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Impact of industrialization and urbanization on water quality of Surma River of Sylhet City

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ABSTRACT

The discharge of households and industrial waste into the river adversely affects the water quality, causing existential problems for aquatic life and health risks to those living near rivers. This study investigated the effect of industrialization and urbanization on the water quality of the Surma River of Sylhet City in Bangladesh. The water samples were obtained and analyzed in the laboratory for water quality monitoring from various sampling areas using geographic information systems and remote sensing. The analysis of water quality was determined using the water quality index of parameters in the National Sanitation Foundation Water Quality Index (NSFWQI), comprehensive pollution index (CPI), and river pollution index (RPI) methods. Based on the NSFWQI techniques, the results revealed that the Surma River's water quality is average. Simultaneously, the CPI indicates severe quality water in 1/3rd of the sampling sites and remains 2/3rd of the sampling areas demonstrating medium-quality water. The RPI implies a moderate water quality. Because of the accelerated urbanization and industrialization on the riverside, river water's pollution level is increasing. It is therefore essential to analyze all factors that affect water quality deterioration and appropriate intervention.

Keywords: Industrialization; Surma River; Water quality index; Geographic information system; National Sanitation Foundation Water Quality Index; Comprehensive pollution index; River pollution index

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1. Introduction

Water, the world's most valuable natural resource, is essential for the survival of all living organisms on the earth. Because of the continual acceleration of population growth, the demand for freshwater is rising at an alarming rate. The indiscriminate extraction of natural resources has driven the ecosystem into disarray, adversely affecting the diversity of flora and fauna [1,2]. The situation is becoming increasingly dire as the availability of the various resources is exceeded by demand [3]. As a result, a growing number of industries are constructed, the majority of which are situated near rivers, resulting in substantial water pollution caused by the untreated discharge of industrial effluents. As a riverine country, Bangladesh has the most severe manifestation of this problem since the bulk of its industries are situated beside rivers, streams, or lakes. The most prominent causes are the transportation of raw materials and finished products for industries such as textiles, tanneries, refineries, chemical fertilizers, pulp, and paper mills. As a result, industrial effluents are dumped directly into streams and rivers. In addition, untreated organic and

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inorganic components are transported and discharged into the water, degrading water quality during decomposition by decreasing dissolved oxygen levels [4,5].

The Surma River's ecological health has suffered a severe deterioration in recent decades as a result of uncontrolled and unplanned rapid urbanization, discharge of partially treated and untreated wastewater, poor land-use planning, overcrowding of bathing areas, and the disposal of solid waste in and around the river stretch. The water quality condition of the Surma River has been categorized on the basis of the comparative assessment of individual water quality indicators to their criteria established at the regional and worldwide scale in a significant number of the published research [6–9]. The information provided by these studies, however, does not offer a comprehensive picture or scenario of overall river water contamination or the ecological health of a river system.

However, a geographic information system (GIS) can also be used to build solutions for water supply concerns, such as monitoring and controlling supply levels at a local or regional level [10,11]. GIS mapping can also reveal the link between land use and water quality, as well as how urbanization affects river water quality [12]. It is also used to monitor and manage suspended particles, phytoplankton, turbidity, and dissolved organic matter. Finally, conventional water quality evaluation and monitoring methods require a lot of time, data, and resources, which are often not available in developing nations. Utilizing the geographic potential of remote sensing and GIS techniques provides a cost-effective and high-quality solution to these issues [13].

Water quality index (WQI) is a convenient and robust method for determining water quality. It is considered a factor for determining surface water quality based on the use of standardized parameters for water characterization in finding the suitability of water for drinking and other purposes [14]. WQI is a measurement tool used to convert large volumes of water analysis data into a single count that reflects water quality standards [15,16]. Most water quality indicators are based on physico-chemical characteristics and, in rare cases, fecal coliform. A comprehensive and accurate assessment of the quality of an aquatic environment requires the use of physicochemical and biological indicators [17,18]. Considering the aforementioned factors, the purpose of this study is to evaluate the effect of industrialization and urbanization on the Surma River water by assessing the physical, chemical, and biological water quality parameters using GIS and remote sensing techniques and compare the applicability of the National Sanitation Foundation Water Quality Index (NSFWQI), the comprehensive pollution index (CPI), and the river pollution index (RPI) methods to obtain an accurate depiction of water quality in the studied area. In order to accomplish this, three indices were calculated using a common dataset, and findings of the study, the water quality was classified into the quality classes associated with each index.

2. Materials and methods

2.1. Study area

Sylhet is one of the most naturally beautiful Bangladesh cities and is located at 24.8917°N 91.8833°E in the northeast part of the country. It is one of the fourth districts of the Sylhet division. Khasia circumscribes it, Jaintia Hills of India, Maulvi Bazar District on the south, India's Cachar and Karimganj Districts (Assam state of India), and Sunamganj and Habiganj districts on the west. The area of the Sylhet district is 3,452.07 km^2 or 1,332.00 mile^2 with a population of a total of 3,957,000 [19]. The Surma River is one of the major rivers in Bangladesh, part of the Surma-Meghna River System. It starts when the Barak River from northeast India divides at the Bangladesh border into the Surma and the Kushiyara Rivers. It ends in Kishoreganj District, above Bhairab Bazar, where the two rivers rejoin to form the Meghna River. Ultimately, the waters from the river flow into the Bay of Bengal. The Surma River, which runs through the city of Sylhet, is a significant part of Sylhet's tradition and history, losing its glory and being polluted due to the expansion of industrialization. The Surma River is covering the eastern parts of Bangladesh, contains at least eight million people making it a populous river basin in Bangladesh [4]. Consequently, the quality of the Surma River water is deteriorating gradually due to human activities and industrial effluents discharge into the river. All the details part of the Sylhet division and study area is shown in Fig. 1.

2.2. Data collection

2.2.1. Sampling

For this study, the samples were collected from ten sampling sites along the Surma River, covering most parts of Sylhet City. The sample sites are shown in Fig. 1; maintaining the width and depths at each point was selected to collect the sample. Samples were collected in clean and dried-out plastic bottles of 2 L with a stopper from 20 cm below the top of the water surface from the sampling points. The sample's sampling and testing were performed multiple times, and mean values are recorded for analysis. The sampling season was denoted as dry season (November–January) and monsoon (May–July) in 2018–19. All the water samples were collected following the standard procedure of the American Public Health Association (APHA) [20].

2.2.2. Selection and testing of water quality parameters

The water quality parameters were selected based on human activities that characterize the study area concerning the possible parameters present in industrial, agricultural runoff, and sewage effluents. After studying extensively from previous works, the essential water quality parameters were selected considering their relevance to rivers' surface water. Some of the water quality parameters (temperature, total dissolved solids) were examined on-site (Surma River) and at two laboratories, namely the Department of Public Health Engineering (DPHE) Laboratory, Sylhet, and Shahjalal Fertilizer Company Ltd. (SFCL) Chemical Laboratory. All the data processing work was done in the Department of Agricultural Construction and Environmental Engineering (ACEE) of Sylhet Agricultural University.

