Open Access Library Journal
2025, Volume 12, e14016
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Assessing Limnological Characteristics and Water Quality Index of the Rivers of Northern Bangladesh

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How to cite this paper: Islam, M.J., Rahman, M.S., Siddiqa, A., Zahan, M.N. and Anika, A.F. (2025) Assessing Limnological Characteristics and Water Quality Index of the Rivers of Northern Bangladesh. *Open Access Library Journal*, **12**: e14016.
https://doi.org/10.4236/oalib.1114016

Received: July 24, 2025
Accepted: September 12, 2025
Published: September 15, 2025

Abstract

Different water quality indices (WQI) were determined to assess the limnological characteristics from five rivers of Dinajpur Bangladesh for fish production, agricultural uses, household and industrial purposes. Water quality index reveals large seasonal variation of two major seasons and indicates that the river water is suitable or unsuitable for drinking and other household uses. In the selected areas, temperatures in all warm-water fishes were within normal limits (20˚C - 32˚C) and the waters were slightly acidic to neutral in characters, excellent for fish production (pH fluctuated from 6.8 - 7.5 during the dry season and 5.8 - 6.6 during the monsoon season). The dissolved oxygen (DO) value for fish production was above the safe limits (5 mg·O_2/L). The COD (chemical oxygen demand) of the river waters was within the satisfactory levels for fish production (4 mg·O_2/L by COD_{Mn}). The most frequent cations were Ca^{2+}, Mg^{2+}, and Na^{+}, while HCO_3^- and Cl^- were the most dominant anions. The principal cation and anion ratios in the water samples indicate that calcium and magnesium-containing minerals predominate over sodium-containing minerals. According to the Canadian Council of Ministers of the Environment's water quality index, the overall quality of the river waters is in the 'marginal' category. The concentrations of Cu^{2+}, Zn^{2+}, Mn^{2+} and Fe^{3+} were within the 'safe' limit for algae production. Ammonia levels in both seasons were within the acceptable limits for fish production. However, continuous monitoring is required to follow changes in river water quality through time and space.

Subject Areas

Environmental Sciences

Keywords

Water Quality Index, River Water Quality, Fish Production, Bangladesh

1. Introduction

Bangladesh has been blessed with an abundance of water resources comprising approximately 700 rivers with tributaries and distributaries [1]-[3]. The majority of the river originates in India and flows into Bangladesh [1]. The rivers provide a key source of water for domestic, agricultural, navigational, and industrial purposes.

Population expansion, intensive agricultural activities, rapid industrialization, reduction of river width and depth, discharge of massive amounts of sewage and wastewater into rivers, etc. are accountable for deteriorating water quality and frightening aquatic biota [4] [5]. Major pollutants in water include toxic metals, plant nutrients, volatile, biodegradable and non-biodegradable organic compounds, suspended solids, microbial pathogens, parasites, etc. [5]. Toxic metals are among these pollutants that can have a major negative impact on the environment because they are not biodegradable in aquatic environments or in human meals [6] [7]. Most of the industries are constructed along the riverbanks, and everyday thousands of tons of waste items and effluents are discarded into the riverine water systems coming from dyeing, electroplating, mining, printing, photographic, cement, fertilizer, textile, tannery, sugar, pulp, paper, plastic, pharmaceutical industries, etc. [1] [8]. In this sense, river pollution has evolved to be a significant issue in Bangladesh. However, recently, river water in Bangladesh is deteriorated by anthropogenic activities and going to be unsuitable for uses [4]. Surface water quality evaluation is an extremely stunning procedure because of its need for multiple parameters that can be set up to produce varying weights on the overall quality of the water. The water quality index (WQI) is a very effective method for assessing the quality of surface and groundwater. Several researchers have proposed mathematical tools for water quality assessment and the policymakers who are concerned about the management of water resources [9]. The WQI provides simplified results with translations of a list of parameters into a single value that translates their existing concentrations in a sample into a single value. These values are used for understanding the nature of water and appropriateness for different uses like irrigation, drinking, fishing, and so on [10]. However, recently, the investigation of heavy metal contamination in surface and groundwater attracted attention to pollution evaluation indices [11]. The single-factor pollution index, heavy metal pollution index, Nemerow pollution index, and the degree of contamination are involved for pollution evaluation indices explanation. Moreover, pollution evaluation indices are required for understanding the pollution level because WQI alone is not enough to assess the water quality appraisal.

Presently, a great deal of work has been continued all through the selected rivers pathway concerning physicochemical parameter investigation, water quality assessment, heavy metal pollution using principal component analysis, correlation analysis, and other related techniques to reveal the connection of mass portion and to recognize the substantial metals in the river water [12]-[15]. Fish productivity is still low in Bangladesh's northern area and farmers are raising their fish in little ponds. However, the need for fish in northern Bangladesh remains unmet. Water of the five rivers of Dinajpur is of utmost importance for fish production. Interestingly, water quality data is limited in the research area. Considering the background, the objective of this research is to find out whether river waters in northern Bangladesh are suitable for various fish species and agriculture uses, as well as their pollution levels.

