suitable for drinking but can be used partially for household and irrigation purposes.

Metal Index (MI) was identified to examine the cumulative impacts of metals. The value of MI of nine stations is shown in Fig 2, where the value of all the sampling stations is comparatively high. The MI ranged from 7.09 to 9.68, with an average of 8.307 (Table 4). All sampling locations exceeded the maximum limit of >6.0 (class VI, severely damaged). The highest value of MI was reported at S-2, S-3, and S-4 (Fig 2) because of the improper disposal of metallic compounds in the LPG station and wastewater containing heavy metals, while cement production mixes with river water during runoff of the rainwater. Metals also come from anthropogenic or geological sources. Anthropogenic sources of metal contamination in the study area include effluents from nearby industries and workshops, automobile batteries, paints and pigments, fishing vessels, fuel stations, and agricultural chemicals. (Islam et al., 2022). However, the value of MI in

S7 and S8 is found to be comparatively lower but exceeds the standard guideline. Thus, the result shows that amount of metal in this region is high and not suitable for drinking purposes.

4.3 Irrigation indices

The presence of minerals in water and soil impacts suitability for irrigation purposes. Plant growth depends on irrigation water quality, and soil drainage is a key aspect of this connection. Table 5 lists the irrigation indices (MH, TH, KR, and SAR) and their classifications. These indices can assist farmers in determining the appropriate management methods to prevent potential dangers.

Table 5. Sodium Adsorption Ratio (SAR), Total Hardness (TH), Magnesium Hazard (MH) and Kelley's ratio (KR).

Station ID	SAR (-)	TH (mg/L)	MH (-)	KR (-)
S1	27.809	363.948	0.587527	1.914
S2	29.043	428.748	0.587095	1.842
S3	31.555	348.613	0.652389	2.253
S4	28.690	367.465	0.702136	2.017
S5	34.656	323.235	0.647072	2.566
S6	30.695	391.590	0.520345	2.005
S7	27.260	339.450	0.548628	1.925
S8	31.262	308.670	0.674419	2.384
S9	27.225	405.705	0.563025	1.765
Average	29.799	364.158	0.609182	2.075
Water Class	Very Sodium	High Very Hard	High Magnesium	Unsuitable

The sodium absorption ratio (SAR) determines the suitability of water for irrigation by evaluating the presence of alkali metals, including Na^+ , Ca^{2+} , and Mg^{2+} ions (Kawo NS, 2018). SAR is significant in irrigation because it evaluates the amount of sodium in the water and the soil's capacity to absorb it. The value of SAR of nine stations is shown in Fig 3, where the variation of values can be identified. The value of SAR ranged from 27.2 to 34.6, with an average of 29.799 (Table 5), which indicates a very high sodium level. Most stations exceeded the maximum limit of ≥ 26 , indicating a serious hazard. The S3 and S5 have the maximum value of SAR (Fig 3), because both the cement and LPG industries discharge wastewater containing sodium salts. The additives, such as sodium silicates or process water, which are used in these cement factories, are responsible for a higher value of SAR. On the contrary, the S7 and S9 show a comparatively lower value, which indicates that the amount of sodium in that region is less. Hence, the result suggests that water in that area can be partially used for irrigation. As well as the treatment of industrial effluent is essential for controlling the level of sodium in Pasur river water.

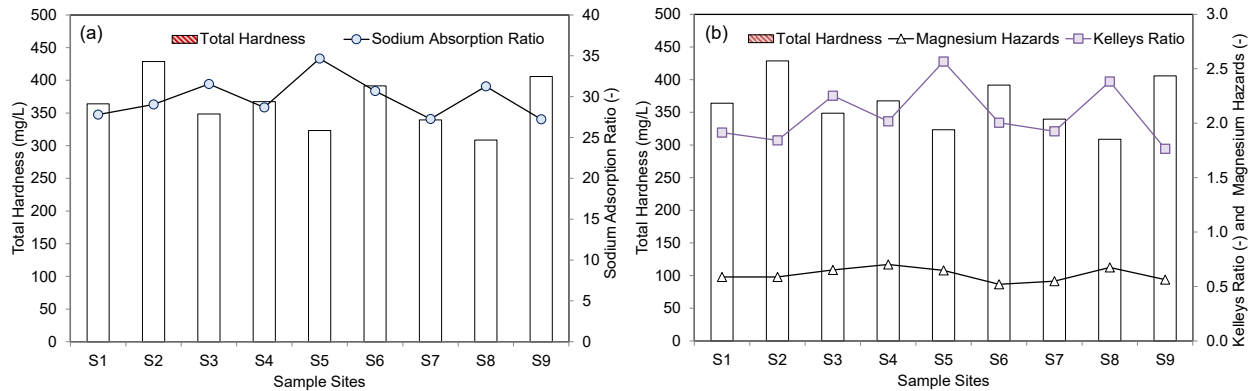


Fig 3. Irrigation indices (a) sodium adsorption ratio (-) in comparison with total hardness (mg/L), and (b) magnesium hazard and Kelley's ratio values in comparison with total hardness (mg/L) for nine stations.