2.2.3. Analysis of various water quality parameter

The measured and analyzed water quality parameters included the physical and chemical parameters are

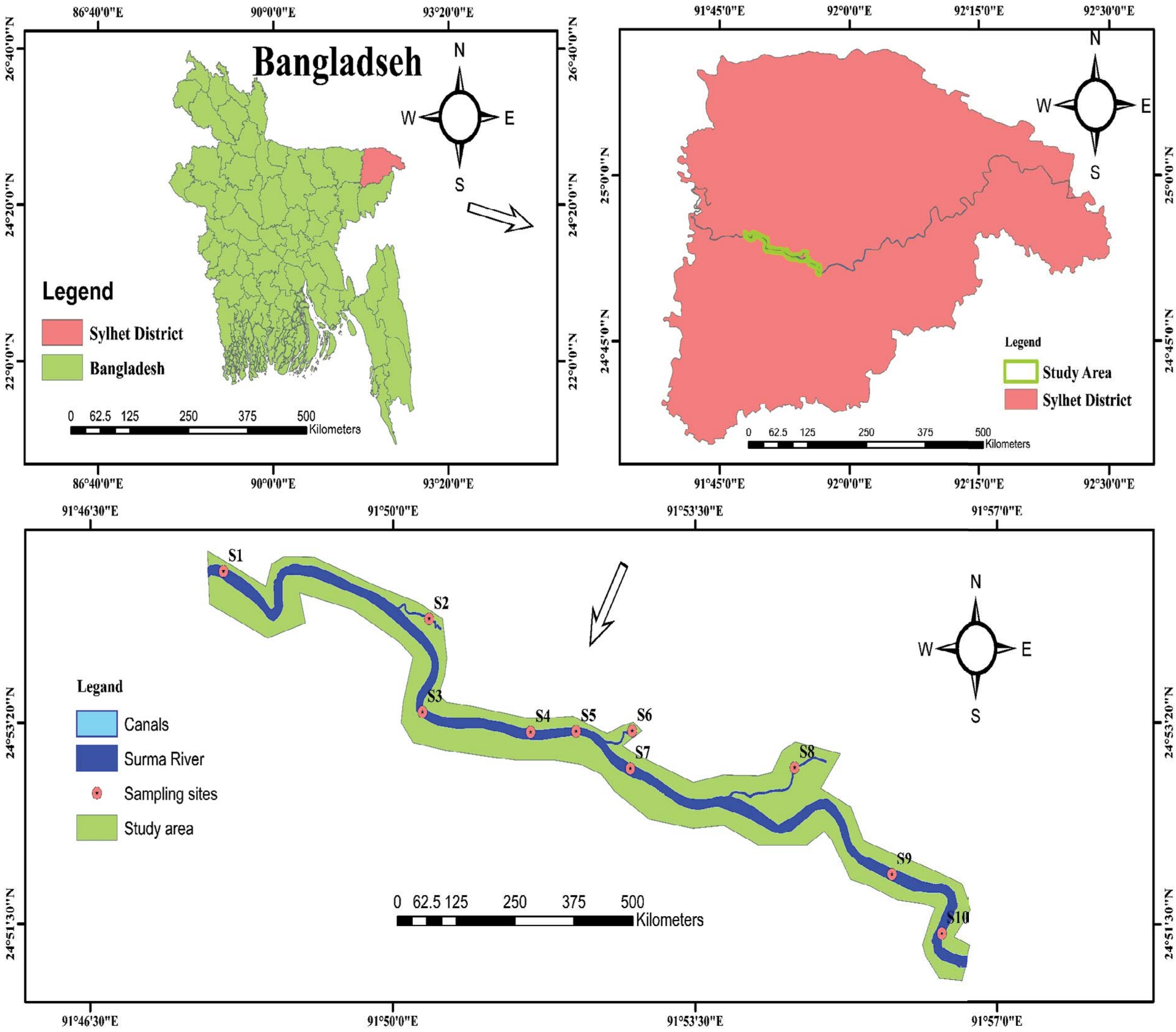

Fig. 1. Study area map locating the sample collection points in the Surma River.

temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), turbidity, fecal coliform (FC), phosphate, ammoniacal nitrogen (NH_3–N), and nitrate nitrogen (NO_3–N). The detailed water quality testing methods are listed in Table 1.

2.2.4. Analysis using GIS and remote sensing

In this study, ArcGIS 10.5 software was used in a Windows Platform (Windows 10) to formulate arc maps. Different types of theme base maps can be created using ArcGIS software, which helps understand water resources. Spatial distribution technique of interpolation through inverse distance weighted (IDW) was used in this study to interpret the results. In this study, IDW was used because of several reasons. The IDW method was used in this analysis to outline the locational allocation of water pollutants or components. This approach uses a defined or selected series of sample points to estimate the value of the grid output cell [21,22]. Apart from this, the IDW is easy to perform the interpolation method, in which the accuracy of a surface can be enhanced by using line layers as barriers.

On the other hand, kriging is opposite from the IDW method, which is considered one of the most complex interpolators. It does not go through any point values and causes interpolated values to be higher or lower than real values. Kriging also required a higher level of knowledge for proper implementation [23]. In this process, ten sample points location was selected for assessing the output grid value. Sample points were used in a linear weighted combination to determine and control the significance of identified points upon the interpolated values founded on their distance from the output point to make thematic isoline [24].

2.3. Determination of WQI

There are several methods for assessing water quality indexing. For river water quality, some of the most common methods used are National Sanitation Foundation Water Quality Index (NSFWQI), comprehensive pollution index

Table 1
Methods used in analyzing water quality parameters and different levels of drinking water quality metric as per WHO and Bangladesh Standard [37,38]

Water quality parameters	Analysis procedure/method	WHO	Bangladesh Standards
Temperature, °C	Thermometer	25	28–30
TDS, mg/L	Multimeter	6.5–8.5	6.5–8.5
pH	pH meter		6
DO, mg/L	DO meter	6	2
BOD, mg/L	Standard method	10	8
COD, mg/L	Spectrophotometer	1,000	1,000
FC, N/100 mL	Membrane filtration		10
TSS, mg/L	Filtration and drying	150	700
Turbidity, NTU	Turbidity meter	10	10
EC, μS/cm	Electrical conductivity meter	0	50
Phosphate, mg/L	UV-spectrophotometer		6
NO_3–N, mg/L	Colorimetric	1.5	0.5
NH_3–N, mg/L	Spectrophotometer	10	10

(CPI), river pollution index (RPI), organic pollution index (OPI), trace metal pollution index (TPI), eutrophication index (EI) and many more. In this study, NSFWQI, CPI, and RPI were determined.

2.4. National Sanitation Foundation Water Quality Index

NSFWQI is one of the most extensively used indices [25], consisting of nine essential water quality parameters. This method is suitable considering the parameters involved in determining pollution in river water [26]. This method can incorporate all the essential physical, chemical, and biological parameters used in this study. The NSF has created an equation of the quality index for water. The WQI calculator or the water quality index curve with their respective parameters may be found for the weighted factor of the individual parameter and sub-index of and water quality parameter.