2. Materials and Methods

2.1. Climate and Lithology

Bangladesh experiences a tropical monsoon climate with considerable seasonal rainfall, high temperatures, and high humidity. The rainy season commences in May, which lasts until October. The dry season lasts from November to March/April, with maximum temperatures occurring in June-August and the coldest months being December-January. During the monsoon, rainfall averages between 1194 and 3454 millimeters. The principal lithological characteristics of this study region are medium to coarse grained sands and gravels with few surface clays.

2.2. Sample Collection and Measurements of Parameters

The experiment was conducted on 5 river waters from 20 sampling sites (The Dhapa River, 1 - 4 site; The Punorbhava River, 5 - 8 site; The Atrai River, 9 - 12 site; The Jamuna River, 13-16 site; and The Kharkharia River, 17 - 20 site) at a distance of 2 km per site of Dinajpur, Bangladesh in the year of 2022 (**Figure 1**). We collected one sample per site and conducted the analysis for three times of each sample. Water samples were collected during dry season (February-March) and the monsoon season (July-August) to reflect spatial variation. The samples were analyzed as soon as feasible after collection. For cleaning of bottles and glassware, P-free detergent, 10% (v/v) HCl and ultra-pure water were used.

We measured temperature, turbidity, pH, EC (electrical conductivity), DO, COD_{Mn}, alkalinity, TDS (total dissolved solids), NO_3^-, TN (total nitrogen), NH_3, PO_4^{3-}, TP (total phosphorus), CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, Zn^{2+}, Cu^{2+}, Mn^{2+}, and Fe^{3+}. Temperature was measured by thermometer. The pH (HANNA pH 211) and electrical conductivity (EC) were determined electrometrically (APHA 2005). A DO meter was used to determine the amount of oxygen in the air (Milwaukee MW 600). By using a turbidimeter, the turbidity was measured (IR TB 100). BOD was measured by incubating sample aliquots in 300 ml glass BOD vials at 20˚C for 5 days in the dark. The 5-day test [16] was used to examine BOD_5 levels. For COD_{Mn}, 30 mL water samples mixed with 5 mN $KMnO_4$

Figure 1. Map of the sampling sites of the selected rivers of Dinajpur along with the map of Bangladesh (Source: https://www.researchgate.net/figure/Map-of-Dinajpur-District_fig1_322790213).

and 1% NaOH were heated for 1 hour at 100˚C in an autoclave. Alkalinity was determined by quantifying the amount of acid (hydrochloric acid) needed to bring the sample to a pH of 4.5. Chlorophyll-a concentration was measured by Lorenzen technique [17].

The dissolved inorganic phosphate (DIP) *i.e.*, PO_4^{3-} was analyzed after GF/F filtration (0.45 μm) by applying the molybdenum blue method at 880 nm, according to [16]. Total phosphorus (TP) was measured from the unfiltered sample as DIP after persulfate digestion followed by Mo-blue method [16]. Total N (TN) was calculated using a flow-injection autoanalyzer after persulfate digestion using the cadmium-reduction method. The Cd-reduction method was used to determine the nitrate level with an auto analyzer. The Nessler method [18] was utilized for measurement of ammonia. The drying and weighing procedure [16] was used to measure total dissolved solids (TDS). Flame emission spectrophotometry was used to calculate K^+ and Na^+ levels. Zn^{2+}, Cu^{2+}, Mn^{2+} and Fe^{3+} were measured by atomic absorption spectrophotometer [16]. Complexometric titration was used to determine the concentrations of Ca^{2+} and Mg^{2+}. Chloride was estimated by argentometric titration [16]. The concentration of SO_4^{2-} was obtained using turbidimetry. CO_3^{2-} and HCO_3^- were analyzed titrimetrically. The precision of measurements was verified taking three replicates from the sample.

2.3. Water Quality Index (WQI)

The water quality index is a metric that measures the overall quality of water using several parameters. For measuring the overall water quality of these rivers, the Canadian Council of Ministers of the Environment WQI (CCME WQI) was used. The CCME WQI is calculated based on three factors (scope, frequency and amplitude). These three parameters combine to provide a number ranging from 0 to 100 that measures overall water quality [19]. The WQI values from the CCME are then transformed into ranks like excellent = 95 - 100, good = 80 - 94, fair = 65 - 79, marginal = 45 - 64, and poor = 0 - 44. Eight parameters such as nitrate-nitrogen (mg/L), pH (units), dissolved oxygen (mg/L), phosphate (mg/L), biological oxygen demand (mg/L), turbidity (NTU), total dissolved solids (mg/L) and temperature (˚C) are used for the calculation of WQI. For each of the three factors, the following equations were used:

1) Scope: F1 (scope) represents the ratio of the number of failed variables to the total number of variables.

