ASSESSMENT OF WATER QUALITY IN A SEGMENT OF BHAIRAB RIVER USING A COMBINATION OF WATER QUALITY INDEX AND POLLUTION INDEX

Saumik Hasan Tanim*[1], Md. Saiful Islam[2]

[1] Undergraduate student, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, e-mail: shtanim30@gmail.com
[2] Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, e-mail: saiful@ce.kuet.ac.bd

***Corresponding Author**

ABSTRACT

This study undertook a critical evaluation of water quality in a specific segment of the Bhairab River adjacent to the Noapara Industrial area of Jashore. Irrigation, industrial process water, and domestic use all rely on this river water. A combination of the National Sanitation Foundation Water Quality Index (NSFWQI) and Comprehensive Pollution Index (CPI) to gauge the overall water quality and pollution status. Water samples were collected from five distinct spots, and subsequent laboratory analysis encompassed physical and chemical parameters. The findings showed severe environmental issues. The computed WQI scores varied from 34 to 44 in the summer season but jumped from 47 to 52 in the monsoon season, indicating that water quality upgraded in the monsoon season. Furthermore, the average CPI_1 value throughout the summer season was 1.37 ±0.28. However, the average CPI_1 value decreased in the monsoon season and became 1.12±0.2. Similarly, the average CPI_2 fell from 0.80±0.35 to 0.42±0.07 during the monsoon season, as evidenced by statistical research. This indicates that in the summer season, the water fell under the medium polluted category, and in the monsoon season, the pollution level decreased, and the water fell in the slightly polluted category. Moreover, using cluster analysis sampling locations were divided into subgroups based on similar characteristics, which will be used to create a sustainable water monitoring plan.

Keywords: *surface water, contamination, water quality index, comprehensive pollution index, sustainability.*

1. INTRODUCTION

Throughout the world, water pollution has become a significant concern due to its importance for a sustainable life. Water pollution is a substantial concern for the planet. In general, surface water is contaminated and polluted by a variety of anthropogenic activities that occur globally, including the disposal of industrial wastes in both treated and untreated conditions and unplanned runoff from mining and toxic storage sites. As a result of a variety of anthropogenic activities, rivers in Bangladesh are also facing increasing pollution challenges. As the majority of the industrial area is located along the rivers, waste is dumped into the water, which pollutes the river. (Uddin & Jeong, 2021).
Noapara Industrial Area is one of the renowned industrial areas of Bangladesh. This industrial area is situated beside the Bhairab River near Abhainagar upazila of Jessore district. Near Khulna city, the river meets the Rupsha River. This river water is mainly used for irrigation, industrial, and domestic purposes. Local farmers use this river water as one of the main water sources for irrigation. The industries and power plants near this industrial area use this river water as their processed water source. As for the residents of this locality, they predominantly rely on this river water for domestic purposes, making it one of their basic water sources.

However, the water of the Bhairab River became polluted because of different industrial wastewater and stormwater. The industrial area has many facilities for processing jute, cement-making, fertilizer, building supplies, and storage of car oil (Khan et al., 2019). Rapid industrial expansion generates heightened pollution from wastewater and stormwater runoff, posing risks to both agricultural yields and human well-being(Adnan et al., 2023). The utilization of contaminated water for irrigation presents a concerning threat, potentially compromising crop quality and posing health hazards for consumers. This convergence of industrial pollutants with agricultural practices underscores the urgent need for comprehensive solutions to safeguard both production and public health (Tabassum et al., 2022). The industries that use this river water as their processed water sources may affect their machinery's lifecycle. The local people who use this river water for domestic purposes may face several health issues.

It is crucial to monitor the water in the Noapara industrial region using both physical and chemical characteristics in light of this circumstance. To ensure food hygiene and human wellness, water quality needs to assesse for different purposes, including irrigation, conservation, industrial, and domestic use (Son et al., 2020). Water quality assessment applies to determine the causes of pollution of water and create, manage, and maintain a sustainable water source for more favorable social and economic development (Goonetilleke et al., 2007) . It has been shown in the Vietnam Environmental Administration (VEA 2011) that after a decade of use, the water quality index (WQI) is useful when combined with with the comprehensive pollution index (CPI) (Son et al., 2020). Using different water parameters, with the use of the National Sanitation and Foundation Water Quality Index (NSFWQI), researchers have created and distributed surface water quality indices globally. (Berlemann, 2013; Javid et al., 2014; Sutadian et al., 2016) and Comprehensive Pollution Index (CPI) (Son et al., 2020; Zhao et al., 2012). By combining the Water Quality Index with the Pollution Index, this investigation attempts to evaluate the water quality of the Bhairab River near the industrial area of Noapara during the summer and the monsoon season.