According to NSFWQI, Eq. (1) was used to calculate the overall water quality index [27–29].

$$\text{NSFWQI} = 0.17I_{\text{DO}} + 0.16I_{\text{FC}} + 0.11I_{\text{pH}} + 0.11I_{\text{BOD}} + 0.10\left(I_{\Delta T} + I_{\text{PO4}} + I_{\text{NO3}}\right) + 0.08I_T + 0.07I_{\text{TS}} \tag{1}$$

where I denoted as the water quality sub-index.

The above equation was used to determine the water quality index. Using the water quality index (WQI), some predictions were made for water uses for different purposes. For this NSFWQI method, the ratings of the water quality have been defined using Table 2.

2.5. Comprehensive pollution index

The CPI methods of determining water quality indexing have been used in many studies previously [30,31]. Based on the single-factor index, the CPI was estimated considering the cumulative impact of all the measured variables, statistical formulas, and the required form to assess pollution level. By the formula given in Eqs. (2) and (3), the CPI can be interpreted as:

Table 2
Water quality rating as per NSF Water Quality Index methods

WQI Quality Scale	
91–100	Excellent water quality
71–90	Good water quality
51–70	Medium or average water quality
26–50	Fair water quality
0–25	Poor water quality

$$\text{CPI} = \frac{1}{n}\sum_{i=1}^{n}\text{PI}_i \tag{2}$$

$$\text{PI} = \frac{C_i}{S_i} \tag{3}$$

where PI is the pollution index of the ith parameter, C_i is the assessed concentration of individual parameter, S_i is the standard permissible limit of the assessed parameter, and n is the number of parameters [26,32]. The maximum permissible limit of water quality in drinking water recommended by the Bangladesh Standard and WHO in Table 1 has been contemplated in this study to check the level of water pollution in the Surma River. The final CPI was decided by checking the calculated value with the CPI quality scaling presented in Table 3.

2.6. River pollution index

The RPI method is a combination of water quality values for the classification of water sampling stations into groups based on the level of pollution. This method is used by the Environmental Protection Administration of Taiwan. In this indexing method, for each group, the results obtained using this index demonstrated the characteristic features and degree of pollution [33]. The RPI can be applied to assess the river water quality index, where mainly four water parameters, namely DO, BOD, TSS, and NH_3–N, are used. It is calculated by using Eq. (4) and Table 4.

$$\text{RPI} = \frac{1}{n}\sum_{i=1}^{n} s_i \tag{4}$$

where $n = 4$ for four water quality parameters, S_i is the indexing score, and these are selected based on tabulated value presented in Table 4 [34,35].

2.7. Statistical analysis data and interpretation

The correlation coefficient, a statistical measurement that calculates the depth of the relationship between the relative movements of two variables. In correlation, Pearson's r is the most used measure of correlation. It is also known as the linear correlation coefficient (r) because of its capability to measures two variables. If the data lie exactly along a straight line with a positive slope, then $r = 1$. The values range between $-1 < r < 1$. A calculated number was greater than 1 or less than –1 means that there was an error in the correlation measurement. A correlation of –1 shows a perfect negative correlation, while 1 shows a perfect positive correlation. If $r = 0$, there is no correlation between the two variables [36]. In this study, water quality results were analyzed using the correlation matrix (Pearson's r) method. Statistical Package for Social Sciences (SPSS) 25.0 and Microsoft Excel 2016 tools were used for data analysis, interpretation of results, and cross-checking of the results. It was also used to determine the correlation among parameters. All the selected physical, chemical, and biological parameters were used in this process.

Table 3
Water quality rating as per CPI Quality Scale

CPI Quality Scale	
0–0.20	Clean
0.21–0.40	Sub clean
0.41–1.00	Slightly polluted
1.01–2.00	Moderately polluted
≥2.01	Severely polluted

3. Results and discussions

3.1. Physical parameters

The collected sample was analyzed in the laboratory to determine the physical properties of water such as Temperature, EC, turbidity, TSS, TDS for the Surma River.

Temperature is a crucial and modifiable environmental element that determines the overall quality of the water. The Surma River's study area's temperature data for the dry and monsoon period did not show much variation. As the temperature did not cross the WHO and EQS permissible limit of 20°C–30°C, it might be tolerable for the river's aquatic life [37,38].

The ability to pass an electrical current through the water is referred to as electrical conductivity. The most important thing for EC is that it assesses the number of dissolved compounds, contaminants, and minerals found in the water. Higher concentrations of these impurities can result in higher conductivity. However, a small number of dissolved salts and chemicals improve the conductivity of water. It is also, therefore, a crucial parameter in the field of industrialization. According to EPA, a failing sewer system would increase conductivity, whereas an oil spill would do the opposite. EC of Surma River's mean value was 343.7 µS/cm in dry season and 211.7 µS/cm in monsoon. The maximum EC was 617.00 µS/cm in the dry season, while the minimum value was 119.00 µS/cm in the monsoon. The study results indicate that the EC of Surma River water is under the permissible limit and somewhat safe for irrigation and aquatic life [39].

The term turbidity is used to express the transparency level of water. It can be caused by a mixture of silt, clay, waste materials, heavy particles, dumps, and so on. In this study, the turbidity value ranged from 7.00 NTU (dry season) to 246.00 NTU (monsoon) with an average of 60.3 NTU in the dry season and 72.20 NTU in the monsoon. The spatial distribution of turbidity for the dry season and monsoon is illustrated in Figs. 2 and 3.

TDS and TSS are related to each other as TDS determines the number of dissolved solids present in water, whereas TSS evaluates the amounts of suspended solids present in water. The maximum TDS level was 370.00 mg/L in the dry season, and the minimum was 78.00 mg/L in monsoon. Similarly, the maximum TSS was 286.00 mg/L in the dry season, while the minimum was 98.00 mg/L in monsoon. By comparing the seasons, both parameters show a lower

Table 4
Classification of degree of water pollution for water quality parameter and indexing number for the parameters

Parameters	Water pollution categorization			
	Unpolluted	Slightly polluted	Moderately polluted	Severely polluted
DO	>6.5	4.6–6.5	2–4.5	<2
BOD	<3	3–4.9	5–15	>15
NH_3–N	<0.5	0.5–0.99	1–3	>3
TSS	<20	20–49	50–100	>100
Index score (S_i)	1	3	6	10
RPI value	<2	2–3	3.1–6	>6