$$\text{F1} = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \tag{1}$$

2) Frequency: F2 (frequency) indicates the percentage of individual tests that do not meet the objectives (failed tests):

$$\text{F2} = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

3) Amplitude: F3 (amplitude) expresses the amount by which failed test values do not meet their objectives. F3 is calculated in three steps as follows:

a) For the cases when the test value must not exceed or fall below the objective the expression is given by

$$\text{excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right) - 1 \tag{3}$$

$$\text{excursion}_i = \left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right) - 1 \tag{4}$$

b) Summation of excursions calculated in step (*i*) divided by the total number of tests is the normalized sum of excursions (nse) expressed as:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{Number of tests}} \tag{5}$$

c) F3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

$$\text{F3} = \frac{\text{nse}}{0.01\text{nse} + 0.01} \tag{6}$$

The F1, F2 and F3 are used to calculate the CCME WQI in the following form:

$$\text{CCME WQI} = 100 - \left(\frac{\sqrt{\text{F}_1^2 + \text{F}_2^2 + \text{F}_3^2}}{100}\right) \tag{7}$$

2.4. Multivariate Statistical Analysis

Multivariate statistical methods like hierarchical cluster analysis (HCA) and correlation matrix might be helpful and trustworthy tools for better understanding and interpreting the complex system of water quality [20]. To detect distinct chemical features of water, hierarchical cluster analysis (HCA) sequentially connects the most comparable findings [21]. Ward's method of creating dendrograms using squared Euclidean distance is the most effective method for cluster analysis [22]. Ward's method adopts the nearest-neighbor chain algorithm to trace the optimal pair of clusters for merge cluster generating most distinct signature clusters. A correlation study was used to identify associations among various hydrochemical constituents. SPSS 26.0 software [23] was used for all statistical calculations.

3. Results and Discussions

3.1. Characteristics of Surface Water

The chemical compositions of the studied rivers water are shown in **Table 1** to **Table 3**. During the dry season, water temperatures ranged from 21.5˚C to 27.5˚C, with pH levels ranging from 6.8 to 7.5. (**Table 1**). DO levels ranged from 6.5 to 8.9 mg·O_2/L. The BOD_5 ranged from 0.8 to 1.7 mg·O_2/L during monsoon while it was 0.7 to 1.4 mg·O_2/L in the dry season. The river water samples were more turbid in monsoon season compared to dry season. COD_{Mn} levels in water samples ranged from 3.2 to 7.9 mg·O_2/L (**Table 1**). Higher COD_{Mn} values indicate the presence of non-biodegradable chemical pollutants in river waters. The EC and TDS ranged between 101 - 139 μS/cm and 20 - 172 mg/L, respectively during the dry season. In monsoon season, the temperature, pH, DO, COD_{Mn}, EC and TDS ranged from 22.7˚C - 27.4˚C, 5.8 - 6.6, 6.9 - 9.5 mg·O_2/L, 3.2 - 7.2 mg·O_2/L, 100 - 220 μS/cm and 65 - 115 mg/L, respectively (**Table 1**).

Table 1. Physico-chemical characteristics of the river waters during dry and monsoon seasons.

SEASONS	STATISTICS	pH	TEMP.	DO	BOD	COD	TURB.	EC	TDS	HARD.	ALKAL.
			˚C	mg·O_2/L	mg·O_2/L	mg·O_2/L	NTU	μS/cm	mg/L	mg/L	mg/L
Dry	Min	6.8	21.5	6.5	0.7	3.2	6.0	101	20	76	16
	Max	7.5	27.5	8.9	1.4	7.9	12.0	139	172	149	56
	Mean	7.1	24.8	7.7	1.1	6.0	8.9	120	84	110	34
	SD	0.2	1.89	0.61	0.2	1.2	2.02	14	42	21	12
Monsoon	Min	5.8	22.7	6.9	0.8	3.2	21.0	100	65	88	21
	Max	6.6	27.4	9.5	1.7	7.2	42.0	220	115	139	46
	Mean	6.2	25.2	7.9	1.3	5.9	30.8	138	81	105	32
	SD	0.2	1.48	0.64	0.24	1.0	6.21	32	12	13	8

Ca^{2+} and Mg^{2+} were the most abundant cations in river water during both seasons. However, in dry season the Ca^{2+} and Mg^{2+} ranged from 0.64 - 1.20 meq/L and 0.89 - 1.85 meq/L, respectively (**Table 2**). The concentrations of Na^+ and K^+ ranged from 0.08 - 0.14 meq/L and 0.20 - 0.51 meq/L, respectively (**Table 2**). In general, K^+ concentrations were higher than Na^+ concentrations. During the dry season, however, trace element concentrations such as Fe^{3+}, Cu^{2+}, Zn^{2+}, and Mn^{2+} ranged from 0.10 - 0.27 mg/L, 0.038 - 0.088 mg/L, 0.028 - 0.067 mg/L, and 0.012 - 0.051 mg/L, respectively (**Table 2**). Ca^{2+}, Mg^{2+}, Na^+, and K^+ concentrations were 0.62 - 1.04 meq/L, 0.98 - 1.76 meq/L, 0.08 - 0.17 meq/L, and 0.14 - 0.32 meq/L, respectively, throughout the monsoon season (**Table 2**).

Table 2. Cationic constituents of river waters during dry and monsoon seasons.