2. METHODOLOGY

2.1 Study area

This study was conducted on the Bhairab River near the Noapara industrial area in the Abhainagar upazila of Jashore district, which flows through the Noapara municipality. It is located 70 km upstream from the Sundarbans mangrove forest in Bangladesh's southwest.

2.2 Sampling points

Water was taken from 5 locations during the summer (April-May) and the monsoon (July-August) seasons of 2023 for water quality and pollution level analysis. Table 1 summarizes the location description of the water sampling point and the sampling points are marked on Figure 1.

Sampling Location			Locations	
No	**Name**	**Description of location**	**Latitude**	**Longitude**
1	Karim Cement Mill	Wastewater from different industry	23° 2'30.89"	89°23'25.59"
2	Noapara Bazar Kheya ghat	Wastewater from different hotels and shops	23° 1'54.15"	89°23'59.25"
3	SAF leather	Wastewater from SAF leather industry	23° 0'57.20"	89°24'46.71"
4	Sahara Ghat	Agricultural and industrial wastewater	23° 0'25.23"	89°25'34.32"
5	Superex leather Ltd	Wastewater from Superex leather industry	23° 0'29.88"	89°26'43.57"

Table 1: Sampling points in the Bhairab river, Bangladesh

2.3 Monitoring parameters

The following parameters are measured: Temperature (Temp), pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Fecal Coliform (FC) and Total Coliform (TC), Dissolvable Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) , Phosphate (PO_4^{3-}), Nitrate (NO_3^-), Ammonium (NH_4^+), Chromium (Cr), Lead (Pb), and Mercury (Hg) for WQI and CPI indexing. The amounts of phosphate, ammonium, and nitrate ions were found using a spectrophotometer. The atomic absorption spectrophotometer (AAS) was used to measure the amounts of heavy metals. Coliform was examined using counting techniques.