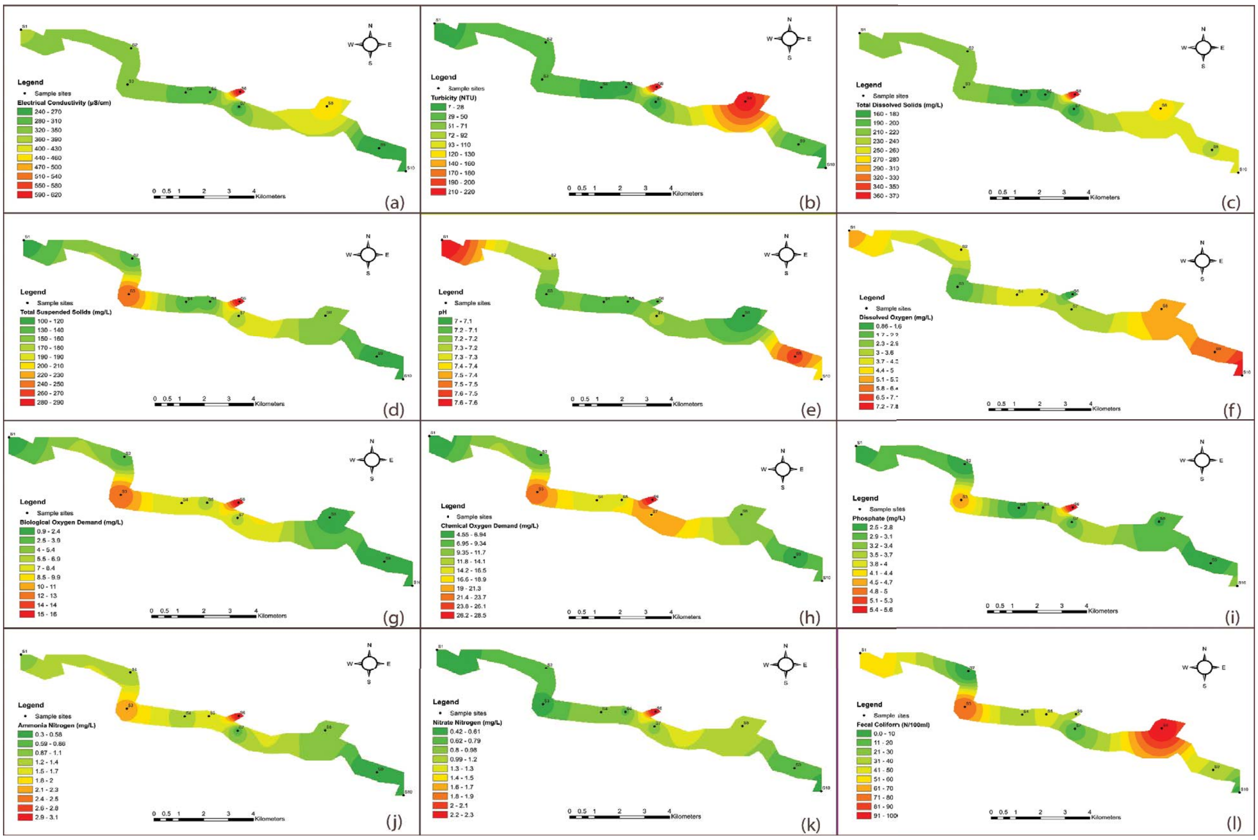

Fig. 2. Spatial distribution of EC, turbidity, TDS, TSS, pH, DO, BOD, COD, phosphate, NH_3–N, NO_3–N, and FC in dry season.

value in the monsoon than the dry season. So, in the monsoon period, the Surma River water is more favorable than the dry season for any purpose. The spatial distribution of TDS and TSS data was presented using ArcGIS maps in Figs. 2 and 3 for both seasons to show the level of concentration water collected from the different sampling points. According to the WHO (2011) guidelines, the maximum permissible limit for TDS is 600 mg/L for drinking water purposes, whereas if the limit crosses the 10,000 mg/L marks, then the water becomes unusable. None of the sample values passes the permissible limit of both the Bangladesh Standard and WHO standards in this study. However, it is not far from being unsuitable for drinking water usage.

3.2. Chemical parameters

The collected samples were analyzed in the chemical laboratory to determine water's chemical properties such as pH, DO, BOD, COD, phosphate, NH_3–N, and NO_3–N for the Surma River.

The negative logarithm of hydrogen ion concentration is referred as pH. On a scale of 0–14, if the pH value is higher than 7, it is called base when less than 7 is acidic. The water bodies' pH value is a crucial measure of water quality and the level of contamination in watershed regions [40]. Depending on the types of chemical or waste substances in water, the pH concentration can be higher or lower. The disposal of industrial effluents or agricultural waste can influence the variation of pH value in the water, which can be the reason for endangering aquatic life [29]. In this study, the selected study area's pH level was ranged from 7–7.6 in dry season, while 6.8–7.8 was in monsoon. The determining pH value is within the WHO's permissible limit (6.5–8.5) and Bangladesh Standard [38].

The amount of oxygen present in water refers to dissolved oxygen. It is one of the critical parameters in determining water quality and stream health [12]. Without oxygen, there is no survival for plants and wildlife in the water [29]. In this study, the DO level ranged from 0.86 to 7.80 mg/L in the dry season, while monsoon displayed a range of 2.60–12.68 mg/L. The colors in the maps represent the level of DO in different sampling points in the river. It is also noticeable that some of the sampling points have lower DO than the minimum requirement. According to the EQS and WHO, the minimum requirement of DO for drinking is 6 mg/L, for aquatic life is 4–6 mg/L, and for other commercial purposes, 5 mg/L. Most aquatic life cannot withstand DO levels lower than 1 mg/L [38,41].

BOD signifies the extent of organic pollutants present in water, which accelerates micro-bacteria growth and degrades water quality. BOD rate can be higher due to defective sewage systems, industrial effluents, and non-point source pollution discharges [12,29]. In this study, the mean BOD values were 5.689 mg/L in the dry season and 3.083 mg/L in monsoon. The spatial distribution was graphically depicted the BOD level in selected sampling points in the study area in Figs. 2 and 3. The maximum allowable limit for BOD is 0.2 mg/L for drinking purposes, 6 mg/L for

