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RESEARCH ARTICLE

Hydrochemical appraisal of surface water from a subtropical urban river in southwestern Bangladesh using indices, GIS, and multivariate statistical analysis

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Abstract

The Gorai River is a significant river in Bangladesh's southwestern region, where residents make great use of the water despite a lack of adequate and reliable information concerning water quality and pollution levels. Thus, the goal of this research was to examine the spatio-temporal variations in water quality and determine whether it was suitable for drinking, agriculture, industrial, or livestock purposes, as well as the influencing factors and potential sources of water pollution. Surface water samples were collected in wet and dry seasons from ten sampling sites, and twenty water quality parameters were evaluated. The results showed that some studied water quality parameters, e.g., temperature, electrical conductivity, alkalinity, and nitrate, exceeded the maximum allowable limit. Water quality index values exhibited that the water quality of all sampling sites was found to be poor to very poor during the wet season, while only St-4 and St-5 were found to be poor and the rest of the investigated sites were good category during the dry season. Based on sodium adsorption ratio, soluble sodium percentage, residual sodium carbonate, residual sodium bicarbonate, and permeability index values, it was depicted that river water was suitable for irrigation purposes, but when compared to Kelly's ratio (KR) and magnesium hazard ratio values, river water was found to be unfit for irrigation. Moreover, potential salinity (PS) and sodium-to-calcium activity ratio (SCAR) values allow the water as moderately suitable for use in irrigation purposes. Langelier saturation index (LSI) and aggressive index (AI) values revealed that the river water was under saturated to supersaturated and moderate to non-aggressive in nature. However, Ryznar stability index (RSI), Puckorius scaling index (PSI), and Larson–Skold index (LS) values describe whether the water was high or severely corrosive, signifying its inappropriateness for industrial consumption. Principal component analysis (PCA) analysis depicted that the fluctuations in water quality are mostly related to point and non-point contaminations, such as urban and industrial effluent discharged and agricultural runoff of fertilizers. Cluster analysis (CA) revealed relative geographical and seasonal changes in water quality, showing the impact of hydrological changes and contamination.

Keywords Fresh water · Gorai River · Drinking suitability · Irrigation feasibility · Livestock permissibility

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Introduction

Water is a valuable natural resource that is at the heart of the ecological system (Proshad et al. 2020, 2021; Hoque et al. 2021). Over a billion people throughout the world do not have access to clean, safe drinking water (Patton et al. 2020; Pal et al. 2022). Every year, approximately 6–8 million people die as a result of water-related diseases and disasters, making water supply a major concern for the world (Rahmanian et al. 2015; Ali et al. 2021). Among the inland water resources, surface water is the most important resource for residential uses, agriculture, recreational, and industrial uses (Razmkhah et al. 2010; Kumar et al. 2022). The final destination of any used water (wastewater) is the aquatic environment of rivers, ponds, or other inland bodies of water (Muhammad and Ullah 2022; Muhammad et al. 2021; Khan et al. 2021; Kabir et al. 2020). Among the aforementioned bodies of water, rivers are the primary providers of water for human use, agriculture, and industrial purposes. In many countries, especially emerging countries like Bangladesh, surface water pollution from anthropogenic impacts and atmospheric deposition of contaminants has become a very delicate and essential issue (Kumar and Singh 2018). The activities like anthropogenic impacts, geochemical variables, floodplain chemical composition, and interaction of natural water with the lithogenic origin (Subramani et al. 2009; Yüksel et al. 2021; Ustaoğlu et al. 2022) all degrade surface water quality and pose substantial hazards to the ecology and human health (Sánchez et al. 2007; Matin and Kamal 2010; Proshad et al. 2020). Organic, inorganic, and biological contaminants, such as extremely toxic heavy metals (Muhammad and Usman 2022; Moore and Ramamoorthy 2012) or non-toxic, biodegradable items like feces, garbage, and wastewater, can all have an impact on surface water quality (Islam et al. 2014, 2015; Bain et al. 2014). Natural systems and human induced such as the discharge of industrial sewage, domestic wastewater, and agricultural runoff water into the river impair its quality (Rehnuma et al. 2016; Islam et al. 2017; Begum et al. 2019; Barakat et al. 2016). Thus, a preliminary analysis of these environmental assets is a critical component of long-term conservation (Yan et al. 2016). Furthermore, regular surface water quality monitoring is critical for environmental health and the achievement of sustainable development goals (SDGs) such as "Goal 6: Clean water and sanitation" and "Goal 14: Life below water" (Bhaduri et al. 2016; Ezbakhe 2018).