SEASONS	STATISTICS	Ca^{2+}	Mg^{2+}	Na^+	K^+	Zn^{2+}	Cu^{2+}	Fe^{3+}	Mn^{2+}
		meq/L	meq/L	meq/L	meq/L	mg/L	mg/L	mg/L	mg/L
Dry	Min	0.64	0.89	0.08	0.20	0.028	0.038	0.10	0.012
	Max	1.20	1.85	0.14	0.51	0.067	0.088	0.27	0.051
	Mean	0.90	1.31	0.11	0.32	0.048	0.068	0.16	0.028
	SD	0.18	0.30	0.02	0.08	0.012	0.014	0.05	0.012
Monsoon	Min	0.62	0.98	0.08	0.14	0.023	0.025	0.012	0.014
	Max	1.04	1.76	0.17	0.32	0.056	0.071	0.121	0.042
	Mean	0.79	1.34	0.12	0.24	0.041	0.047	0.086	0.027
	SD	0.12	0.20	0.03	0.05	0.009	0.012	0.023	0.008

The concentrations of nitrate-N varied from 1.64 - 6.95 mg/L in dry season and 1.28 - 3.25 mg/L in monsoon season (**Table 3**). Higher concentrations of NO_3^--N and trace amount of ammonia were noticed in all the rivers. Increased nitrate concentrations in some test locations could be the result of fertilizers applied to nearby agricultural fields [24]. Phosphate (PO_4^{3-}) concentrations in the dry season varied from 0.011 to 0.266 mg/L, while they were 0.016 to 0.123 mg/L during the monsoon season (**Table 3**).

Table 3. Different anionic constituents and chlorophyll-a value of river waters during dry and monsoon seasons.

SEASONS	STATISTICS	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-	NH_3	TN	PO_4^{3-}	TP	TN:TP	CHL.a
		meq/L	meq/L	meq/L	mg/L	mg/L	mg/L	mg/L	mg/L	ratio	mg/L
Dry	Min	0.25	1.20	0.002	1.64	0.25	5.65	0.011	0.081	11	25.25
	Max	1.35	1.85	0.192	6.95	1.34	13.52	0.266	0.798	98	85.48
	Mean	0.71	1.45	0.066	4.56	0.72	8.91	0.038	0.203	58	61.19
	SD	0.31	0.21	0.039	1.37	0.31	1.87	0.055	0.164	25	17.41
Monsoon	Min	0.45	0.96	0.53	1.28	0.11	2.95	0.016	0.125	9	34.55
	Max	0.95	1.80	1.47	3.25	0.42	7.44	0.123	0.504	38	90.76
	Mean	0.69	1.42	0.99	2.53	0.24	4.13	0.046	0.254	19	61.96
	SD	0.14	0.23	0.25	0.55	0.09	1.00	0.023	0.093	9	18.59

The TN:TP ratios in dry season ranged from 11 - 98:1 while in case of wet season it was 9 - 38:1. For optimal growth of microbes and algae, the Redfield's N:P

= 16 [25] could be the consequence of protein: RNA ratio suggested by a recent mathematical model [26]. Alkalinity ranged from 16 - 56 mg/L in the dry season and 21 - 46 mg/L in the wet season, according to the findings (**Table 1**). During the dry season, chlorophyll concentrations ranged from 25.25 to 85.48 mg/m^3, but during the monsoon season, chlorophyll concentrations ranged from 34.55 to 90.76 mg/m^3 (**Table 3**).

Hardness values of the studied rivers ranged from 76 - 149 mg/L in the dry season while in case of monsoon it was 88 - 139 mg/L with levels averaging 105 mg/L (**Table 1**). In both seasons, all water samples had appreciable amount of HCO_3^- and negligible CO_3^{2-}. The ranges for HCO_3^- were 1.20 - 1.85 meq/L in dry season and 0.96 - 1.80 in monsoon season (**Table 3**). The Cl^- concentrations ranged from 0.25 - 1.35 meq/L and 0.45 - 0.95 meq/L in the dry and wet seasons, respectively (**Table 3**). $Mg^{2+} > Ca^{2+} > K^+ > Na^+$ and $HCO_3^- > Cl^- > SO_4^{2-}$ were the most abundant main cations and anions, respectively.

3.2. Stoichiometry of River Water

The Na^+:Cl^- ratio in most water samples was less than one (**Figure 2(c)**). A ratio of one indicates that NaCl is dissolved, whereas a ratio of more than one indicates that Na^+ is released via silicate weathering [27]. The increase in Na^+ concentration was not associated with an increase in Cl^- concentration that supports a cation exchange process [28]. **Figure 2(c)** shows that some samples depart from the predicted 1:1 relationship, showing that a portion of Na relates to another anion. The ratio of Mg^{2+}:Ca^{2+} was greater than unity in the surface water showed in **Figure 2(e)** in both the seasons. Weathering of calcium and magnesium minerals can be a source of significant cations like Ca^{2+} and Mg^{2+} in river water [29].

Carbonate weathering occurs when the HCO_3^-:Na^+ ratio is larger than 1, while a ratio smaller than 1 indicates silicate weathering. The ratio of $Ca^{2+} + Mg^{2+}$: $HCO_3^- + CO_3^{2-}$ (**Figure 2(i)** and **Figure 2(j)**) was larger than unity in all river water samples in this investigation, but the ratio of Na^+: $HCO_3^- + CO_3^{2-}$ was less than unity, indicating that Ca and Mg-containing minerals predominated over Na-containing minerals in the study area. As a result, most of the water samples' $Ca^{2+} + Mg^{2+}$: otal cations ratios (**Figure 2(b)**) were close to unity, whereas the ratios of $Na^+ + K^+$:total cations were considerably below unity (**Figure 2(a)**).