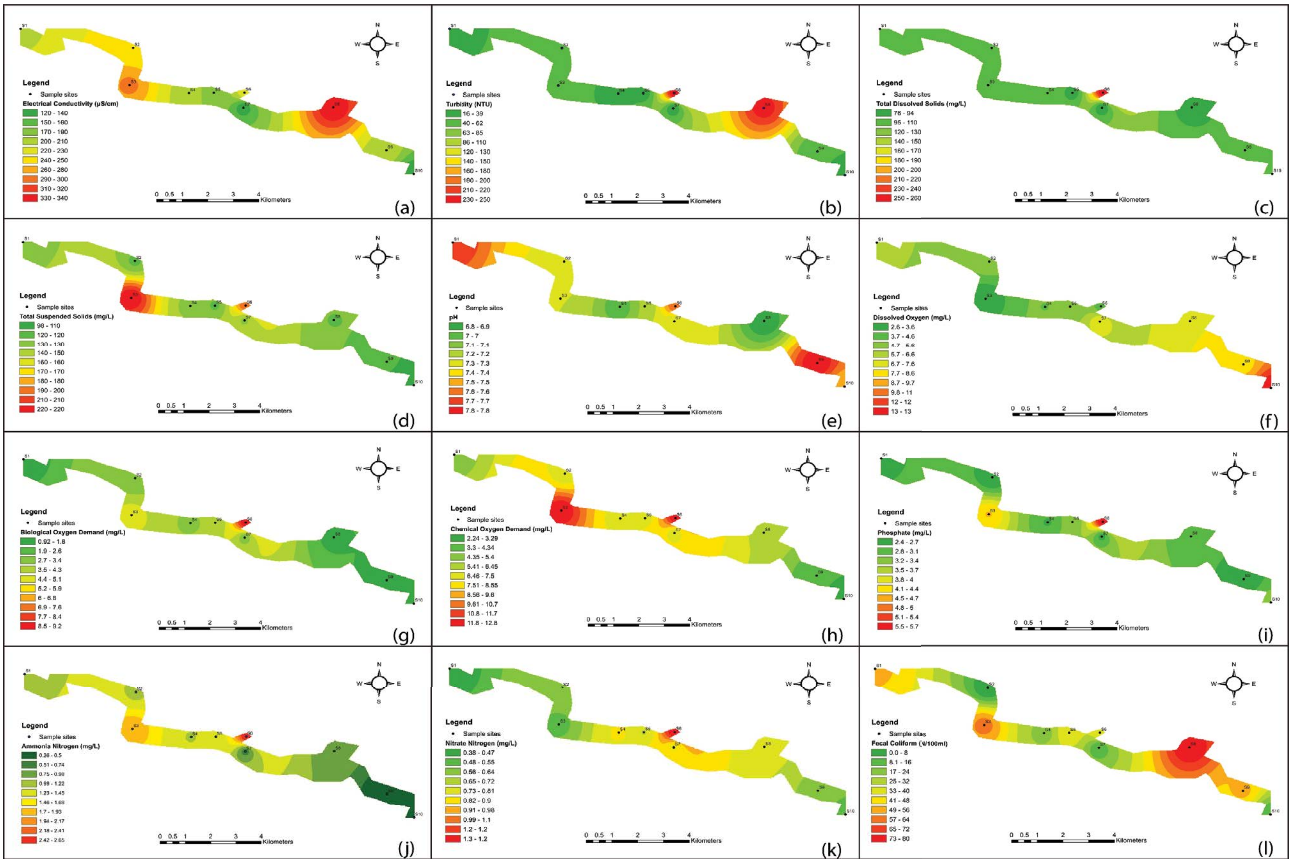

Fig. 3. Spatial distribution of EC, turbidity, TDS, TSS, pH, DO, BOD, COD, phosphate, NH_3–N, NO_3–N, and FC in monsoon.

aquatic life, and 10 mg/L for agricultural activities [37,41,42]. Notably, most sampling points have passed the allowable limit of BOD for drinking water, but the water is still useable for other activities. It gives a clear idea that the Surma River water is polluting day by day.

COD is a critical criterion when determining water quality in microorganisms' presence [12]. In this study, the mean COD values were 13.721 mg/L in the dry season and 6.975 mg/L in monsoon. The maximum COD value was found in the dry season (28.50 mg/L), and the minimum was seen in monsoon (2.24 mg/L). Although WHO has no guidelines, COD's permissible limit is 4 mg/L for drinking water [37,42].

3.3. Parameterization of phosphate, ammonia, and nitrate

Three very crucial water quality parameters concerning industrial effluents are phosphate, NH_3–N, and NO_3–N. Phosphate emerges from detergents of liquid waste and chemical products from farm fields as well. Every phosphate compound is found in dissolved form, attached, or attached to aquatic organisms [43]. It can be higher when the sources are from the industrial effluences that use detergent and the food wastes that disposing directly into the rivers, streams, or canals [44]. Similarly, NH_3–N also derives from metabolic activities, industrial wastes, and agricultural activities. While ammonia does not directly affect health, it can impair water disinfection [38,42]. Lastly, a naturally occurring ion, namely nitrate, derives from industrial wastes, pesticides, fertilizers, animal, and human feces. It is considered one of the major water quality problems [24,29].

In this study, the mean phosphate values were 3.24 mg/L in the dry season and 3.19 mg/L in monsoon. The maximum and minimum phosphate levels found in monsoon are 5.70 and 2.40 mg/L. According to the EQS, the maximum permissible limit for phosphate is 6 mg/L for drinking, 10 mg/L for aquatic life, and 10 mg/L for agricultural activities [37]. Similarly, the mean value of NH_3–N was 0.975 mg/L in the dry season, while 0.878 mg/L was in monsoon. NH_3–N range was found at 0.233 to 2.407 mg/L in the dry season, and 0.202 to 2.058 mg/L was in monsoon. According to the EQS, the maximum acceptable limit for NH_3–N is 0.5 mg/L for drinking, 0.075 mg/L for fishing, and 2 mg/L for other activities [37]. Likewise, the mean NO_3–N values were found at 0.874 mg/L in the dry season and 0.696 mg/L in monsoon. The maximum NO_3–N value was found in the dry season (2.28 mg/L), and the minimum was seen in monsoon (0.38 mg/L). The permissible limit for nitrate is 10 mg/L [37,38]. None of the values crosses the allowable limit. All the values determined from sampling points were spatially distributed using IDW interpolation of ArcMap in Figs. 2 and 3.

3.4. Biological parameter

The collected sample was analyzed in the laboratory to determine water's biological properties, such as fecal coliform. ArcGIS maps presented the concentration of fecal coliform for Dry season and Monsoon and the statistical analysis of the parameter.

Coliform bacteria are vital parameters of the microbial constancy of drinking water. While this type of bacteria does not explicitly cause a specific disease, its appearance in drinking water suggests a lower hygiene standard. Therefore, there should be no kind of coliform present in drinking water. The greater the level of contamination of the coliform bacteria, the higher the likelihood of other pathogens [29,41]. In this study, FC's average values in both seasons surpass the permissible limit of water quality standards [37]. For other activities, it may be acceptable. The spatial distribution of FC values is shown in Figs. 2 and 3, indicating the FC values in different sampling points. The minimum values in some points were 0.00 N/100 mL, whereas the maximum values were 100 N/100 mL and 80 N/100 mL in the dry season and monsoon, respectively.

3.5. Water quality index

The value of the nine most important water quality parameters such as BOD, DO, FC, nitrate, pH, temperature change, TDS, total phosphate, and turbidity from ten sampling points were used for the calculation of WQI. As stated earlier in the methodology, the National Sanitation Foundation Water Quality Index (NSFWQI) method was the medium in this process. In the NSFWQI, a scale from 0 to 100 is used for water quality, where 100 is the highest possible score. The overall WQI score can be compared against the following scale to determine how healthy the water is on a given day [29,34]. Along with NSFWQI, the CPI and RPI were determined.