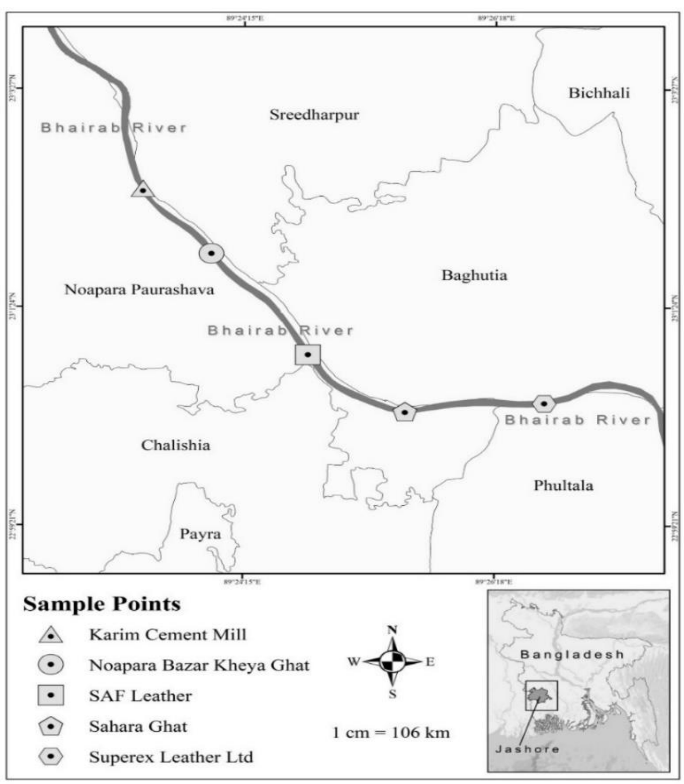


Figure 1: The sampling points in Bhairab River near Noapara Industrial Area

2.4 Water quality and water pollution index

2.4.1 Water Quality Index (WQI)

For the determination of the WQI the NSFWQI index method is applied. The most widely used technique for figuring the WQI of surface waters globally is the NSFWQI, which also guides the development of innovative WQI evaluation techniques (Ratnaningsih et al., 2016). Nine factors are included in the NSFWQI: Temp, pH, BOD, DO, NO_3^-, PO_4^{3-}, turbidity, TSS, and FC. The weighting of each characteristic is determined by how much of an impact it has on the general condition of the water (Sutadian et al., 2016). After measuring the 9 factors mentioned above, each sub-index value can be either derived from a table or curve (developed by NSF)(Berlemann, 2013). The equation (1) is applied to calculate of the final WQI index:

$$WQI = \sum_{i=1}^{p} W_i I_i \tag{1}$$

where: I_i – the sub-index for variables related to water quality obtained from conversion curves according to Table 2, W_i– the weightage of significance associated with i, p – the number of water quality variables (Javid et al., 2014).

The NSFWQI index is a deduction index, meaning it falls as pollution level of water rises. This index is categorized in accordance with Table 3 and has a value between 0 and 100.

Table 2: Weight factor of NSFWQI

Parameters	**Turbidity**	**BOD**	**DO**	**FC**	**NO_3^-**	**pH**	**Temp**	**TDS**	**PO_4^{3-}**
Weighting factor	0.08	0.11	0.1	0.17	0.16	0.11	0.1	0.07	0.1

Table 3: Water Quality index according to NSFWQI

WQI value	**Quality of water**
0-25	Extremely poor water quality
26-50	Bad water quality
51- 70	Medium water quality
71- 90	Good water quality
76-100	Excellent water quality

2.4.2 Comprehensive pollution index (CPI)

The CPI is applied to assess the pollution status of the study area. Previous research has used this CPI approach to assess water quality qualitatively (Son et al., 2020; Yadav et al., 2018; Zhao et al., 2012). The following equation (2) is applied for the calculation of the final index:

$$CPI = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i} \tag{2}$$

where CPI = comprehensive pollution index, C_i is the measured concentration of the parameters of sampling water, S_i represents the limits allowed by the Bangladesh water quality standard (ECR 2023) for water quality, and n is the number of particular pollutants. By comparing the numbers in Table 4, the calculated CPI values may be used to categorize the river water's water quality.

To calculate the CPI in this study, we take into account eleven water parameters: total coliform, pH, DO, BOD, NO_3^-, NH_4^+, NO_3^-, Cr, Pb, and Hg. The Bhairab River water monitoring study included an analysis of these factors. Additionally, the CPI value is established using two distinct regulatory parameters one is based on industrial (CPI_1) and irrigation (CPI_2) purpose for a more thorough examination (Bangladesh water quality standard ECR 2023).

Table 4: Pollution Index Classification

CPI values is divided into five categories		
Category	**CPI value**	**Water quality level**
1	0 to 0.2	clean
2	0.21 to 0.40	sub clean
3	0.41 to 1.00	slightly polluted
4	1.01 to 2.00	medium polluted
5	≥ 2.01	heavily polluted

2.5 Data analysis

The correlation matrix of water parameters in the Bhairab River is determined for summer and monsoon seasons to understand the correlation among the monitoring parameters. The significant variation in water indicators between monsoon and summer seasons in the Bhairab River was assessed using a t-test method. Later by using the WQI scores, CPI_1 and CPI_2 values the cluster analysis assesses the pollution level and water quality between sampling points. The cluster analysis is done using statistical software and to generate the dendrogram Ward Linkage has been followed. A different group is created from the points with comparable pollution and water quality.