The water quality index (WQI) is a measure that policymakers, executives, and governments use to analyze the current state of water quality. The WQI incorporates measurable paradigms and conveys results as a mathematical rating of water quality from excellent to poor class (Paca et al. 2019). During water quality determination, all the physical, chemical, and biological properties of water are considered (Ombaka and Gichumbi 2012). Because of the high vulnerability of surface water resources to contaminants like toxic elements, evaluation of freshwater quality is very important, especially for developing countries like Bangladesh (Ongley 2000; Yan et al. 2015; Islam et al. 2021a, b). Due to the single value and simplicity to grasp, a great number of countries presently adopt the WQI technique to assess the overall status of a river (Bhargava 1983). Changes in water quality can have a number of consequences on irrigation, which ultimately diminished the fertility and productivity of agricultural soil. Excess salts can destroy field soil by affecting its structure, permeability, aeration, and texture (Bhardwaj and Singh 2011). Excess soluble salts arising from inappropriate irrigation practices with contaminated surface water and soil management can also cause the formation of an alkaline character in soil (Haritash et al. 2016). As a result, evaluating water quality for irrigation is critical, especially in arid and semiarid locations where salt and sod formation are common for agricultural soil (Meireles et al. 2007). Corrosion and scale potentials are taken into account during water management for the purpose of irrigation and distribution of water to the fields because of undesirable changes in water quality and economic, hydrological, and aesthetic losses (Alipour et al. 2015). Excessive fouling can reduce efficiency and induce tubal obstruction of equipment used in industries, resulting in higher total costs for industrial operation (Bhardwaj and Singh 2011; Shah et al. 2019). Therefore, assessing water quality is critical to understanding the state of quality representing properties of water for industrial usage. As a whole, consideration of irrigation, drinking, and industrial uses, water quality is a critical concern for water resource management and future planning for judicious utilization of surface water (Yehia and Sabae 2011).

The Gorai is an important river in the southwestern region of Bangladesh. The Gorai River is a right-bank distributive branch of the Ganges River, providing an interface between freshwater and brackish water in the estuary linking the Bay of Bengal and an important source of highland freshwater supplies in the southwest part of Bangladesh (Nahar et al. 2016; Shamsad et al. 2014). Presently, the outflow of the study river discharges the receiving waste into the Bay of Bengal via the Madhumati and Baleswar rivers, and the economy of the entire region fully depends on this river (Bari et al. 2012; Islam and Gnauck 2011). The Ganges water flow has decreased dramatically downstream since the construction of the Farakka Barrage (17 km from the Bangladesh border) on the Ganges River in India (Islam and Gnauck 2011). As a result, upstream of the Gorai River, sea saline water is infiltrating and increasing salinity in the Gorai River basin (IECO 1980). The Ganges' dry-season flow has dropped, hastening the natural decline of the Gorai River, which becomes completely cutoff from the Ganges during the dry season, since 1988 (BWDB 2001). However, over the last two decades, the large removal of Ganges outflow during the dry season has had a significant impact not only on water quality in Padma/Ganges dependent areas, but also on agriculture, fishery, forestry, industry, and navigation (Rahman et al. 2000). On the other hand, the dumping of household, commercial, municipal, and industrial trash and waste water into the open environment has been going on for quite some time. As a result, a field investigation of the Gorai River's water quality was done during both the dry and wet seasons. So far, no scientific research has been undertaken on the water of the study river based on WQI, irrigation, industrial, or livestock implications. Thus, the current study is the first comprehensive work that evaluates the seasonal and spatial variations of the physicochemical properties of the river water, the factors and sources influencing spatio-temporal differences in river water quality by dint of multivariate statistical tactics, and the suitability of the river water for drinking, irrigation, industrial, and livestock purposes of the most important river in Bangladesh. The findings of the study will offer policymakers useful information for accomplishing the UN Agenda-2030 and Sustainable Development Goals (SDGs-2030) in this ecosystem by reducing pollution and restoring riverine ecology.

Materials and method

Geo-morphological description of the study area

The Gorai River is found in Bangladesh's Khulna division, in the southwestern portion of the country (Fig. 1). The Gorai River originates on the Ganga River's right bank near Talbaria in the Kushtia district, 19 km downstream from Hardinge Bridge. Before joining the Jamuna River near Aricha, this river is the Ganga River's only major distributary (Nahar et al. 2016). From the Kamarkhali River in the Faridpur district, the study river is known as the Modhumati River. The Chandana Barasia River meets the Madhumati River in Bhatiapara in the Gopalganj district. The majority of the Madhumati' flow now passes through Bardia's Nabaganga River, which joins the Rupsa River via the Atai River. The Ganges River runs for around 260 km from the Ganges to Chitalmari in Bagerhat district (Haque 2008). This system is critical for the growth of the southwest region as well as the survival of the Sundarbans' ecology (the primary source of fresh water). The Gorai-Madhumati is one of Bangladesh's longest rivers, with a basin that is both vast and extensive. It runs through five districts, and it is heavily reliant on this river system for irrigation and industrial usage in these areas. On the banks of the Gorai River, the significant places include Kushtia, Kumarkhali, Janipur, Sheuria, Ganeshpur, and Pangsha (Shamsad et al. 2014). The Gorai-Madhumati has a large, long, and meandering course, and its downstream is navigable all year. The river's