3.6. Indexing of Surma River water quality

The water quality indexing has been measured using the in-site and laboratory-tested data. The results of NSFWQI, CPI, and RPI are shown in Table 5. The NSFWQI was found to mostly average (WQI scale 51–70) except for the sampling sites S7, S9, and S10. The sampling site S6 was found fair (WQI Scale 26–50), indicating the sites' pollution level is inching towards severe. It is also notable that many industries and shops are near this sampling point. The overall NSFWQI was found for dry season 62.49 and monsoon 67.28, where both scaled in the average water quality. It was also observed that water quality was comparatively better in monsoon than in the dry season, indicating the wastewater discharge was higher in the dry season. The NSFWQI for both dry season and monsoon were plotted graphically in Fig. 4 to check the variation during these seasons.

Similarly, the CPI measurement demonstrates that most of the sampling sites' water quality is moderate (1.01–2.00 water quality rating) except for the sampling sites S3, S6, and S8 illustrate severely polluted water considering the drinking water quality allowable limit. The overall CPI measurement for dry season-monsoon was found 2.52–2.28, where both rated as severe quality water. All the calculated values for each sampling point are shown in Table 5, and the variation of CPI in dry season and monsoon are demonstrated in Fig. 5.

Likewise, RPI reveals a very mixed result. The measured RPI for sampling sites S3, S5, and S6 shows severely polluted water, while the S10 proves to be the least polluted point. Other sampling points show moderately contaminated water. The overall RPI for the dry season-monsoon combination was found 5.78–2.28, where both categorize as moderate quality water. The RPI in each sampling point is shown in Table 5, and the variation of RPI in various sample sites in both dry season and monsoon is presented in Fig. 6.

In several previous studies in the Surma River and subsequently connected rivers, namely the Brahmaputra, Ganga River, Old Brahmaputra River, the water quality showed a variation in WQI rating. In some previous studies, the water quality of the Surma River was classified as slightly polluted [45], poor quality of water [46], marginal water quality [47] in the different periods. Similarly, the water quality of Brahmaputra was categorized as average [48], very polluted for the Old Brahmaputra River, which is directly connected to the Surma River [49]. The WQI of another river that joined in the upstream of Surma River is Ganga in India.

Table 5
Calculated results of NSFWQI, CPI, and RPI at all the sampling sites in dry season and monsoon

Sample site	NSFWQI			CPI			RPI		
	Dry season	Monsoon	Quality scale	Dry season	Monsoon	Quality rating	Dry season	Monsoon	Category
S1	68.12	72.06	Average	1.67	1.76	Moderate	4.25	4.25	Moderate
S2	54.62	58.57	Average	1.81	1.80	Moderate	5.00	4.25	Moderate
S3	51.48	57.89	Average	3.58	2.95	Severe	8.00	6.25	Severe
S4	64.49	67.51	Average	1.97	1.76	Moderate	7.00	4.75	Moderate
S5	61.70	66.55	Average	2.03	1.80	Moderate	7.00	5.50	Severe
S6	45.36	54.44	Fair	5.54	4.57	Severe	9.00	7.00	Severe
S7	65.99	78.54	Good	2.08	1.70	Moderate	6.25	3.25	Moderate
S8	62.65	69.55	Average	3.47	3.41	Severe	4.25	3.75	Moderate
S9	69.89	75.15	Good	1.70	1.70	Moderate	3.75	3.25	Moderate
S10	80.63	72.53	Good	1.32	1.36	Moderate	3.25	2.25	Slight
Overall	62.49	67.28	Average	2.52	2.28	Severe	5.78	4.45	Moderate

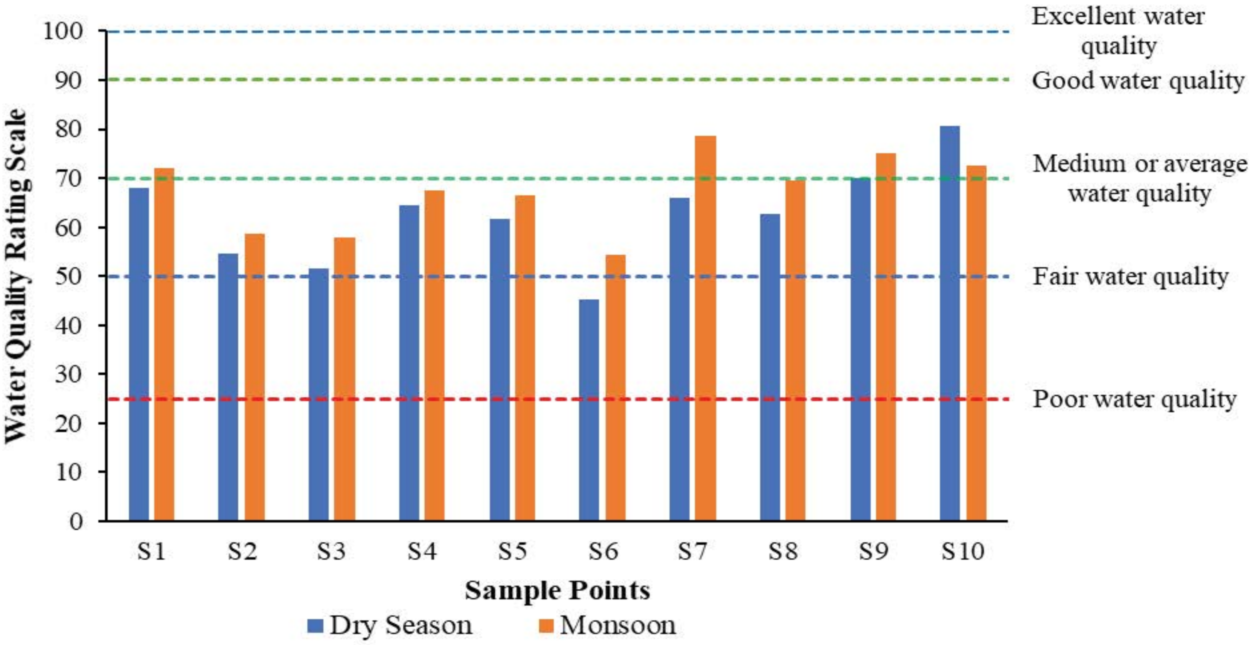

Fig. 4. Variation of NSFWQI among all sampling points in dry season and monsoon.