3.3. PH, Alkalinity, Hardness and Turbidity on Fish Growth

During the dry and monsoon seasons, the pH of the research locations was 6.8 - 7.5 and 5.8 - 6.6, respectively. The pH range for most aquatic organisms is 6.0 - 8.5 [30]. Fishes are susceptible to extreme pH especially at reproductive stage. Low pH makes hydrogen sulfide (H_2S), copper, and other heavy metals more harmful to fish and algae. Water with low pH interferes with the ability of fish to take up oxygen, changes the acid-base regulation at the gills, and has other deleterious effects on the physiology of fish [31]. High pH reduces the ability of fish to excrete ammonia or regulate their internal ion balance [32]. The discharge of home or industrial wastewater containing acidic or alkaline substances can cause rivers to have unusually low or high pH levels.

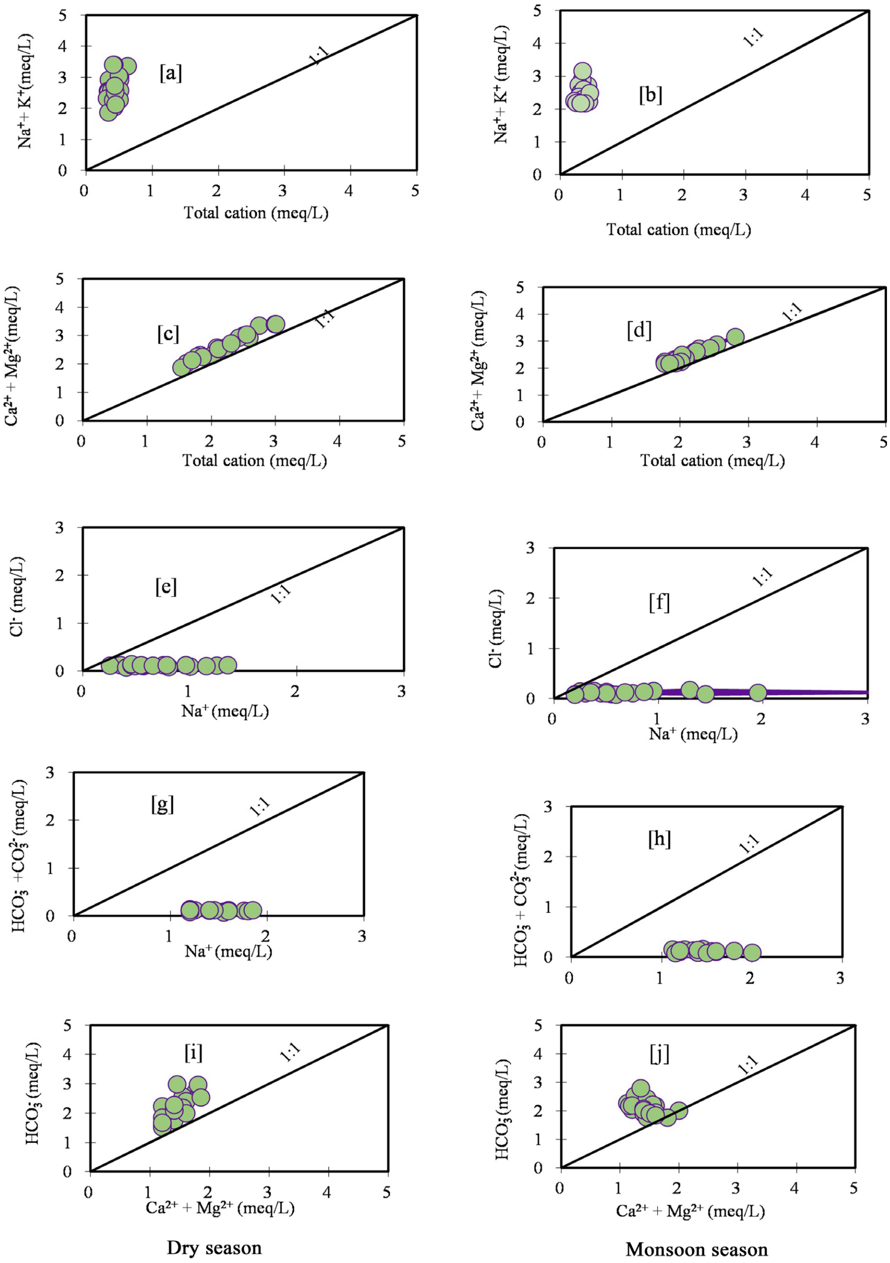


Figure 2. Stoichiometric relations among the chemical parameters of the study rivers during dry and monsoon season (a) $Na^+ + K^+$ vs total cations (dry); (b) $Na^+ + K^+$ vs total cations (monsoon); (c) $Ca^{2+} + Mg^{2+}$ vs. total cations (dry); (d) $Ca^{2+} + Mg^{2+}$ vs. total cations (monsoon); (e) Na^+ vs. Cl^- (dry); (f) Na^+ vs. Cl^- (monsoon); (g) Na^+ vs. $HCO_3^- + CO_3^{2-}$ (dry); (h) Na^+ vs. $HCO_3^- + CO_3^{2-}$ (monsoon); (i) $Ca^{2+} + Mg^{2+}$ vs HCO_3^- (dry) and (j) $Ca^{2+} + Mg^{2+}$ vs HCO_3^- (monsoon).