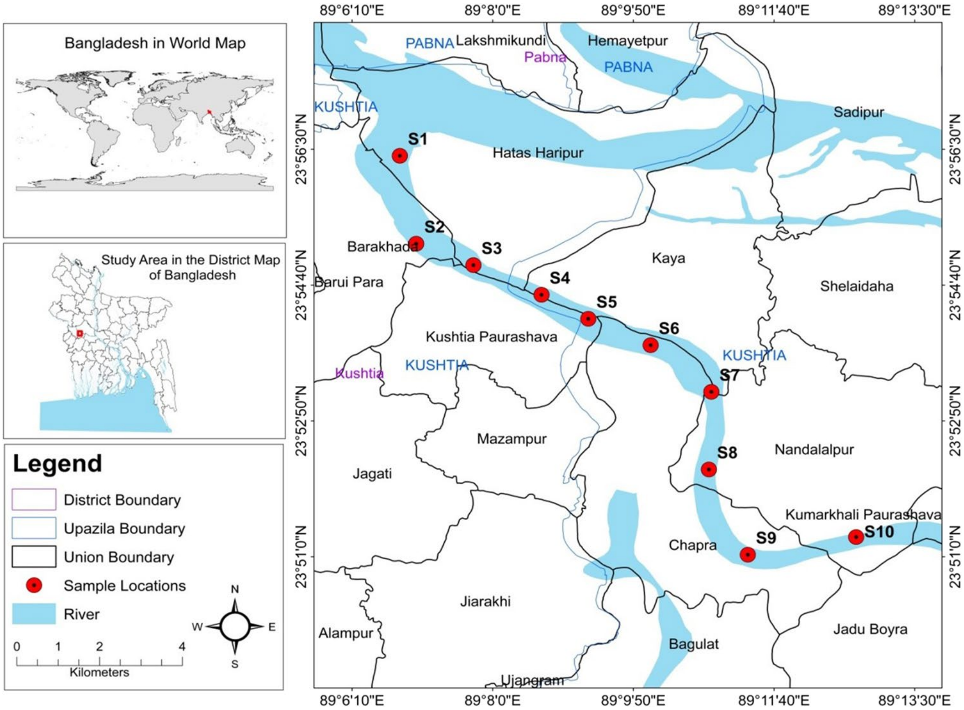

Fig. 1 Map showing the sampling sites of Gorai River, Bangladesh

width widens as it goes down, reaching around 3 km at the end (Haque 2008). The rainfall pattern of the study area fluctuates seasonally, with substantial peaks occurring from June to September and dry spells occurring from November to February. The average annual rainfall is 1467 mm. The wet season in Kushtia is hot, humid, and gloomy, whereas the dry season is mild and usually clear. The average high temperature is 37.8 °C and the average low is 9.2 °C (Islam et al. 2014). Water samples were obtained from ten sampling sites in the Kushtia district of Bangladesh (23° 56′ 24.69″ N to 89° 6′ 47.37″ E; 23° 51′ 15.99″ N to 89° 12′ 44.20″ E). Sampling sites are subjected to urban runoff, as well as garbage and waste water from neighboring agricultural areas and regional human settlements. In the majority of the sampling sites, there are several sand excavation rigs with varying extents of human interaction. The study sites receive a substantial amount of contaminants and lithologies because it is a transboundary river distributary.

Collection and analysis of water sample

Water samples were collected at random from prior selected 10 sampling sites (Fig. 1) along a 25-km section of the Gorai River, following upstream to downstream flow in the wet (July 2020) and dry (November 2020) seasons. To acquire good homogenized samples from every sampling point, composite samples were obtained manually from a depth of 30 cm below the water's surface, especially where the flow of water was high (Souza et al. 2020; Asare-Donkor et al. 2018). Each water sample was created by mixing water collected at each sampling site (3 times) and creating 10 pairs of composite water samples. Prior to sampling, 500 ml polyethylene bottles were cleansed with detergents, then thoroughly washed with distilled water and immersed in a 10% (v/v) HNO_3 solution overnight. After collection, the samples were transported to a laboratory with a favorable temperature (4 °C) for subsequent chemical analysis.

Temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), and total dissolved solids (TDS) were measured on-site using a digital thermometer, pH, and DO meter (Hannah, Woonsocket, RI, USA), respectively, while the EC and TDS were analyzed using digital EC and TDS meters (HM digital, Redondo Beach, CA, USA), respectively. All the digital meters used were standardized with deionized water and buffer solution in advance of sample analysis. The titration technique was used to determine total alkalinity, acidity, and total hardness (Asare-Donkor et al. 2018). For cations analysis, samples were filtered through 0.45 µm filters and then 10 drops of ultra-pure HNO_3 were added to one set of samples (Saha et al. 2019). Ca and Mg were determined by an atomic absorption spectrophotometer (Shimadzu AA 7000) at 422.7 and 285.2 nm wavelengths, respectively (Saha et al. 2019). The flame photometric method was used to analyze Na and K ion concentrations at a wavelength of 589 and 766.5 nm, respectively (Saha et al. 2019; Asare-Donkor et al. 2018). The water samples were prepared for an anion test followed by the procedure of APHA (2012) before chromatographic (Shimadzu Ion Chromatograph, HIC-10-A, Japan) analysis. After instrumental measurements, the values of anions including fluoride (F^-), chloride (Cl^-), bromide (Br^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}) carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) were calculated using computer-aided tools (Shah et al. 2019; Gupta et al. 2016).

Quality assurance/quality control

For greater accuracy and precision, analytical-grade (Merck, India) chemicals and reagents were used. We followed the standard method of APHA (2012) for water quality analysis. Prior to sample analysis, all on-site testing equipment was standardized with deionized water and buffer solution for analytical perfection. Procedural blanks with repeating experiments were carried out through the analytical processes to achieve quality assurance and quality control (Amankwaa et al. 2020). Every stage of the laboratory analysis process was meticulously documented. These records were preserved for data management and to identify missing steps and values, as well as to serve as recall points for repeat analyses (Kabir et al. 2021).

Calculation of water quality index

The WQI is a useful tool for assessing the surface water quality and its acceptability for drinking (Amiri et al. 2016; Islam et al. 2022). Pre-evaluation of water quality is helpful for decision makers to take a decision on policy implications and future management of water. WQI is a rating that reflects the total or composite impact of various water quality metrics on overall water quality (Sahu and Sikdar 2008; Batabyal and Chakraborty 2016). As a new technique, WQI is used for evaluating the overall river health, rather than as an absolute assessment of contamination or actual water quality (Guettaf et al. 2014). WQI approaches combine various environmental parameters and successfully turn them into a single number reflecting the status of water quality, as opposed to traditional water quality evaluation. As a result, rather than comparing the numerous assessment results of multiple metrics, the WQI method is an effective approach to water quality evaluation and management that gives integrated information about the overall quality (Wu et al. 2018).

Temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), alkalinity, total hardness (TH), dissolved solids (TDS), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), fluoride (F^-), chloride (Cl^-), nitrate ($NO_3{}^-$), phosphate ($PO_4{}^{3-}$), sulfate ($SO_4{}^{3-}$), and bicarbonate

(HCO_3^-) were considered for calculating the WQI in the Gorai River. The calculation of the WQI index followed 3 steps (Sahu and Sikdar 2008):

In the first step, each of the above-mentioned 17 characteristics was given a weight (wi) based on its relative value in determining the overall quality of drinking water (Table 1). The metrics TDS and NO_3^- TDS have been given a maximum weight of 5 because of their importance in water quality assessment. Temperature and PO_4^{3-} are given a weight of 1 since they play such a minor role in determining water quality. Other parameters are given a weight of 2 to 4 based on their importance in determining water quality.

In the second step, the relative weight (Wi) of each parameter is calculated using Eq. 1, and the results are presented in Table 1.

$$\mathrm{Wi} = \frac{\mathrm{wi}}{\sum_{n=1}^{n} \mathrm{wi}} \tag{1}$$

where, Wi is the relative weight, wi is the weight of each parameter, and n is the number of parameters. Calculated Wi values of each parameter are also given in Table 1.

In the third step, a quality rating scale (qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the WHO standards, and the result is multiplied by 100 (Eq. 2):

Table 1 Relative weight of the physicochemical parameters used in this study

Sl. No	Parameters	WHO (2011) (Si)	Weight (wi)	Relative weight (Wi)
1	Temperature	25	1	0.02
2	pH	6.5	4	0.08
3	EC	250	3	0.06
4	DO	6	4	0.08
5	Alkalinity	200	2	0.04
6	TH	300	3	0.06
7	TDS	500	5	0.10
8	Na	200	3	0.06
9	K	12	2	0.04
10	Ca	75	2	0.04
11	Mg	50	2	0.04
12	F^-	1.5	4	0.08
13	Cl^-	250	3	0.06
14	NO_3^-	50	5	0.10
15	PO_4^{3-}	0.5	1	0.02
16	SO_4^{2-}	250	4	0.08
17	HCO_3^-	120	2	0.04
			$\sum \mathrm{wi} = 50$	1

$$\mathrm{qi} = \left(\frac{\mathrm{Ci}}{\mathrm{Si}}\right) \times 100 \tag{2}$$

where, qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in milligrams per liter, and Si is the WHO drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of WHO.

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$\mathrm{SI} = \mathrm{Wi} \times \mathrm{qi} \tag{3}$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SI} \tag{4}$$

where, SIi is the subindex of the ith parameter, qi is the rating based on the concentration of the ith parameter, and n is the number of parameters. Water types, determined based on the values of WQI, are given in Table S6. The computed WQI values were classified according to the proposed categorization of Brown et al. (1972) (Table S1).

Calculation of water quality for irrigation purposes

The appropriateness of irrigation water is primarily determined by the presence of unwanted dissolved salts or components, with plant nutrients being considered in some circumstances (FAO 2008; Haritash et al. 2016). Sodium adsorption ratio (SAR), soluble sodium percentage (SSP), Kelly's ratio (KR), magnesium hazard ratio (MHR), sodium-to-calcium activity ratio (SCAR), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), permeability index (PI), and potential salinity (PS) were used to assess the suitability of surface water for irrigation purposes, as shown in Table S2.

Evaluation of water quality for industrial purposes

Water is used extensively in industries as well as manufacturing processes that require high water quality. This varies among different industries depending on the type of industry. Some industries require water quality capable of preventing pipe corrosion and scale formation, while others require drinking water standards for their operations (Singh et al. 2008). However, water of poor quality entering the drinking water distribution network often results in corrosion and scaling. Consequently, it causes a variety of challenges, including pipe clogging, decreased equipment longevity, and health and economic issues caused by dissolved substances in the water (Mirzabeygi et al. 2016). Thus, corrosion and scale formation are the most serious issues in heavy industries. As a consequence, the Langelier saturation index (LSI), Ryznar stability index (RSI), Puckorius scaling index (PSI), Larson–Skold index (LS), and aggressiveness index (AI) were used to establish the appropriateness of water for industrial use. Table S2 summarizes the equation and categorization criteria.

Statistical interpretations

The SPSS software version 20 was used to produce descriptive statistics for all observed physicochemical parameters, as well as Pearson correlation analysis (PCA) and cluster analysis (CA) to discover existing relationships and their regulating effects on water quality. The *T*-test was done to understand the seasonal variations in water quality parameters. The *T*-test helps to decide which effects are statistically significant and to measure their contribution to the difference in the response. The cluster analysis technique was performed to classify the sampling sites into simplified groups (clusters) (Amankwaa et al. 2020; Kabir et al. 2021). The principal component analysis was carried out to explore the plausible sources and influencing factors on the variation of pollution (Gupta et al. 2016; Asare-Donkor et al. 2018). The spatio-seasonal mapping for different water quality parameters was done by using ArcGIS 10.4 software.