3. RESULTS AND DISCUSSION

3.1 Water Quality in Bhairab River

Total five sampling stations on the were surveyed during the summer and monsoon seasons. Table 5 gives the average and standard deviation values of physiochemical properties for five locations. The values show that Cr and Pb concentrations exceeded regulatory levels at several sampling locations, particularly during the summer season according to Bangladesh water quality standards (ECR 2023). This range was from 0.0532 to 0.3044 mg/L for Cr and 0.0613 to 0.6108 mg/L for Pb. However, the rainwater volume diluted these concentrations during the monsoon season. Also, the COD is higher than the permission level in both the summer and monsoon seasons, ranging from 129.04 to 243.75 mg/L in the summer season and 104.64

to 182.74 mg/L in the monsoon season. Most other parameters were found to fall within the regulatory limits. However, most of the monitoring parameters were higher in concentration in the summer season than in the monsoon season; details are shown in Table 5. After the criteria for water quality are determined in both seasons, the correlation matrix is determined to find a strong relationship among the monitoring parameters. Tables 6(a) and 6(b) illustrate the detailed correlation matrix among the monitored parameters. The analysis reveals a strong correlation between the chemical parameters COD, BOD, NO_3^-, NO_2^-, and PO_4^- and the physical parameters TDS, TSS, and turbidity.

Table 5: Variation of water quality between summer and monsoon season

				ECR 2023	
Parameters	**units**	**Summer season (Avg ± SD)**	**Monsoon Season (Avg ± SD)**	**Industrial purpose**	**Irrigation purpose**
Temperature	ºC	33.3 ± 0.66	26.8 ± 0.76	-	-
pH	-	8.02 ± 0.45	7.58 ± 0.19	6.5-8.5	6.5-8.6
Total Dissolved Solid	mg/L	860.04 ± 174.07	240.6 ± 11.50	1000	1000
Total Suspended Solid	mg/L	146.8 ± 26.34	60.2 ± 9.86	-	-
Turbidity	NTU	1056.6 ± 266.66	60.2 ± 14.64	-	-
Fecal Coliform	Nos/100 mL	100 ± 27	37 ± 16	-	-
Total Coliform	Nos/100 mL	137 ± 44	52 ± 18	-	50000
Dissolved Oxygen	mg/L	4.55 ± 2.36	5.974 ± 1.22	1	-
Biochemical Oxygen Demand	mg/L	1.68 ± 0.89	1.538 ± 1.03	12	12
Chemical Oxygen Demand	mg/L	164.19 ± 48.08	134.902 ± 28.96	100	100
Nitrate	mg/L	2.78 ± 1.87	0.66 ± 0.64	-	5
Ammonium	mg/L	0.406 ± 0.11	0.292 ± 0.09	2.7	1.5
Phosphate	mg/L	0.826 ± 0.24	1.962 ± 0.34	-	2
Chromium	mg/L	0.13476 ± 0.10	0.07862 ± 0.07	0.1	0.1
Led	mg/L	0.2734 ± 0.23	0.068 ± 0.02	0.1	0.1
Mercury	mg/L	0.000102 ± 0	0.000038 ± 0	0.05	0.002

Avg = Average, SD = Stander Deviation

Table 6 (a) : Correlation matrix of water parameters in Bhairab River

	Temperature	pH	TDS	TSS	Turbidity	FC	TC	DO	COD	BOD	NO_3^-	NH_4^+	PO_4^-	Cr	Pb	Hg
(a) Summer Season																
Temperature	1.00															
pH	-0.341	1.000														
TDS	-0.312	-0.426	1.000													
TSS	-0.646	-0.157	0.923	1.000												
Turbidity	-0.426	-0.409	0.990	0.957	1.000											
FC	-0.210	0.061	0.701	0.689	0.677	1.000										
TC	-0.552	-0.038	0.902	0.963	0.916	0.853	1.000									
DO	0.266	-0.938	0.189	-0.010	0.208	-0.231	-0.149	1.000								
COD	0.026	0.858	-0.243	-0.144	-0.299	0.257	0.045	-0.953	1.000							
BOD	0.035	0.833	-0.225	-0.138	-0.286	0.194	0.030	-0.950	0.991	1.000						
NO_3^-	0.065	0.869	-0.327	-0.229	-0.382	0.183	-0.043	-0.942	0.996	0.987	1.000					
NH_4^+	0.343	0.446	-0.016	-0.085	-0.100	0.624	0.185	-0.562	0.741	0.675	0.724	1.000				
PO_4^-	0.235	-0.644	0.651	0.401	0.582	0.071	0.305	0.366	-0.314	-0.218	-0.355	-0.256	1.000			
Cr	-0.610	0.868	-0.057	0.233	-0.028	0.120	0.267	-0.900	0.729	0.749	0.710	0.182	-0.286	1.000		
Pb	-0.807	0.325	0.559	0.778	0.605	0.332	0.710	-0.454	0.223	0.270	0.162	-0.171	0.224	0.737	1.000	
Hg	-0.219	-0.435	-0.137	-0.088	-0.061	-0.741	-0.352	0.577	-0.726	-0.661	-0.694	-0.985	0.197	-0.238	0.027	1.000