The total hardness (TH) of water is important in irrigation as it affects the quality of the water and the irrigation system's efficiency. The value of TH of nine stations is illustrated in Fig 3 where the fluctuation of values can be seen. The value of TH ranged from 308.67 to 428.74, with an average of 364.158 (Table 5). All the stations exceeded the maximum limit of ≥ 300 , indicating a serious level of hardness. The S2 and S9 (Fig 3) show a high value of hardness because raw materials used in the ceramic industry include feldspar, kaolin, clay, and limestone, all of which include calcium and magnesium compounds. The runoff of raw materials used in LPG stations are also responsible for greater value of hardness. However, S-5, S-7, and S-8 showed comparatively lower values of hardness, indicating a low amount of Ca^{2+} and Mg^{2+} ions in those regions. Thus, the result represents a slightly higher level of hardness, which can be partially suitable for irrigation.

Magnesium hazard (MH) is a significant value in irrigation as it indicates how much suitable water is for agriculture. The value of MH of nine stations is represented in Fig 3, where the variations of values can be seen. The value of MH ranged from 0.52 to 0.70, with an average of 0.60 (Table 5), indicating a high magnesium level. All the stations exceeded the maximum limit of ≥ 0.5 , indicating a serious hazard level. The S3, S4, and S5 (Fig 3) have a higher value of magnesium level because cement manufacture utilizes raw minerals like limestone, dolomite, and shale, which frequently include magnesium carbonate. These components of magnesium seep into wastewater and end up in rivers during material processing and washing, which higher the level of Mg^{2+} . On the other hand, the S6 and S7 have a relatively lower value of magnesium in those areas. Therefore, the result shows a slightly higher level of magnesium level indicating the water can be used for irrigation to some extent. In irrigation class, Kelley's ratio (KR) is significant because it measures the concentration of various salts in the water to determine irrigation water quality. The value of KR of nine stations is shown in Fig 3b, where the variations of values can be identified.

The value of KR ranged from 1.7 to 2.5, with an average of 2.075 (Table 5), which indicates a high salt level. All the stations exceeded the maximum limit of ≥ 1 , indicating a serious salt presence. The S-5 has the highest recorded KR (Fig 3), because of the high use of sodium-based raw material and runoff of these components into the Pasur river water. However, the value of some stations was found to be lower. Thus, the result shows that water in this region contains salt to some extent which can be partially used for irrigation.

4.4 Spatial Distribution of Water Quality Indices

GIS analysis were employed to improve the characterization and visualization of the spatial distribution of different water quality indices., such as the Water Quality Index (WQI), Comprehensive Pollution Index (CPI), Sodium Absorption Ratio (SAR), Magnesium Hazards (%), Total Hardness, Kelleys Ratio (KR), and Metal Index (MI) in Fig 4. For each measurement point, the concentration of these spatially distributed river indices was analyzed. When the values at the measurement points differed significantly, the spatially distributed value tended to be closer. This is because, in a river system, sampling points that are located near each other are influenced by the same water flow, and the pollutant concentrations from one point can affect neighboring points.

The spatially distributed computed indices, including the WQI ranging from 94.23 to 108.08, CPI from 2.05 to 2.13, MI between 8.12 and 8.43, SAR ranging from 28.89 to 30.35, MH from around 0.59 to approximate 0.62, KR between 1.99 and 2.12, and TH ranging from 360.59 mg/L to around 370 mg/L, all exceeded the standard limits. This suggests that the contamination in the river is driven by both natural (geogenic) and human-induced (anthropogenic) sources. The spatial distribution analysis revealed that the areas near discharge points experienced higher concentrations of metal parameters and other pollutants. Lower values of water quality indices were represented by deep green colors, while areas with higher pollution levels were indicated by

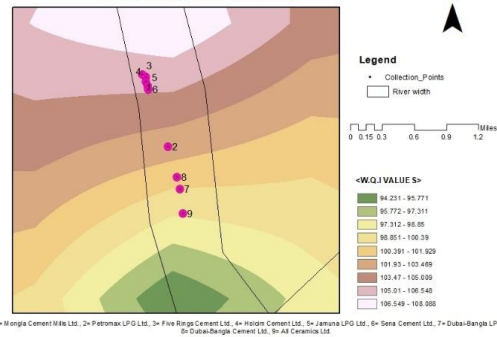
light pink, as per Fig 4. Based on nine sample locations' datasets, the analysis showed that five of these points (S1, S3, S4, S5 and S6), which are located near each other, had a significant impact on the overall pollution levels in their respective zones. These areas, including the discharge points, are consistently marked in the red zone, indicating high pollution levels. This trend was particularly evident for total hardness and CPI distributions, where higher values were observed near the S7 and S8 sample measurement zones. This suggests that metal discharge was more prominent during the sampling period. The pollution levels were found to be much higher near the river shoreline, where these factories are situated. From the WQI, it was observed that the sample point near Ali Ceramics Ltd. had the lowest metal ion concentrations, signifying better water quality compared to other areas. This indicates that the water quality in this zone was relatively good in comparison to the surrounding polluted areas. The five factories near each other (S1, S3, S4, S5 and S6) showed the highest pollution levels, primarily due to wastewater discharge.