Results and discussion

Physicochemical characteristics of river water

The descriptive statistics of the analytical data for both the wet and dry seasons in the Gorai River are presented in Table 2, while the spatial distributions are portrayed in Fig. 2. The mean water temperature (°C) ranged from 31.80 to 32.80 during the wet season and 21.20 to 22.00 during the dry season. The highest average temperature (°C) was found at 32.80 and the lowest at 21.20 during the wet season and dry season, respectively. Similar studies were conducted on the Rupsa River and Shitalakhya River during the wet and dry seasons (Irin et al. 2017; Islam et al. 2018). It was noted that the temperature exceeded the maximum allowable limit by Bangladesh Environmental Conservation Rules (ECR 1997) at certain sampling sites and seasons.

The pH of water is a crucial water quality measure since it impacts both aquatic life and people (Vaishali and Punita 2013). The mean value of pH ranged from 7.40 to 8.20 and 6.70 to 7.70 in the wet and dry seasons, respectively (Table 3). The highest average pH was found at 8.20 and the lowest at 6.70 during the wet season and dry season, respectively (Fig. 2). The tiny improvement in pH at some sampling locations could be linked to industrial and domestic

Table 2 Descriptive statistics of the analytical data for both the wet and dry seasons in the Gorai River

Parameter	Wet season					Dry season				
	Unit	Minimum	Maximum	Average	SD (±)	Unit	Minimum	Maximum	Average	SD (±)
Temperature	(°C)	31.80	32.80	32.32	0.39	(°C)	21.20	22.00	21.64	0.29
pH	–	7.40	8.20	7.75	0.24	–	6.70	7.70	7.22	0.34
EC	(µS/cm)	240	320	279	25.98	(µS/cm)	220	295	251	24.61
DO	mg/l	7.10	8.20	7.67	0.39	mg/l	6.60	7.70	7.16	0.40
Acidity	mg/l	2.23	3.19	2.67	0.32	mg/l	2.83	4.43	3.33	0.50
Alkalinity	mg/l	145	215	173	23.21	mg/l	124	184	149	17.36
TH	mg/l	130	180	157	17.61	mg/l	112	172	142	22.39
TDS	mg/l	142	195	164	18.18	mg/l	132	162	148	10.36
Na	mg/l	37.50	65.50	49.00	10.74	mg/l	22.50	35.20	28.28	4.47
K	mg/l	3.95	4.98	4.34	0.40	mg/l	2.39	3.89	3.11	0.52
Ca	mg/l	3.22	8.25	5.29	1.54	mg/l	2.23	3.98	3.12	0.61
Mg	mg/l	1.86	3.78	2.63	0.74	mg/l	1.56	3.58	2.42	0.78
F^-	mg/l	0.36	0.67	0.52	0.10	mg/l	0.18	0.37	0.31	0.06
Cl^-	mg/l	172	243	203	20.89	mg/l	118.0	157.0	134.30	11.94
Br^-	mg/l	0.12	0.80	0.23	0.20	mg/l	0.06	0.16	0.11	0.03
NO_3^-	mg/l	28.23	86.26	50.29	18.79	mg/l	15.23	29.17	19.41	5.22
PO_4^{3-}	mg/l	0.38	2.25	1.06	0.66	mg/l	0.15	0.46	0.26	0.10
SO_4^{2-}	mg/l	8.45	22.34	12.73	4.68	mg/l	6.60	9.70	7.88	1.03
HCO_3^-	mg/l	48.23	176	82.65	47.52	mg/l	19.43	46.89	29.75	9.68
CO_3^{2-}	mg/l	0.40	0.90	0.61	0.17	mg/l	0.05	0.28	0.14	0.07