Table 6 (b) : Correlation matrix of water parameters in Bhairab River

	Temperature	pH	TDS	TSS	Turbidity	FC	TC	DO	COD	BOD	NO_3^-	NH_4^+	PO_4^-	Cr	Pb	Hg
	(b) Monsoon Season															
Temperature	1.00															
pH	0.345	1.00														
TDS	0.748	0.419	1.00													
TSS	0.943	0.127	0.821	1.00												
Turbidity	0.608	0.285	0.890	0.756	1.00											
FC	-0.609	-0.727	-0.302	-0.324	0.023	1.00										
TC	-0.580	-0.656	-0.219	-0.288	0.116	0.994	1.00									
DO	-0.781	-0.187	-0.190	-0.634	-0.157	0.581	0.602	1.00								
COD	0.345	0.448	-0.156	0.123	-0.046	-0.495	-0.499	-0.758	1.00							
BOD	-0.578	-0.895	-0.768	-0.455	-0.580	0.678	0.592	0.175	-0.171	1.00						
NO_3^-	0.287	0.310	-0.182	0.128	0.026	-0.293	-0.296	-0.720	0.973	-0.046	1.00					
NH_4^+	0.559	0.228	0.322	0.564	0.594	-0.082	-0.041	-0.673	0.699	-0.215	0.796	1.00				
PO_4^-	0.340	-0.011	-0.074	0.156	-0.467	-0.651	-0.720	-0.416	0.051	-0.023	-0.121	-0.390	1.00			
Cr	-0.572	-0.951	-0.488	-0.354	-0.385	0.788	0.723	0.468	-0.621	0.875	-0.500	-0.464	-0.048	1.00		
Pb	-0.791	-0.628	-0.876	-0.781	-0.885	0.416	0.327	0.442	-0.307	0.814	-0.294	-0.676	0.216	0.754	1.000	
Hg	-0.280	-0.526	-0.113	-0.184	-0.377	0.193	0.142	0.483	-0.827	0.330	-0.878	-0.867	0.477	0.654	0.570	1.000

3.2 The Water Quality Index

The monitoring parameters from five sampling points are used for water quality assessment to calculate the WQI score according to The NSFWQI indexing and presented in Table 7. The WQI scores vary from 34 to 44 in the summer season and fall in the bad water quality classification category according to the NSFWQI classification. On the other hand, in the monsoon season, the WQI scores increased from 47 to 52. This indicates that the water quality gets preferable in the monsoon season. During the monsoon season, two sampling points fall under the Bad Water Quality classification, and the other 3 fall into the medium water quality classification according to the NSFWQI. Figure 2 clearly shows that the WQI scores in the monsoon season are very stable, but the WQI score fluctuates at different sampling points in the summer season. In the summer season, the WQI scores are much lower which means the water quality at that point is not in good quality. But in the monsoon season, the water quality gets better as we see that the WQI scores also increase. This indicates that the overall condition of the water becomes better in the monsoon season.

Table 7: Water Quality Index Value of summer season and monsoon season

	Summer Season	**Monsoon Season**
Sampling Point	**WQI (NSF)**	**WQI (NSF)**
1	42	47
2	44	51
3	34	50
4	43	52
5	40	49
Average	41	50
SD	4	2