The spatial distribution also revealed higher concentrations of sodium ions near Mongla Cement Mills Ltd. Additionally, the elevated Kelley's ratio observed in the areas around Five Rings Cement Ltd., Holcim Cement Ltd., Jamuna LPG Ltd., and Sena Cement Ltd. was attributed to the waste dumping from these factories. The magnesium hazard distribution further indicated that Mongla Cement Mills Ltd. was discharging a high amount of metal ions through untreated wastewater, contributing more than 0.61 of the pollution. In contrast, Ali Ceramics Ltd. exhibited a lower value, around 0.60. Lower values of SAR were detected in the areas near Dubai-Bangla LPG Ltd., Dubai-Bangla Cement Ltd., and Ali Ceramics Ltd. (< 8.2), while the five factories located closer to each other (S1, S3, S4, S5 and S6) had SAR values exceeding 8.4, as depicted in Fig 4. For these five factories, the SAR value was around 29.5, whereas the other factories had SAR values above 30. However, when analyzing total hardness and CPI, a different scenario

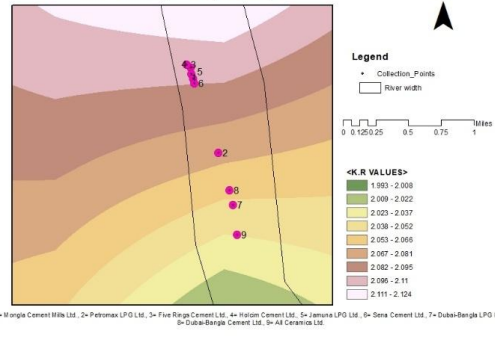
406 emerged. For the factories near Dubai-Bangla LPG Ltd., Dubai-Bangla Cement Ltd., and All
407 Ceramics Ltd., total hardness values were found to be above 369 mg/L, indicating an increased
408 concentration of dissolved minerals, primarily calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, in the
409 water. In contrast, the total hardness values for the other factories (Five Rings Cement Ltd., Holcim
410 Cement Ltd., Jamuna LPG Ltd., Sena Cement Ltd., and Mongla Cement Mills Ltd.) were below
411 362. The CPI values were also higher in these areas.

412 In summary, the spatial analysis highlighted the significant impact of wastewater discharge
413 from nearby factories on the river's water quality, with certain areas experiencing higher pollution
414 levels, particularly near the discharge points. These findings underline the importance of
415 monitoring and addressing industrial effluent discharge to protect the river's ecological and public
416 health.

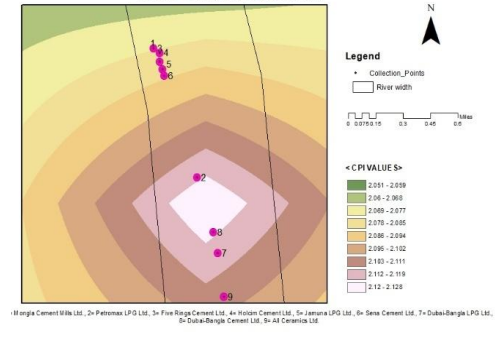
**Spatial distribution of Water Quality Index (W.Q.I)
in the study area (Khulna)**



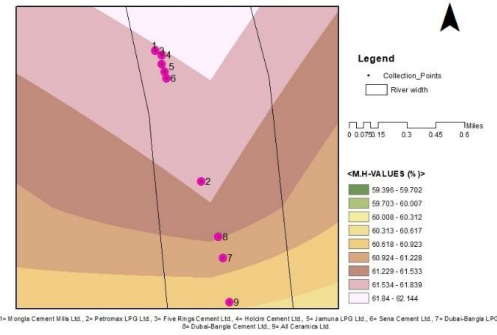
**Spatial distribution of Kelleys Ratio (K.R)
in the study area (Khulna)**



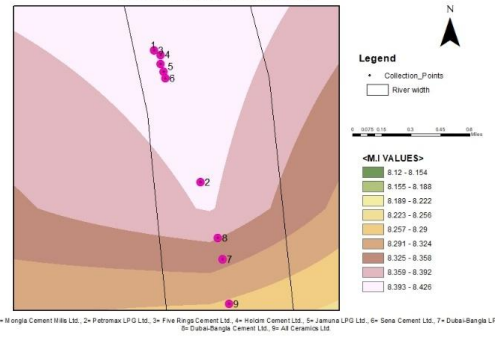
**Spatial distribution of Comprehensive Pollution Index (CPI)
in the study area (Khulna)**



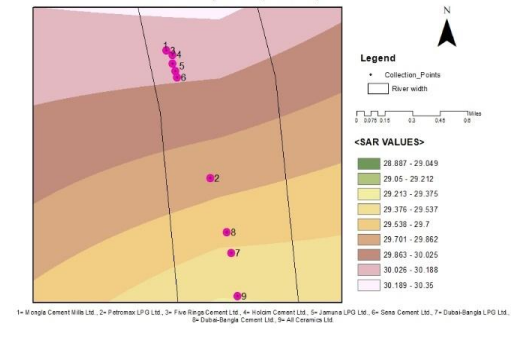
**Spatial distribution of Magnesium Hazards (%)
in the study area (Khulna)**



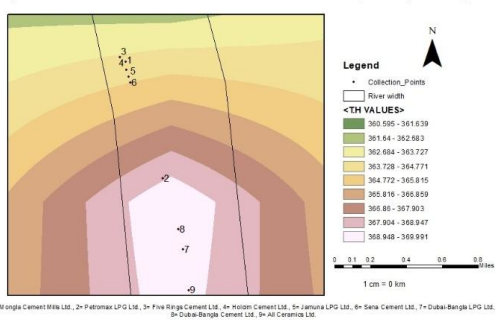
**Spatial distribution of Metal Index (M.I)
in the study area (Khulna)**



**Spatial distribution of Sodium Absorption Ratio (SAR)
in the study area (Khulna)**



Spatial distribution of Total Hardness in the study area (Khulna)



417

418 **Fig 4.** Maps showing the spatial distribution of Water Quality Indices.