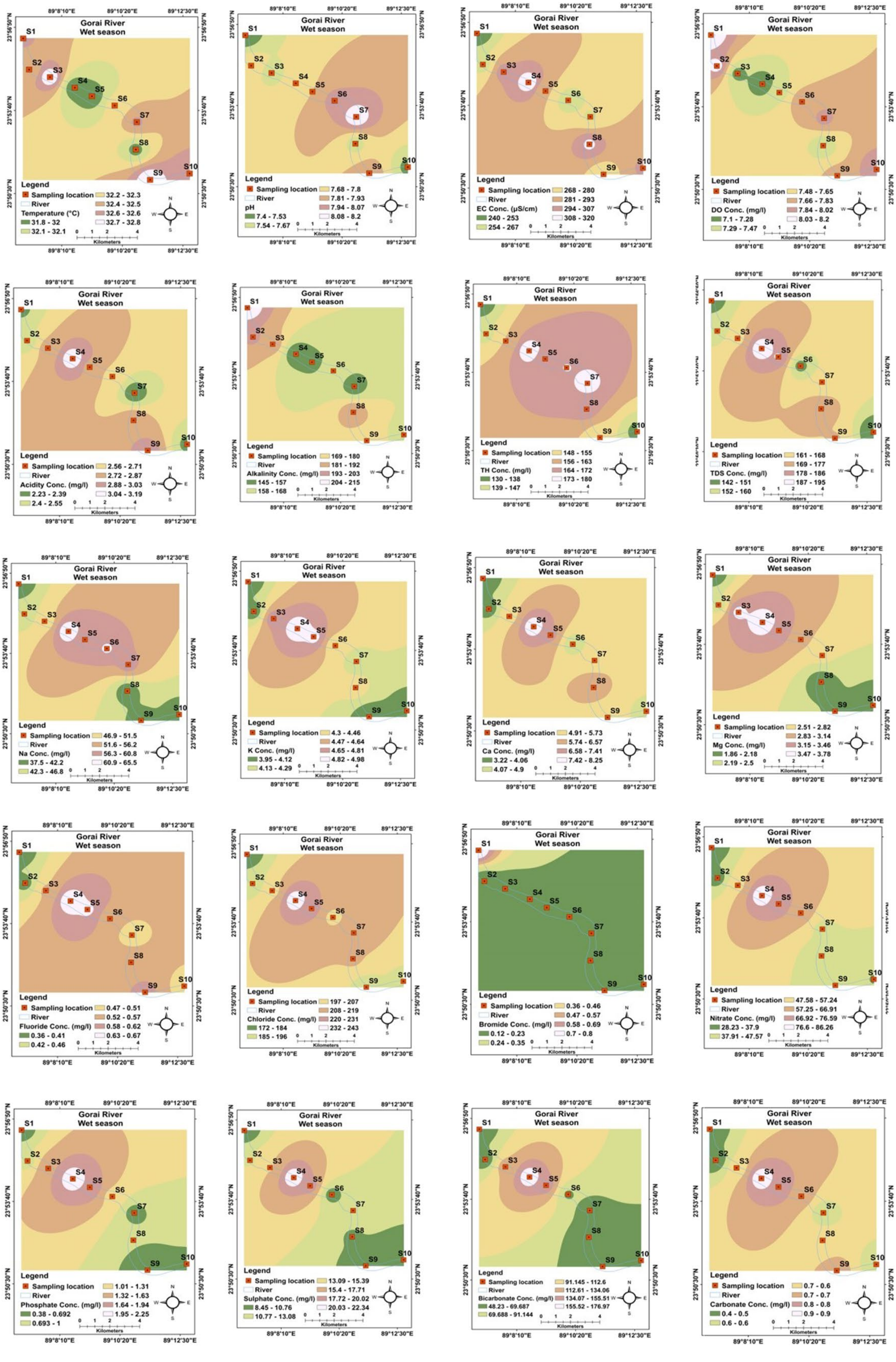

Fig. 2 Spatial distribution of water quality parameters of Gorai River, Bangladesh

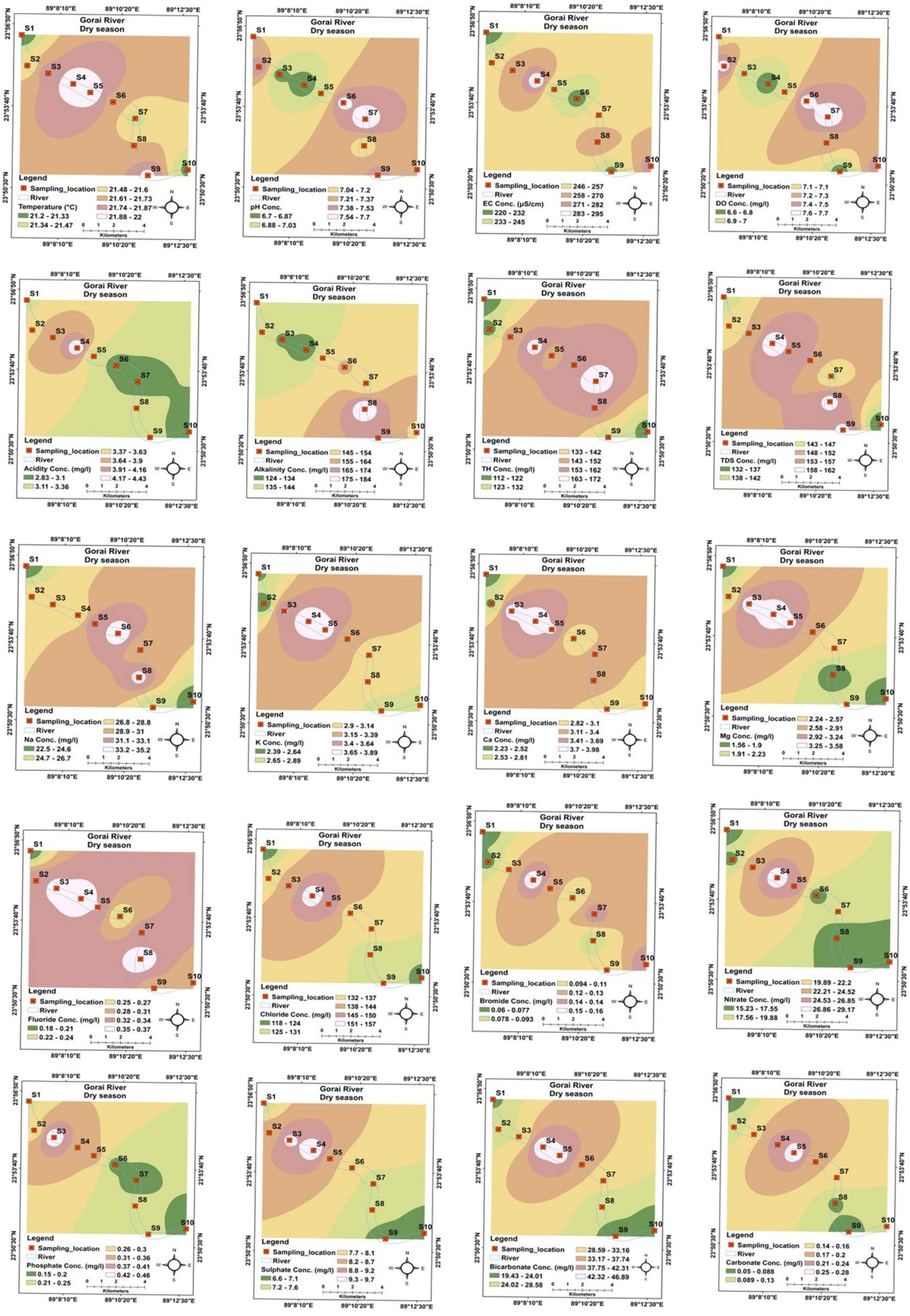

Fig. 2 (continued)