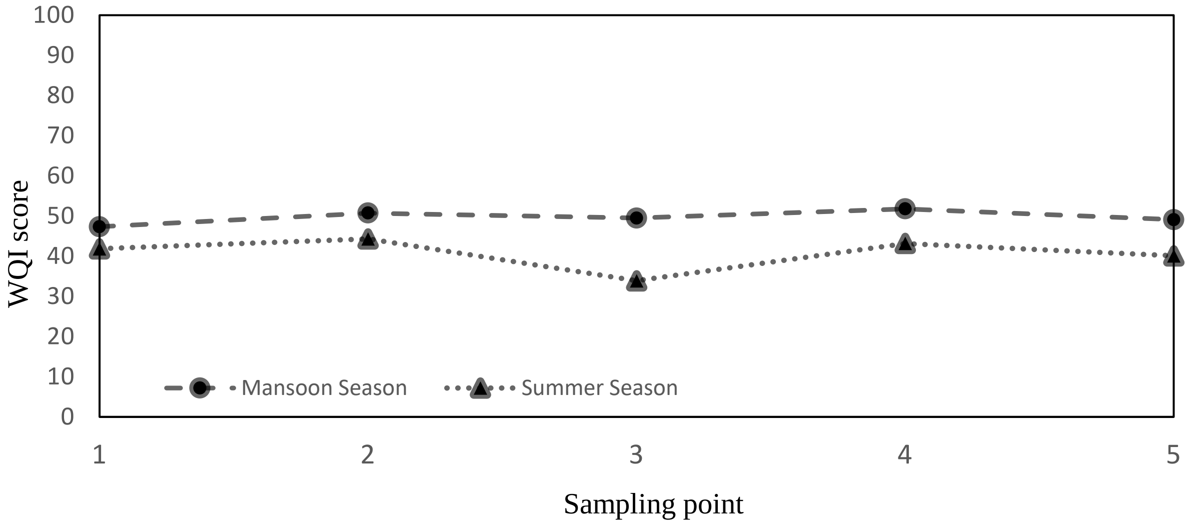


Figure 2: Seasonal water quality variation of sampling point

3.3 Comprehensive Pollution Index (CPI)

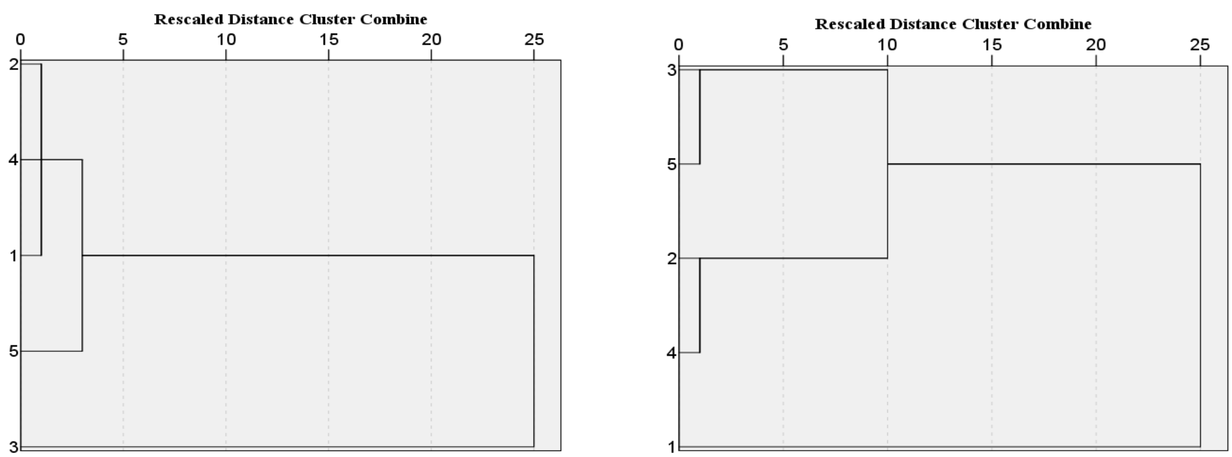
There is a considerable difference in the results since CPI_1 is based on industrial purposes whereas CPI_2 is based on irrigation purposes. Based on the CPI_1 results, the water of all the sampling points is included in the medium polluted category; the average CPI_1 scores were 1.37 in the summer season, and in the monsoon season, the CPI_1 value became lower with an average value of 1.12 in some of the sampling point water quality increased from Medium polluted to Slightly polluted category. On the other hand, based on CPI_2, the water samples of the sampling locations are included in some medium polluted and some slightly polluted categories in the summer season with an average score of 0.80; the CPI_2 value became lower with an average value of 0.42 in some of the sampling point water quality the medium polluted water became slightly polluted, the slightly polluted water became sub clean category. Specially the sampling point 2 and 4 fall under sub clean category according to the CPI scores. As their CPI_2 scores are 0.38 and 0.36 respectively with in the rage of 0.21 to 0.40. The detailed classified results of the sampling points are shown in Table 8. After the above discussion, it is seen that the overall water quality upgraded from the summer season to the monsoon season as the pollution level decreased based on both CPI_1 and CPI_2 indexing. We also performed the t-test to analyse the perceptible contrast between the two seasons. The null hypothesis is rejected since the p-value is less than $\alpha = 0.05$, denoting that the seasonal difference's variance is logical according to statistical evidence.