4.5 Pearson Correlation Analysis

Pearson correlation is used to identify the relationships between different ions and the contamination levels. Pearson's correlation analysis (Table 6) demonstrates substantial correlations between water quality metrics, implying possible similar sources and geochemical interactions. pH is closely associated with Ca^{2+} ($r = 0.676$) and EC ($r = 0.674$), indicating that mineral dissolution processes impact water chemistry. DO correlates strongly with EC ($r = 0.649$) and Mg^{2+} ($r = 0.608$), suggesting that ionic composition may influence oxygen availability. TDS has an effective correlation with As^{3-} ($r = 0.663$), suggesting potential contamination from anthropogenic sources. Fe^{2+} has a positive correlation with Ca^{2+} ($r = 0.116$), Mg^{2+} ($r = 0.751$), and DO ($r = 0.638$), suggesting redox-sensitive interactions. The negative association between Na^+ and BOD_5 ($r = -0.756$) implies that greater sodium levels may inhibit microbial activity and organic breakdown. These interrelationships illustrate the complexities of water chemistry and highlight the importance of multivariate approaches in monitoring water quality and identifying pollution sources.

433 **Table 6.** Pearson’s correlation analysis.

	<i>pH</i>	<i>EC</i>	<i>TDS</i>	<i>DO</i>	<i>Na⁺</i>	<i>Ca²⁺</i>	<i>Mg²⁺</i>	<i>Pb⁴⁺</i>	<i>Al³⁺</i>	<i>As³⁻</i>	<i>Fe²⁺</i>	<i>BOD₅</i>
pH	1.000											
EC	0.674	1.000										
TDS	0.422	-0.107	1.000									
DO	0.410	0.649	0.122	1.000								
Na ⁺	0.141	0.154	-0.031	0.388	1.000							
Ca ²⁺	0.676	0.506	0.384	0.210	0.238	1.000						
Mg ²⁺	0.339	0.420	0.237	0.608	0.218	0.168	1.000					
Pb ⁴⁺	-0.082	-0.187	0.377	0.137	0.137	0.453	0.026	1.000				
Al ³⁺	0.213	-0.295	0.314	0.134	0.326	0.211	0.095	0.254	1.000			
As ³⁻	-0.281	0.121	-0.663	0.156	0.315	-0.195	-0.377	-0.299	0.087	1.000		
Fe ²⁺	0.398	0.397	0.295	0.638	-0.262	0.116	0.751	0.147	0.135	-0.412	1.000	
BOD ₅	0.114	0.203	-0.118	-0.377	-0.756	0.033	0.111	-0.371	-0.457	-0.354	0.237	1.000

4.6 Cluster analysis and specific source Identification

After implementation of hierarchical clustering analysis and principal component analysis, and after analyzing applicable parameters such as pH, conductivity, total dissolved solids, and others, the following inferences can be made about the nine sampling locations. This PCA helped to identify the reduction of the dimensionality of the dataset, revealing that PC1 and PC2 explain a combined total of around 51.86% of the total variance of the dataset. PC1 and PC2 account for 30.79% and 21.07% of the variance respectively. It was also found that variables like BOD₅, TDS, Na⁺, and Fe²⁺ appear to influence the first two components the most. These variables are crucial in differentiating sample profiles.

From the PCA Biplot and HCA Dendrogram, the three groups are revealed in Fig 5. In the biplot, sites that appear closer to one another have comparable contamination profiles, while sites which are far apart have disparate contamination sources. Here, it is recorded that BOD₅ correlates with PC1, indicating organic contamination is an important factor in differentiating sites. Apart from Ca²⁺, Na⁺, and Fe²⁺, which are important in PC1 and PC2, the significance of these parameters with respect to contamination patterns is highlighted. Similarly, for S1, S7, S8, and S4 stations, positioned in the top right of the plot, indicating moderate levels of contamination with proportionally smaller BOD₅ and metal contamination levels compared to other stations. Moreover, S3, S6, and S5 are at the bottom-left regions showing elevated metallic pollution and organic contamination, well-controlled by cement and LPG effluents. S9 and S2 are located towards the far-right region showing distinct contaminating signatures of ceramic and LPG effluents with elevated TDS and ionic pollution but relatively lower BOD₅ compared to others.