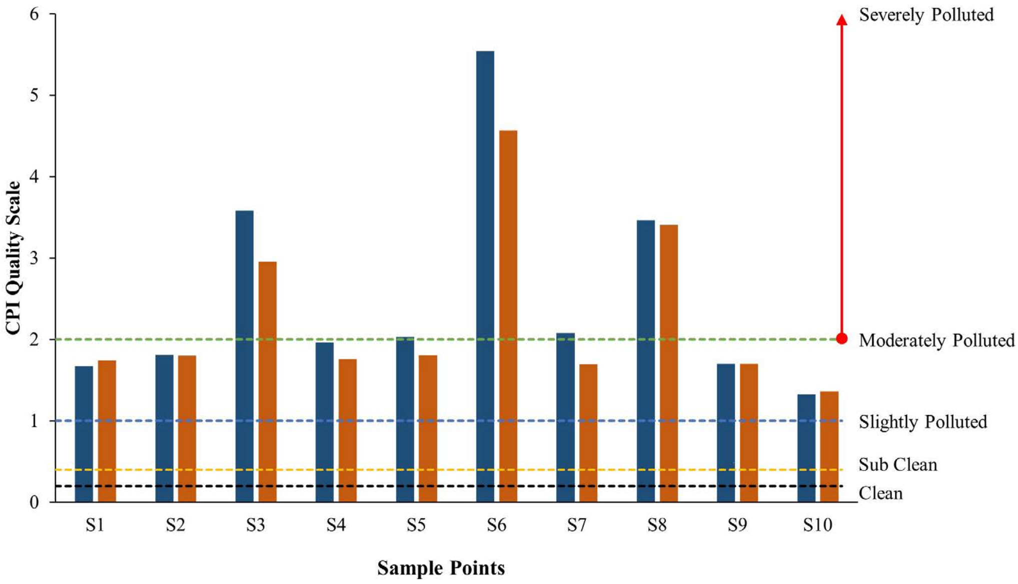

Fig. 5. Variation of CPI among all sampling points in the dry season and monsoon.

The water of that river in recent studies was categorized as poor quality [50], very poor quality [51], and good and medium categories [52].

3.7. Statistical analysis among tested water quality parameters

The basic statistical analysis calculated for the Surma River's water quality is briefly tabulated in Table 6. The correlation matrix was performed twice separately for dry season and monsoon. On the other side, the correlation matrix among all the parameters is shown in Tables 7 and 8 for dry season and monsoon separately. Table 7 demonstrates the correlation matrix among all the parameters used in this study to determine the significance of parameters with each other in the dry season. Firstly, the temperature has a moderately negative correlation with the pH. On the other hand, TDS has significantly strong positive correlation with EC ($r = 0.79$, $p < 0.01$), turbidity ($r = 0.79$, $p < 0.01$), phosphate ($r = 0.65$, $p < 0.05$), and NO_3–N ($r = 0.72$, $p < 0.05$), while BOD has very strong positively significant correlation with COD ($r = 0.95$, $p < 0.01$), TSS ($r = 0.93$, $p < 0.01$), phosphate ($r = 0.88$, $p < 0.01$), NO_3–N ($r = 0.67$, $p < 0.05$), and NH_3–N

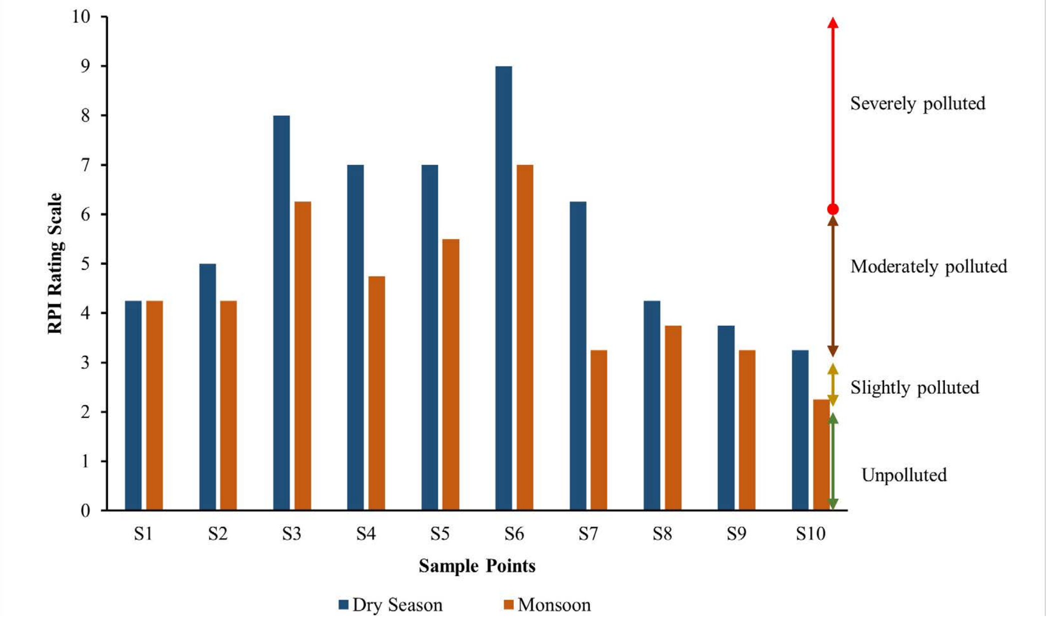

Fig. 6. Variation of RPI among all sampling points in dry season and monsoon.

Table 6
Descriptive statistics of chemical, physical, and microbial properties of the water samples collected from sampling points of Surma River

Parameters	Dry season						Monsoon					
	Mean	SD	SE	CV	Min.	Max.	Mean	SD	SE	CV	Min.	Max.
Temp.	22.81	0.074	0.022	0.003	22.7	22.9	21.96	0.51	0.15	0.02	21.4	22.8
EC	343.7	113.21	34.13	0.329	235	617	211.7	68.44	20.64	0.32	119	345
Turbidity	60.3	82.47	24.86	1.37	7	220	72.2	89.74	27.06	1.24	16	246
TDS	226	63.22	19.06	0.28	157	370	112.3	52.97	15.97	0.47	76	260
TSS	155.4	61.68	18.6	0.397	102	286	137.2	38.72	11.68	0.28	98	220
pH	7.22	0.193	0.058	0.027	7	7.6	7.3	0.33	0.1	0.05	6.8	7.8
DO	4.24	2.02	0.609	0.477	0.86	7.8	6.37	2.84	0.86	0.45	2.6	12.68
BOD	5.689	5.08	1.53	0.894	0.9	15.85	3.08	2.48	0.75	0.8	0.92	9.25
COD	13.72	7.90	2.38	0.576	4.55	28.5	6.98	3.41	1.03	0.49	2.24	12.76
Phosphate	3.24	1.02	0.306	0.313	2.5	5.6	3.19	1.06	0.32	0.33	2.4	5.7
NH_3–N	0.975	0.656	0.198	0.673	0.233	2.41	0.88	0.56	0.17	0.64	0.2	2.06
NO_3–N	0.874	0.533	0.161	0.61	0.42	2.28	0.7	0.24	0.07	0.34	0.38	1.24
FC	41.8	32.13	9.69	0.769	0	100	35.7	25.82	7.79	0.72	0	80

Note: SD = standard deviation, SE = standard error, CV = coefficient of variance, Min. = minimum, Max. = maximum

($r = 0.91$, $p < 0.01$). DO indicated a negatively significant trend with BOD ($r = –0.92$, $p < 0.01$), COD ($r = –0.86$, $p < 0.01$), TSS ($r = –0.87$, $p < 0.01$), phosphate ($r = –0.71$, $p < 0.05$), NH_3–N ($r = –0.88$, $p < 0.01$). BOD has most positively significant correlation for $p < 0.01$ with COD ($r = 95$), TSS ($r = 93$), phosphate ($r = 88$), and with NO_3–N ($r = .67$, $p < 0.05$). pH has a positively significant correlation with DO but less significantly correlated with other parameters. On the other side, EC has the most strongly positively significant correlation ($0.73 < r < 0.95$) with phosphate, turbidity, and NH_3–N.