Table 8: Comprehensive pollution index of summer season and monsoon season

	Summer Season	**Monsoon Season**	**Summer Season**	**Monsoon Season**
Sampling Point	**CPI_1**	**CPI_1**	**CPI_2**	**CPI_2**
SP1	1.84	1.41	1.09	0.53
SP2	1.24	1.27	0.55	0.38
SP3	1.41	0.94	1.27	0.44
SP4	1.18	1	0.49	0.36
SP5	1.17	1	0.62	0.41
Average	1.37	1.12	0.80	0.42
SD	0.28	0.20	0.35	0.07
P value of seasonal difference	0.0287		0.0246	

3.4 Cluster analysis of sampling point

Cluster analysis is done for both summer and monsoon seasons using the WQI, CPI_1 and CPI_2 scores (Figure 3). From the cluster analysis of Figure 3 it is clear the sampling point is divided into three groups in summer season. The sampling points 2,4,1 are fall in the same group and this sampling points water are best in the category. Then comes sampling point 5 this point water sample is a little bit lower than the first category, lastly, sampling point 3 is lower in the category according to the cluster. On the other hand in the monsoon season we also find 3 different groups of water sampling points. This time the 2,4 no sampling points came in the best category secondly the 3,5 no sampling points are a bit lower in category than the first category, Lastly, the sampling point 1 is the lower in category according to the cluster analysis. Additionally, this cluster demonstrates that during the monsoon season, the water quality improves relative to the summer. Water monitoring stations with similar features can be grouped to help managers plan ways to use water for multiple uses, including irrigation, aquaculture, domestic water supply, and other uses. These advantages offer significant groundwork for long-term sustainable water resource management.



Dendrogram of Summer Season   Dendrogram of Monsson Season

Figure 3: Cluster analysis of sampling point in Bhairab River

4. CONCLUSIONS

This study presents the Bhairab River's water grade categorization in a nearby area of the Noapara industrial region based on the water quality indexing and comprehensive pollution indexing. The indexing was done based on the different environmental parameters of surface water. In the summer season Cr and Pb concentrations exceeded regulatory levels ranging 0.13476 ± 0.10 mg/L and 0.2734±0.23 mg/L respectively according to Bangladesh water quality standard (ECR 2023). Later in the monsoon season the concentration for both Cr and Pd within the regulated value. The other parameters are almost within the regulated values in both seasons. The correlation matrix of the monitoring parameters shows a proper relation between both the chemical and physical parameters. Using the NSF indexing it is found that the water quality of the sampling points falls under the bad water quality in the summer season. Since the WQI scores of the five sampling points are 41±4, they fall between the 26–50 range, which indicates bad water quality. In the monsoon season, the WQI scores for the sampling points are 50±24 which fall under the medium water quality as WQI scoring range 26-50. In the monsoon season, the water quality improves due to the high-water volume. The CPI_1 scores of five sampling points vary from 1.01 to 2.00 in both seasons, indicating the pollution level of those water samples falls under the medium-polluted category. The CPI_2 scores decreased from 0.80±0.35 to 0.42±0.07 in the monsoon season. Considering the values of these scores range from 0.41 to 1.00, it may be decided that the overall pollution level is slightly polluted. The monsoon season's lower CPI scores indicate an improvement in overall pollution status. The significant change of their change in the dry and monsoon season also statically satisfied. Based on the decrease in water quality from the first group to the third group, three groups were created from the sampling points in the cluster analysis. This study improves the water quality monitoring systems which will significantly contribute towards a sustainable environment. Moreover, in future this study will help to manage and monitor water sources along the Bhairab River based on scientific evidence.

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