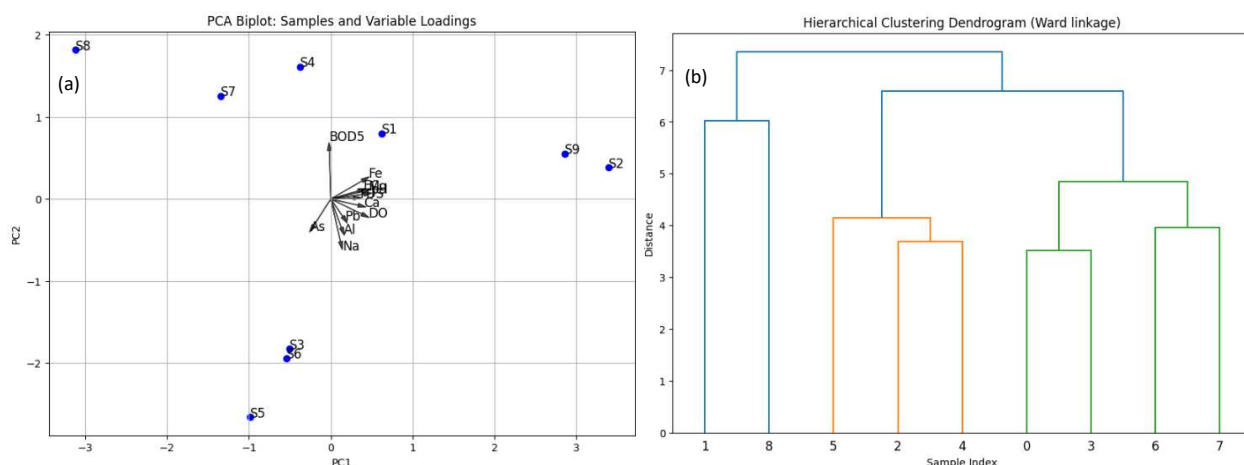


Fig 5. Cluster analysis and specific source Identification ((a) PCA Biplot and (b) HCA Dendrogram).

In the HCA Dendrogram, first Cluster 1 (Blue Cluster), S1, S7, S8, and S4 site are seen. These sample locations form a tight group, showing moderate contamination levels with relatively lower BOD5 and metallic contamination. Additionally, Sampling site 8 is part of this group and shares similar contamination characteristics with S1, S7, and S4. These sites are influenced by moderate pollution sources, likely related to industrial or natural contamination but not as severe as other sites.

Regarding Cluster 2, color tagged in Orange Color includes the S5, S2, and S4 sites. They are clustered together due to moderate pollution with varying chemical signatures. S5 and S4 are impacted by cement effluents and LPG effluents, while S2 is impacted by LPG effluents. Clustering suggests that the stations share similar TDS as well as metal pollution levels, but the types of contaminants vary slightly between them.

For the third Cluster 3, covering sites S6, S5, S3, are extremely contaminated with cement and LPG effluents, which result in high BOD5 and metallic contamination. These sites have the most severe pollution profiles with high MI and BOD5 values, which indicate the need for complete remediation programs with metallic as well as organic pollutants.

Therefore, for Cluster 1 (S1, S7, S8, S4) these regions experience moderate contamination with relatively lower BOD₅ and metallic contamination. General water quality management would be suitable here to reduce moderate levels of pollution. Regarding the Cluster 2 (S5, S2, S4) sites, the regions experience moderate levels of contamination mainly owing to ceramic and LPG effluents, which cause high TDS and metallic contamination. Special measures to reduce TDS and metallic pollution would be effective in these regions. Finally, Cluster 3 (S6, S5, S3) are the heavily polluted sites with the occurrence of high organic pollution (BOD₅) and metallic pollution (Fe, Pb). Cement and LPG waste are significant sources of pollution here, where there is a need for combined pollution control for metal and organic contamination.

4.7 Impact Analysis

Impact analysis is essential for monitoring river water quality because it helps identify, measure, and comprehend the effects of natural processes and human activities on aquatic ecosystems. The process is also critical because it connects pollution levels to the effects on ecosystems, human health, and sustainability, ensuring that river water resources are safeguarded and managed properly. Table 7 illustrates the impact of Pasur River water pollution on human health and the ecology of that region. The findings presented in Table 7 reveal significant anthropogenic impacts on the water quality of the Pasur River, primarily arising from industrial discharges, leaching, and surface runoff from cement and LPG industries. Across all sites, several physicochemical parameters particularly total dissolved solids (TDS), sodium (Na⁺), magnesium (Mg²⁺), and biological oxygen demand (BOD₅) exceeded the permissible limits established by WHO and national environmental standards. These elevated concentrations reflect severe

contamination from industrial effluents, urban solid waste, and raw material runoff, which together pose considerable risks to both human health and aquatic ecology.

High TDS levels, ranging from 1491 mg/L at Five Rings Cement Ltd. (S3) to 2400 mg/L at Petrom LPG Ltd. (S2), indicate excessive mineralization of river water, often associated with saline intrusion and effluent mixing. Elevated sodium concentrations (up to 234–235 mg/L) suggest potential risks of hypertension and cardiovascular stress among local populations relying on this water for domestic use. Similarly, Mg^{2+} concentrations frequently surpassed the standard limit (35 mg/L), which can aggravate gastrointestinal irritation and neuromuscular complications. The presence of heavy metals such as Pb^{2+} , Fe^{2+} , and As^{3+} , although in trace quantities, further underscores the toxicological concern—especially considering their potential for bioaccumulation and long-term ecological persistence.