Table 8 illustrates the correlation matrix among all the parameters used in this study to determine the significance of each other's parameters in monsoon. Initially, BOD has the very strong positively significant correlation with COD ($r = 0.87$, $p < 0.01$), TDS ($r = 0.84$, $p < 0.01$), TSS ($r = 0.78$, $p < 0.01$), phosphate ($r = 0.88$, $p < 0.01$), NO_3–N ($r = 0.79$, $p < 0.01$), and NH_3–N ($r = 0.92$). Likewise, TDS has a positively significant correlation with phosphate ($r = 0.82$, $p < 0.01$), NH_3–N ($r = 0.74$, $p < 0.05$), NO_3–N ($r = 0.73$, $p < 0.05$). Meanwhile, COD shows a strong positively significant correlation with TSS ($r = 0.94$, $p < 0.05$) and ammonia N ($r = 0.92$, $p < 0.05$), and moderately positively significant with phosphate ($r = 0.79$, $p < 0.05$). On the other hand, DO has a negatively significant

Table 7
Correlation matrix (Pearson's r) for all the water quality parameters in dry season

	Parameters	1	2	3	4	5	6	7	8	9	10	12	13	14
1	Temp.	1												
2	pH	–0.48	1											
3	DO	–0.24	0.46	1										
4	BOD	0.27	–0.5	–0.92**	1									
5	COD	0.15	–0.63	–0.86**	0.95**	1								
6	TDS	–0.03	–0.070	–0.15	0.32	0.28	1							
7	TSS	0.18	–0.45	–0.87**	0.93**	0.90**	0.51	1						
8	EC	0.02	–0.37	–0.55	0.58	0.54	0.79**	0.72*	1					
9	Turbidity	–0.02	–0.44	–0.34	0.36	0.41	0.79**	0.56	0.89**	1				
10	FC	–0.01	–0.21	–0.17	0.15	0.15	0.17	0.26	0.34	0.5	1			
11	Phosphate	0.11	–0.36	–0.71*	0.88**	0.83**	0.65*	0.93**	0.73*	0.54	0.2	1		
12	NH_3–N	0.28	–0.46	–0.88**	0.91**	0.80**	0.45	0.87**	0.78**	0.53	0.26	0.85**	1	
13	NO_3–N	0.01	–0.46	–0.57	0.67*	0.70*	0.72*	0.69*	0.84**	0.79**	0.06	0.70*	0.71*	1

Note: **Correlation is significant at the $p < 0.01$ level;
*significant at the $p < 0.05$ level.

Table 8
Correlation matrix (Pearson's r) for all the water quality parameters in monsoon

	Parameters	1	2	3	4	5	6	7	8	9	10	12	13	14
1	Temp.	1												
2	pH	0.12	1											
3	DO	0.15	0.18	1										
4	BOD	0.43	0.06	–0.62	1									
5	COD	0.19	–0.15	–0.82**	0.87**	1								
6	TDS	0.46	0.35	–0.29	0.84**	0.55	1							
7	TSS	0.14	0.01	–0.71*	0.78**	0.94**	0.51	1						
8	EC	–0.2	–0.32	–0.46	0.13	0.43	0.08	0.4	1					
9	Turbidity	0.47	–0.1	–0.15	0.51	0.44	0.63	0.35	0.63	1				
10	FC	–0.02	–0.06	–0.25	0.02	0.25	0.03	0.32	0.71*	0.54	1			
11	Phosphate	0.33	0.15	–0.4	0.88**	0.79**	0.82**	0.81**	0.18	0.56	0.22	1		
12	NH_3–N	0.11	–0.02	–0.79**	0.92**	0.92**	0.74*	0.84**	0.36	0.49	0.2	0.84**	1	
13	NO_3–N	0.75*	–0.14	–0.3	0.79**	0.53	0.73*	0.36	0.07	0.65*	–0.01	0.58	0.57	1

Note: **Correlation is significant at the $p < 0.01$ level;
*significant at the $p < 0.05$ level.

correlation with COD ($r = –0.82$, $p < 0.01$), TSS ($r = –0.71$, $p < 0.05$), and NH_3–N ($r = –0.79$, $p < 0.05$).

Overall, if the current situation is prolonged, it is possible that the river water quality would deteriorate and become contaminated, which might be caused by an increase in human activity within the river basin. The graphical interpretation in this research could be regarded as the trends for the Surma River and might be applied as a baseline model for other major rivers in Bangladesh and India, such as Meghna River, Kushiyara River, Brahmaputra, Barak, Ganga River. However, a future study could be conducted depending on the availability of sufficient data on water quality in downstream areas to validate the study's results.

4. Conclusions and recommendations

The study aims were to evaluate the impact of industrialization and urbanization on the water quality of the Surma River flowing through Sylhet City. The results and analysis showed that most sampling sites' water quality is not suitable for drinking water purposes. It is also limited to the usage of other activities because of the degradation of water quality. It was found from the present and the previous studies that the quality of water is deteriorating day by day. The principal rationale for this is the direct and indirect disposal of industrial effluents and sewage from the city's waste disposal systems. There could be a variation in the test results of the parameters at different test centers because of the lab techniques or methods used. This analysis reveals that the mean FC level was 41.8 N/100 mL in monsoon and 35.7 N/100 mL in the dry season. Similarly, the mean values of DO, BOD, and COD in the dry season-monsoon sequence were 4.236–6.371 mg/L, 5.689–3.083 mg/L, and COD 13.721–6.975 mg/L while the sequence for phosphate, NH_3–N, and NO_3–N were 3.24–3.19 mg/L, 0.975–878 mg/L, and 0.874–0.696 mg/L. The mean values of other parameters in the dry season-monsoon combination were pH 7.22–7.30 mg/L, TSS 155.4–137.2 mg/L, turbidity 60.3–72.2 mg/L. These values signify the occurrence of pollution in the river water. The statistical analysis and GIS water quality mapping demonstrate the most vulnerable areas of the river.

Furthermore, the NSFWQI indicated that most of the water quality was average except for the sampling sites S7, S9, and S10, which was good. At the same time, S6 was found fair, which indicates the sites' pollution level is edging towards severe water quality. Also, the measurement of CPI demonstrates that most of the sampling sites' water quality is in a moderate state (1.01–2.00 water quality rating) except for the sampling sites S3, S6, and S8 illustrate severely polluted water while considering the permissible limit of drinking water quality. On the other hand, the RPI for sampling sites S3, S5, and S6 show severely polluted water while the S10 proves to be the least polluted point. Water usage remained unsafe for drinking and other domestic works without any treatment. However, it can be used in other events such as irrigation, recreation, washing, and other non-sensitive activities.

The study, therefore, emphasized the need for periodic monitoring of water levels, the management of industrial effluents before discharge into the river, and the introduction of appropriate mitigation strategies to resolve problems and deterioration to facilitate the safe state of the river.

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