Alkalinity ranged from 16 - 56 mg/L and 21 - 46 mg/L with the respective mean values of 34 and 32 mg/L. A suitable alkalinity ranges from 50 - 300 mg/L [16]

[33]. The average hardness values in dry and monsoon seasons were 110 and 105 mg/L respectively (**Table 1**). To produce bones and scales, fish require calcium and magnesium. Desirable level of total hardness for fish should be 20 - 300 mg/L.

Phytoplankton is most likely to blame for high turbidity. When flows are low, turbidity decreases, and light becomes less limiting, thus phytoplankton could be expected to take advantages of nutrients, possibly leading to blooms. The average readings of turbidity in dry and monsoon were 8.9 and 30.8 NTU, respectively. Highly turbid rivers influence the biologic productivity by limiting light availability and can also irritate fish if fine particulates are present. Erosion issues, nutrient enrichment, or other sorts of agricultural, commercial, or industrial contamination could all be indicators.

3.4. Temperature, DO, TDS and Heavy Metals on Fish Growth

The temperature in the research area ranged from 21.5˚C - 27.5˚C in the dry season and 22.7˚C - 27.4˚C in the wet season. However, the acceptable range of temperature is between 20˚C - 30˚C [30]. Temperature has a pronounced effect on chemical and biological processes. Water temperatures influence the onset of fish spawn, aquatic vegetation growth and BOD in rivers. Fish are sensitive to temperature fluctuations. Fish can be stressed or killed by even a 5˚C temperature difference.

The DO values varied from 6.5 - 8.9 mg·O_2/L in dry season and 6.9 - 9.5 mg·O_2/L in wet season (**Table 1**). This range was appropriate for fish growth and development in the study area [34]. The growth and development of fish is optimum at more than 5 mg·O_2/L. Almost all aquatic species can survive continuously at levels beyond 5 mg·O_2/L if other environmental conditions are kept within acceptable ranges [34]. DO concentration has an impact on fish behaviors, particularly 1) juvenile growth; fish food consumption and growth may be slowed at low DO levels, and 2) swimming behavior; swimming falls at DO concentrations below 5 mg·O_2/L [35]. Low DO levels also lead to chemical reactions that result in the release or formation of other toxic compounds such as ammonia and hydrogen sulphide in sediments and bottom waters. The solubility of oxygen in water also decreases as salinity increases.

TDS levels above a certain threshold impact freshwater species' osmoregulation and reduce gas solubility. At the individual, population, community, and ecological levels, salinity pollution or elevated TDS have wide-ranging detrimental effects on aquatic ecosystems [36]. Freshwater organisms have a limited tolerance to salinity and usually cannot adapt to salinity concentrations significantly higher than natural background levels. The maximum recommended concentrations of Fe, Cu, Zn and Mn are 2.0, 0.5, 5.0 and 5.0 mg/L, respectively for fish life [37]. In the study area, Fe content in dry season varied from 0.10 - 0.27 mg/L and was within the limit of the Department of Environment [37]. During dry season, the concentrations of Cu and Mn of the study area were also within the limits of [37].

3.5. Fish Growth Suitability Based on Chloride, Ammonia and Nitrate

Chloride is another parameter of concern to the status of the fishery. High chloride concentration can impair the osmoregulation of fish and other organisms and impair their survival, growth, and/or reproduction [38]. Chloride can derive from a variety source, including those associated with organic pollution such as domestic wastewater. Hence it is sometimes present in high concentrations when BOD levels are also high.

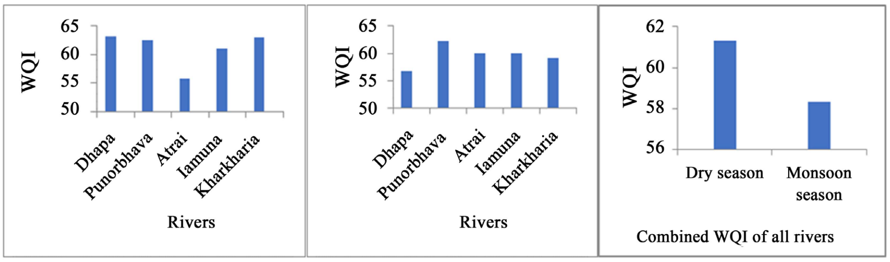
The concentrations of ammonia varied from 0.25 - 1.34 mg/L and 0.11 - 0.42 mg/L (**Table 3**) in dry and wet seasons, respectively. Ammonia poisoned fish congregates close to the water surface, gasp for air and are restless [30]. However, fishes can withstand ammonia (NH_3) concentrations up to 0.6 - 2.0 mg/L for a short period of time [30]. Depending on pH and water temperature, the $NH_4^+ \leftrightarrow NH_3$ equilibrium may be shifted to the right causing toxicity to fish. Unionized ammonia (NH_3) is extremely toxic to fish and is the predominant form of ammonia when pH is high. Some study sites had NO_3^- concentrations (1.64 - 6.95 mg/L) somewhat higher than the allowed limit (5 mg/L) during the dry season [39], which could be linked to nitrogenous fertilizers used on agricultural field crops. Nitrate concentrations of zero to 200 mg/L, on the other hand, are considered safe.