Table 3 *T*-test values showing the seasonal variation of water quality parameters of the Gorai River

Parameters	Mean	Std. deviation	*df*	*t*	Sig
Temperature	10.68	0.56	9	60.16	0.000
pH	0.53	0.28	9	5.92	0.000
EC	28.0	11.83	9	7.48	0.000
DO	0.51	0.33	9	4.91	0.001
Acidity	−0.66	0.38	9	−5.39	0.000
Alkalinity	24.60	25.37	9	3.06	0.013
TH	14.80	6.41	9	7.30	0.000
TDS	15.60	11.34	9	4.34	0.002
Na	20.72	9.56	9	6.85	0.000
K	1.22	0.16	9	24.06	0.000
Ca	2.17	1.01	9	6.77	0.000
Mg	0.21	0.071	9	9.50	0.000
F^-	0.22	0.08	9	8.47	0.000
Cl^-	69.50	12.44	9	17.65	0.000
Br^-	0.12	0.21	9	1.80	0.105
NO_3^-	30.87	14.56	9	6.70	0.000
PO_4^{3-}	0.81	0.59	9	4.26	0.002
SO_4^{2-}	4.85	3.80	9	4.03	0.003
HCO_3^-	52.90	39.52	9	4.23	0.002
CO_3^{2-}	0.47	0.13	9	11.76	0.000

wastewater inputs. According to Khan et al. (2016), the water pH of Ramganga River and its tributaries ranged from 6.5 to 8.0 and 7.5 to 8.0, respectively, demonstrating that the water was moderately alkaline. Furthermore, Irin et al. (2017) discovered a pH of 7.7 in the Shitalakhya River of Narayanganj, and this is frequently similar to the current work.

Electrical conductivity (EC) is a term that covers the concentration of cations in water, which can naturally contain weathering of sedimentary rocks or anthropogenic sources such as industrial and sewage waste (WHO 2004). In the wet and dry seasons, the mean EC values for Gorai River water were 240.00–320.00 and 220.00–295.00 µS/cm, respectively (Table 2). Bakali et al. (2014) found that the Turag River's surface water EC values ranged from 73 to 160 µS/cm; however, Khan et al. (2007) discovered that the EC values at Ashulia point on the Turag River ranged from 250 to 608 µS/cm throughout the season. However, all test locations exhibited the largest level of EC concentrations, which is due to the influence of ionic contaminants from industrial releases and agricultural runoff (Khan et al. 2016). Furthermore, the study's findings revealed that the increased level of EC concentration in river water surpassed the permitted amount for drinking water suggested by the ECR (1997) and WHO (2011).

The most important water quality parameter is dissolved oxygen (DO), which simulates the physical and biological processes that occur in water (Trivedy and Goel 1986). During the pre-monsoon, monsoon, and post-monsoon seasons, average DO concentrations ranged from 7.10 to 8.20 and 6.60 to 7.70 mg/l, respectively (Table 2). The highest DO level was 8.20 mg/l at S-1 during the wet season, while the lowest was 6.60 mg/l at S-4 during the dry season. DO content drops in the research area during the dry season (Fig. 2), which could be owing to greater temperatures and a faster rate of decomposition of organic matter since industrial activities play a large role in lowering DO levels. Islam et al. (2012) stated that the DO of the Dhaleshwari River ranged from 5.7 to 9.8 mg/l, whereas Damanik-Ambarita et al. (2016) found the surface water DO at 7.5 mg/l in the Guayas River. However, the present study revealed that the acquired result of DO was within the safe limit as defined by ECR (1997) and WHO (2011).

The mean acidity concentrations in this study were 2.23–3.19 in the wet season and 2.83–4.43 mg/l, respectively (Table 2). The highest acidity levels were seen in all of the study locations during the dry season, which could be related to the CO_2 levels, photosynthesis, respiration, and decomposition all contributing to pH fluctuations.

The total alkalinity (TA) of an aqueous solution is a measure of its ability to neutralize an acid. The presence of many carbonates, bicarbonates, and hydroxide ions in water results in the presence of TA (Bora and Goswami 2017). The mean TA was found to be 145–215 mg/l during the wet season and 124–184 mg/l during the dry season, whereas S-1 had the highest mean TA concentration (215 mg/l) (Fig. 2). Bora and Goswami (2017) studied the water quality of the Kolong River and discovered that alkalinity concentrations ranged from 154.14 to 210.7 mg/l, which is almost similar to the current study. According to Islam et al. (2018), the alkalinity concentration in Bangladesh's Rupsha River water was 90.45 mg/l. The study's findings found that the discovered alkalinity levels were greater than the ECR's (1997) recommended level for drinking water.