Based on ecological perspective, the high BOD_5 levels (2.0–2.8 mg/L) across all sampling stations reflect an oxygen-depleted environment, which can cause hypoxia and disrupt aquatic biodiversity. The observed eutrophication and microbial proliferation, particularly near Sena Cement Ltd. (S6) and Dubal Bangla Cement Ltd. (S8), highlight the nutrient enrichment of the river system, likely driven by untreated organic waste discharge. These conditions favor algal blooms, alter microbial community structures, and reduce dissolved oxygen, collectively impairing the survival of sensitive aquatic organisms. The continuous deposition of suspended solids and chemical residues from cement industries also threatens benthic habitats and affects the food chain integrity through trophic transfer of pollutants. Residents exposed to such contaminated water may experience neurological disorders, gastrointestinal irritation, and dermatological conditions, as indicated in several affected sites (e.g., S3, S4, S5). The chronic exposure to metal ions and high salinity levels can also induce systemic toxicity, especially in children and vulnerable

519 populations. Therefore, the cumulative effects observed across multiple industrial zones
520 demonstrate an urgent need for improved waste management strategies, enforcement of effluent
521 treatment regulations, and continuous water quality monitoring to safeguard both ecological and
522 human health.

Location	Site Name	Source of Pollutants	Ions Exceeding Limit	Concentrations (mg/L)	Standard Limit (mg/L)	Impact on Health	Impact on Ecology
S1	Mongla Cement Mills Ltd.	i) Discharge from the industrial effluents ii) Urban solid and liquid waste.	TDS Na+ Mg2+ Fe2+ BOD	1847 202 62 1.13 2.6	1000 200 35 0.3-1.0 0.2	Harmful ions affect the nervous system and muscles.	Alters mineral balance and increases salinity.
S2	Petromax LPG Ltd.	i) Leaching from waste dumps. ii) Runoff mixed with urban wastes.	EC TDS Na+ Mg2+ Fe2+ BOD	2400 1914 229 73 1.13 2.6	2000 1000 200 35 0.3-1.0 0.2	Causes hypertension and skin diseases.	Damages aquatic plants and inhibits microbes.
S3	Five Rings Cement Ltd.	i) Cement dust and particles leaching. ii) Surface runoff of raw materials.	TDS Na+ Mg2+ Pb4+ As3- BOD	1941 221 64 0.05 0.05 2.2	1000 200 35 0.05 0.05 0.2	Causes neurological damage and affects the immune system, especially for children.	Alters the food chain and nutrient cycle.
S4	Holcim Cement Ltd.	i) Residual waste runoff. ii) Improper solid waste disposal.	TDS Na+ Mg2+ Fe2+ BOD	1909 204 71 1.12 2.8	1000 200 35 0.3-1.0 0.2	Causes gastrointestinal irritation and cathartic effect.	Affects algae growth and reduces biodiversity.
S5	Jamuna LPG Ltd.	i) Poor solid waste management. ii) Surface runoff from paved areas.	TDS Na+ Mg2+ As3- BOD	1942 234 59 0.05 2.1	1000 200 35 0.05 0.2	Causes heart diseases and risk for skin cancer.	Alters microbial communities and is toxic to fish.
S6	Sena Cement Ltd.	i) Cement dust and raw materials carried via stormwater.	TDS Na+ Mg2+ Pb4+ BOD	1923 235 61 0.05 2.4	1000 200 35 0.05 0.2	Causes waterborne diseases and neurotoxicity risk.	Causes eutrophication, which alters the food chain.

S7	Dubai-Bangla LPG Ltd.	i) Oil and grease washed away into the river water.	TDS Mg ²⁺ As ³⁻ BOD	1921 55 0.05 2.8	1000 35 0.05 0.2	Causes organ damage and increases hypertension risk.	Causes hypoxia and osmotic stress for fish.
S8	Dubai-Bangla Cement Ltd.	i) Clinker materials and waste slurry discharge into the river water.	TDS Na ⁺ Mg ²⁺ BOD	1863 205 58 2.7	1000 200 35 0.2	Contribute to hard water, causing cardiac and neuromuscular problems.	Microbial growth increases, altering river water chemistry.
S9	Ali Ceramics Ltd.	i) Raw materials and ceramic waste disposal into the river water.	TDS Na ⁺ Mg ²⁺ Pb ⁴⁺ Fe ²⁺ BOD	2528 210 67 0.05 1.1 2.5	1000 200 35 0.05 0.3-1.0 0.2	Causes hemochromatosis and alters water taste and odor.	Affects aquatic plant growth and promotes bacterial activities.

525 **5. Conclusions**

526 Rivers are vital water sources for domestic and irrigation use, but industrial effluents are
527 degrading them. This study found that total dissolved solids, electrical conductivity, and
528 magnesium exceed guideline values, and that the water quality indices (WQI, CPI, and MI)
529 indicate high pollution levels across the nine sampling stations. Irrigation indices (SAR, TH, MH,
530 and KR) also exceed their limits, so the Pasur River water is unsuitable for domestic use and only
531 partly suitable for irrigation without treatment.