3.6. Water Quality for Algae

Climate impact assessments typically show associated changes in ecosystem functioning, such as earlier blooms or higher concentrations of planktonic algae [40]. Because chlorophyll content is a surrogate metric for algal concentration, we can forecast overall water quality by measuring it in the examined rivers. The chlorophyll-a concentration ranged from 25.25 - 85.48 mg/m^3 in dry season and 34.55 - 90.76 mg/m^3 in wet season. Algae are a zooplankton food source and can be exploited to create an ideal aquatic habitat for fish growth. The production of algae is influenced by nutrients, pH, and temperature [35]. In fish growth and development where fish are not provided supplemental feed, plankton forms the most abundant base of the food web. Temperature interacts with light to influence the growth rate and productivity of algae [35]. Different algae have different pH optima, for example, green algae such as Chlamydomonas sp. prefer acidic circumstances, whereas blue-green algae and desmids prefer alkaline environments [35]. The availability of nutrients, as well as metabolic and other physiological processes, are affected by pH.

3.7. Water Quality Index

River water quality indexes were derived using a variety of physicochemical data from both seasons. Water quality assessment by means of an index is easier than comparing experimentally determined parameter values with existing guidelines. The meaningful summaries of water quality data can be easily understood for both technical and non-technical individuals [38]. According to the CCME WQI, the water quality is in the marginal category (WQI = 45 - 64), suggesting that water quality is frequently endangered or harmed, and conditions frequently deviate from natural or acceptable values. During dry season, the CCME WQI of the Atrai river was low compared to other four rivers while in monsoon the water quality index was low in Dhapa river (**Figure 3**). The average CCME WQI of the five rivers during dry and monsoon seasons were above 61 and 58, respectively. Any single representation of data (for example, in terms of an index or an average) does not, however, convey the entire picture.



Dry season Monsoon season Overall WQI

Figure 3. Water quality index of the study rivers during dry and monsoon seasons Example.

3.8. Multivariate Statistical Analysis

Based on similarity, hierarchical cluster analysis classifies ungrouped data into homogeneous sets depicted as dendrogram. HCA was used to create two statistically significant clusters from a standardized dataset. During dry season Cluster-I has 8 sampling sites and the water analysis results indicated that most of the samples had high concentrations of EC, TDS, Cl^-, HCO_3^-, Ca^{2+} and Mg^{2+} compared to other sampling sites (**Figure 4**). The high levels of these characteristics could be attributed to industrial, irrigational, agricultural, or population density activities. During monsoon season, Cluster I was associated with highest average concentrations of EC, TDS, HCO_3^-, Ca^{2+} and Mg^{2+} compared to Cluster II (sites 1, 12, 17, 19 and 20). This study successfully established HCA as a potent exploratory data analysis model which can be employed extensively for spatial classification and categorization of water resources. Because freshwater resources must be monitored and assessed on a regular basis, cluster analysis effectively lowers the number of sampling sites by identifying a few representative samples that may be used to predict water quality across a large area.

The correlation matrix of 11 parameters, for the 20 samples in the study area is shown in (**Table 4**). In both seasons, the measured parameters showed few meaningful connections. There were no significant associations for majority of the factors, though. The significant correlation between EC and TDS (r = 0.67) during the monsoon indicates their interdependency as generic indicators of total dissolved solutes. However, the correlation between temperature and DO was negative suggesting that the increase of temperature decreases DO during the monsoon.

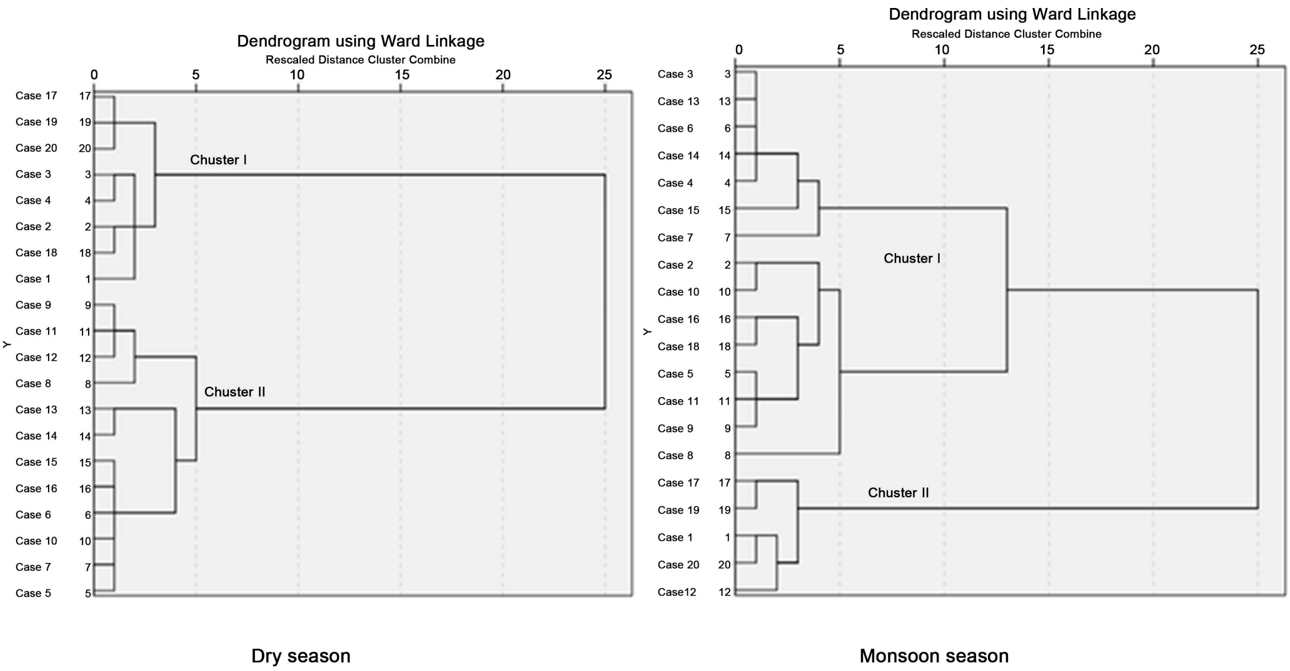


Figure 4. Dendrograms of the study rivers during dry and monsoon seasons.

Table 4. Correlation matrix of different water parameters during dry season and monsoon season.

DRY SEASON	Temp.	EC	TDS	DO	COD	Alkal.	Hard.	NH_3	NO_3^-	PO_4^{3-}	Chla
Temp.	1.00										
EC	0.12	1.00									
TDS	0.08	0.25	1.00								
DO	0.18	0.08	−0.43	1.00							
COD	0.29	0.34	0.32	0.04	1.00						
Alkal	0.23	0.02	0.76	−0.52	0.34	1.00					
Hard	0.21	−0.11	0.62	−0.39	0.37	0.81	1.00				
NH_3	−0.03	−0.35	0.24	−0.46	−0.12	0.47	0.27	1.00			
NO_3^-	−0.13	0.20	0.14	0.03	−0.13	0.14	−0.17	0.20	1.00		
PO_4^{3-}	−0.38	−0.40	−0.13	0.06	−0.18	−0.24	−0.21	0.03	−0.10	1.00	
Chla	−0.38	−0.19	−0.17	0.13	−0.32	−0.25	−0.12	0.05	0.39	0.09	1.00
MONSOON SEASON	TEMP	EC	TDS	DO	COD	Alkal	Hard	NH_3	NO_3^-	PO_4^{3-}	Chla
Temp.	1.00										
EC	−0.14	1.00									
TDS	0.03	0.67	1.00								
DO	−0.32	0.07	0.12	1.00							
COD	0.20	0.01	−0.37	−0.39	1.00						
Alkal.	0.18	−0.27	−0.15	0.10	0.12	1.00					
Hard.	0.19	0.37	0.03	0.21	0.15	0.22	1.00				

Continued

NH_3	0.31	0.02	0.34	−0.47	−0.02	−0.21	−0.34	1.00			
NO_3^-	0.16	−0.12	−0.04	−0.14	−0.25	0.11	−0.25	−0.09	1.00		
PO_4^{3-}	−0.04	−0.10	0.30	0.09	−0.27	−0.23	−0.23	0.06	−0.31	1.00	
Chla	−0.04	−0.26	−0.47	0.11	−0.21	0.02	−0.02	−0.28	0.44	−0.42	1.00

4. Conclusion

The interaction between temperature, nutrients, and oxygen plays a critical role in many common problems, such as excessive algal growth, oxygen depletion, and fish kills. Fish growth, survival, and the toxicity of other substances such as ammonia and metals can all be affected by pH, alkalinity, and hardness. All rivers' water was acceptable for fish production, based on temperature, pH, DO, COD, alkalinity, and hardness. Magnesium and calcium are abundant among the cations, while bicarbonate and chloride are abundant among the anions in the research area's water. All the river waters in the district of Dinajpur, Bangladesh, were found to be suitable for fish production based on the evaluated parameters. These findings add to our understanding of river water quality in the studied area. A continued monitoring of physicochemical properties of river water is needed for fish production.

Acknowledgements

This work was supported by a fund (ES 334) of the Ministry of Science and Technology (MOST) under special allocation for science and technology, Government of the People's Republic of Bangladesh. The authors gratefully acknowledge the Chairman of the department of Agricultural Chemistry of the Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh for conducting and supporting this research in the laboratory of Agricultural Chemistry.

Conflicts of Interest

The authors declare no conflicts of interest.

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