532 Spatial analysis shows that wastewater from nearby factories has the greatest impact on water
533 quality around the discharge points. Principal component and cluster analyses link each
534 contamination pattern to a specific effluent type: cement and LPG discharges drive the high
535 organic and metal loads at S3, S5, and S6. In contrast, ceramic and LPG discharges drive the high
536 dissolved-solids and ionic loads at S2 and S9. The results give regulators and plant operators a
537 practical, repeatable workflow built on routine monitoring data:

- 538 • Screen compliance using WQI, CPI and MI at each discharge point.
- 539 • Target monitoring by using the IDW hotspot maps to place additional sampling stations
540 along the shoreline, where pollutants from the five adjacent facilities (S1, S3, S4, S5 and
541 S6) concentrate.
- 542 • Prioritise treatment by cluster. Cement and LPG facilities in the high-load cluster need
543 combined metal and organic treatment. Ceramic and LPG facilities need controls on
544 dissolved solids and salts. Facilities in the moderate cluster need routine effluent treatment
545 and supervision.

546 Protecting the river also requires effectively removing heavy metals from industrial and municipal
547 effluents, properly treating domestic wastewater, and enforcing effluent discharge limits.
548 Continuous monitoring of the Pasur River and the surrounding agricultural land is needed to track
549 risks to human health and aquatic ecosystems. Because this study is a single sampling campaign,
550 seasonal monitoring should be the next step to confirm these patterns and measure the effect of
551 any treatment measures introduced. The same framework can be applied to other rapidly
552 industrializing river systems in the region.

References

- Ahmed, M. T., Hasan, M. Y., Monir, M. U., Samad, M. A., Rahman, M. M., Islam Rifat, M. S., Islam, M. N., Khan, A. A. S., Biswas, P. K., & Jamil, A. H. M. N. (2020). Evaluation of hydrochemical properties and groundwater suitability for irrigation uses in southwestern zones of Jashore, Bangladesh. *Groundwater for Sustainable Development*, 11, 100441. <https://doi.org/10.1016/j.gsd.2020.100441>
- Ali, M. M., Ali, M. L., Islam, M. S., & Rahman, M. Z. (2018). Assessment of toxic metals in water and sediment of Pasur River in Bangladesh. *Water Science and Technology*, 77(5), 1418–1430. <https://doi.org/10.2166/WST.2018.016>
- Bhuyan, M. S., Bakar, M. A., Rashed-Un-Nabi, M., Senapathi, V., Chung, S. Y., & Islam, M. S. (2019). Monitoring and assessment of heavy metal contamination in surface water and sediment of the Old Brahmaputra River, Bangladesh. *Applied Water Science*, 9(5), 1–13. <https://doi.org/10.1007/s13201-019-1004-y>
- Bi, S., Wang, L., Li, Y., Zhang, Z., Wang, Z., Ding, X., & Zhou, J. (2021). A Comprehensive Method for Water Environment Assessment considering Trends of Water Quality. *Advances in Civil Engineering*, 2021. <https://doi.org/10.1155/2021/5548113>
- Bora, M., & Goswami, D. C. (2017). Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India. *Applied Water Science*, 7(6), 3125–3135. <https://doi.org/10.1007/s13201-016-0451-y>
- Chandra, S., Singh, A., Tomar, P. K., & Kumar, A. (2011). Evaluation of physicochemical characteristics of various river water in India. *E-Journal of Chemistry*, 8(4), 1546–1555. <https://doi.org/10.1155/2011/430232>
- Choudhury, T. R., Acter, T., Uddin, N., Kamal, M., Sarwaruddin Chowdhury, A. M., & Safiur Rahman, M. (2021). Heavy metals contamination of river water and sediments in the mangrove forest ecosystems in Bangladesh: A consequence of oil spill incident. *Environmental Nanotechnology, Monitoring & Management*, 16, 100484. <https://doi.org/10.1016/J.ENMM.2021.100484>
- Fawaz A, Mohammad Shuhaimi O, M. B. G. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*.
- Hasan, M. F., Nur-E-alam, M., Salam, M. A., Rahman, H., Paul, S. C., Rak, A. E., Ambade, B., & Towfiqul Islam, A. R. M. (2021). Health Risk and Water Quality Assessment of Surface Water in an Urban River of Bangladesh. *Sustainability* 2021, Vol. 13, Page 6832, 13(12), 6832. <https://doi.org/10.3390/SU13126832>
- Hasan, M. R., Anisuzzaman, M., Choudhury, T. R., Arai, T., Yu, J., Albeshr, M. F., & Hossain, M. B. (2023). Vertical distribution, contamination status and ecological risk assessment of heavy metals in core sediments from a mangrove-dominated tropical river. *Marine Pollution Bulletin*, 189, 114804. <https://doi.org/10.1016/J.MARPOLBUL.2023.114804>
- Hasan, Md. K., Shahriar, A., & Jim, K. U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon*, 5(8), e02145. <https://doi.org/10.1016/j.heliyon.2019.e02145>
- Hossain, M. S., Nahar, N., Shaibur, M. R., Bhuiyan, M. T., Siddique, A. B., Al Maruf, A., & Khan, A. S. (2024). Hydro-chemical characteristics and groundwater quality evaluation in southwestern region of

593 Bangladesh: A GIS-based approach and multivariate analyses. *Heliyon*, 10(1), e24011.
594 <https://doi.org/10.1016/j.heliyon.2024.e24011>

595 Islam, M. S., Nakagawa, K., Abdullah-Al-mamun, M., Khan, A. S., Goni, M. A., & Berndtsson, R. (2022).
596 Spatial Distribution and Source Identification of Water Quality Parameters of an Industrial Seaport
597 Riverbank Area in Bangladesh. *Water (Switzerland)*, 14(9). <https://doi.org/10.3390/w14091356>

598 Jewel, M. A. S., Zinat, A., Khatun, B., Akter, S., Chandra Barman, A., Satter, A., & Haque, M. A. (2024).
599 Ecological and public health risk assessment of potentially toxic elements in the surface sediments of
600 the Pasur river estuary, Bangladesh. *Heliyon*, 10(8), e29278.
601 <https://doi.org/10.1016/j.heliyon.2024.e29278>

602 Kannel, P.R., Lee, S., Lee, YS. et al. (2007). Application of Water Quality Indices and Dissolved Oxygen
603 as Indicators for River Water Classification and Urban Impact Assessment. *Environ Monit Assess*
604 132, 93–110.

605 Kawo NS, K. S. (2018). Groundwater quality assessment using water quality index and GIS technique in
606 Modjo River Basin, central Ethiopia. *Journal of African Earth Sciences*.

607 Lipy, E. P., Rahman, M. T., Islam, S., Raknuzzaman, M., Islam, M. M., Akhter, S., Islam, D., Naim, M. R.,
608 Moniruzzaman, M., Biswas, A., Hakim, M., & Lyzu, C. (2025). Occurrence of heavy metals in fish
609 species, water and sediments of the Pasur River in Bangladesh along with assessments of ecological
610 and human health risks. *Discover Environment*, 3(1), 1–21. <https://doi.org/10.1007/S44274-025-00238-2/TABLES/11>

612 Mazumder, P., Bin, S., Ahmed, J., & Islam, M. R. (2023). Urban Climate Measuring and modeling PM 2 .
613 5 zonal distributions , assembling geospatial and meteorological variables in the Khulna metropolitan
614 area. *Urban Climate*, (March), 101518. <https://doi.org/10.1016/j.uclim.2023.101518>

615 Mekuria, D. M., Kassegne, A. B., & Asfaw, S. L. (2021). Assessing pollution profiles along Little Akaki
616 River receiving municipal and industrial wastewaters, Central Ethiopia: implications for
617 environmental and public health safety. *Heliyon*, 7(7), e07526.
618 <https://doi.org/10.1016/j.heliyon.2021.e07526>

619 Ojekunle, O. Z., Ojekunle, O. V., Adeyemi, A. A., Taiwo, A. G., Sangowusi, O. R., Taiwo, A. M., &
620 Adekitan, A. A. (2016). Evaluation of surface water quality indices and ecological risk assessment for
621 heavy metals in scrap yard neighbourhood. *SpringerPlus*, 5(1). <https://doi.org/10.1186/s40064-016-2158-9>

623 Rahman, M.M., Mahmud, A., Amin, M. A. (n.d.). Hydrogeochemical facies analysis of groundwater at
624 parts of southwestern Bangladesh: a case study. *Arab J Geosci* 16, 644 (2023).

625 Roy, T. K., Hossain, S. A., Mazrin, M., Antu, U. B., Islam, M. S., Ismail, Z., Bilal, M., Abukhadra, M. R.,
626 & Alarifi, N. S. (2025). Assessing seasonal fluctuations in physicochemical properties and heavy
627 metals in the Pasur River, Bangladesh. *International Journal of Environmental Analytical Chemistry*.
628 <https://doi.org/10.1080/03067319.2025.2483319>

629 Saha, P., & Paul, B. (2019). Assessment of heavy metal toxicity related with human health risk in the
630 surface water of an industrialized area by a novel technique. *Human and Ecological Risk Assessment*,
631 25(4), 966–987. <https://doi.org/10.1080/10807039.2018.1458595>

- 632 Son, C. T., Giang, N. T. H., Thao, T. P., Nui, N. H., Lam, N. T., & Cong, V. H. (2020). Assessment of Cau
633 River water quality assessment using a combination of water quality and pollution indices. *Journal of*
634 *Water Supply: Research and Technology - AQUA*, 69(2), 160–172.
635 <https://doi.org/10.2166/aqua.2020.122>
- 636 Tamara, M., Olesya, K., & Natallia, K. (2019). *EFFICIENCY OF INTERPOLATION METHODS BASED*
637 *ON GIS FOR ESTIMATING OF SPATIAL DISTRIBUTION OF PH IN SOIL*. 53–59.
638 <https://doi.org/10.22616/j.balticsurveying.2019.017>
- 639 Tikadar, K. K., Jahan, F., Mia, R., Rahman, M. D. Z., Sultana, M. A., Islam, S., & Kunda, M. (2024).
640 Assessing the potential ecological and human health risks of trace metal pollution in surface water,
641 sediment, and commercially valuable fish species in the Pashur River, Bangladesh. *Environmental*
642 *Monitoring and Assessment*, 196(11), 1–26. <https://doi.org/10.1007/S10661-024-13192-Y/METRICS>
- 643 Withanachchi, S. S., Ghambashidze, G., Kunchulia, I., Urushadze, T., & Ploeger, A. (2018). Water quality
644 in surface water: A preliminary assessment of heavy metal contamination of the Mashavera river,
645 Georgia. *International Journal of Environmental Research and Public Health*, 15(4), 1–25.
646 <https://doi.org/10.3390/ijerph15040621>