The presence of cations (calcium and magnesium) and anions in water can be used to determine total hardness (TH). For the wet and dry seasons, the investigated mean TH contents of the Gorai River water varied from 130 to 180 and 112 to 172 mg/l, respectively (Table 2), and the TH contents were below the appropriate limit indicated by the ECR (1997) and WHO (2011). The TH contents of Dhaleshwari River water vary from 32 to 50.1 mg/l according to Islam et al. (2012). Bora and Goswami (2017) discovered that the TH content of Kolong River water varied from 88 to 288, and 72 to 296 mg/l throughout the time period, which is largely relevant to the current study.

Total dissolved solids (TDS) refer to the total amount of dissolved solids in water, such as sodium, calcium, magnesium, bicarbonate, and chloride (Parveen et al. 2017). The average TDS content was determined from 148.70 to 164.30 mg/l during the wet and dry seasons, respectively

(Table 2), which was within the WHO (2011) recommended limit of 500 mg/l. During the wet season, all sampling locations exhibited high TDS values due to the low water level in the river, which increases the concentration of TDS in the river (Table 2). The dissolving of salts from agricultural surplus and industrial discharge due to anthropogenic activity might be the reason for elevated levels of TDS in the post-monsoon (Jindal and Sharma 2011).

Major cations and anions of river water

Sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) were the most abundant alkali metals in the Gorai River water studied, as shown in Table 2 and Fig. 2. The sodium concentration in the Gorai River ranges from 37.50 to 65.50 and 35.20 to 22.50 mg/l during the wet and dry seasons, respectively. Also, the average potassium (K) concentration in the Gorai River water ranged from 3.95 to 4.98 in the wet season and 2.39 to 3.89 mg/l with the highest K concentration found at S-4. In addition, the maximum concentration of Ca is 8.25 mg/l, the minimum calcium content is 2.23 mg/l, and the average value for the concentration of Ca is 4.21 mg/l. Furthermore, the average concentration of magnesium (Mg) in the study is 3.78 mg/l, whereas the maximum content of Mg is 23.4 mg/l at S-4. The sources of Na, K, Ca, and Mg may be attributed to fertilizer use, breakdown of animal or waste products, weathering and decomposition of minerals, and agricultural by-products (Khan et al. 2014; Mostafa et al. 2017; Hem 1989; Sultana 2009; Pandey et al. 2019). The Dor River and its tributaries in Northern Pakistan have greater Ca, Mg, Na, and K contents, with average values of 42.6, 7.6, 16.0, and 6.86 mg/l, respectively (Amin et al. 2021). Industrial effluent and agrochemicals from surrounding agricultural regions could both contribute to higher amounts of these parameters in the water (Amin et al. 2021).

In the wet season, fluoride (F^-) concentrations in the Gorai River water ranged from 0.36 to 0.67 mg/l, and in the dry season, F^- concentrations ranged from 0.18 to 0.37 mg/l (Table 2). Ravikumar et al. (2013) conducted an investigation in Mallathahalli Lake and discovered F^- concentrations of 0.32, 0.42, and 0.47 mg/l, which are similar to the current findings (Table S3). Furthermore, the F^- concentration was lower than the ECR (1997) and WHO guidelines (2011). The Hunza River and its tributaries in Gilgit–Baltistan reported average F^- contents of 0.26 mg/l, which was below the WHO (2011) drinking water limits (Muhammad and Ahmad 2020).

The wet and dry seasons' chloride (Cl^-) concentrations in the Gorai River water ranged from 172 to 243 and 118 to 157 mg/l (Table 2; Fig. 2). All seasons' recorded Cl^- concentrations were significantly below the permitted range set by the ECR (1997) and WHO (2011). According to Ahsan et al. (2018), the concentration of Cl^- in the Dhaleshwari River water varied between 98 and 148 mg/l in several sites along the river, which was likely similar to the previous exploration (Table S4).

In wet and dry seasons, the mean bromide (Br^-) levels in the Gorai River water ranged from 0.12 to 0.80 and 0.06 to 0.16 mg/l, respectively (Table 2; Fig. 2). Br^- levels were lower than the permitted threshold set by the ECR (1997). In several places along the Dhaleshwari River water, Ahmed et al. (2015) observed a Br^- concentration of 0.50 mg/l, which is mainly equivalent to the current examination (Table S4).

The mean nitrate ($NO_3{}^-$) values were found at 28.23–86.26 mg/l during the wet season and 15.23–29.17 mg/l in the dry season; whereas, S-4 had the highest mean $NO_3{}^-$ concentration (86.26 mg/l) (Table 2; Fig. 2). It is clear that S-3 had the highest level of $NO_3{}^-$ concentration found in the wet season than in the dry season. The average $NO_3{}^-$ concentration (34.85 mg/l) surpassed the ECR's permitted limit (1997). The highest $NO_3{}^-$ concentrations in some sites of the study river are mostly due to the discharge of waste from the fertilizer industry and washed nitrogen fertilizers and manures from the nearby aquaculture and agricultural farms (WHO 2004). The Hunza River and its tributaries in Gilgit–Baltistan had mean $NO_3{}^-$ values of 2.10 mg/l, which could be attributed to manmade sectors such as farming (Muhammad and Ahmad 2020).

The mean concentration of phosphate ($PO_4{}^{3-}$) was found to be 0.38–2.25 mg/l during the wet season and 0.46–0.15 mg/l during the dry season, whereas; S-4 had the highest mean $PO_4{}^{3-}$ concentration (2.25 mg/l) (Table 2; Fig. 2). The mean concentration of $PO_4{}^{3-}$ was found to be 0.66 mg/l, which is within the safe limit by the ECR (1997) and WHO guidelines (2011).

Gypsum and other readily available common minerals are natural sources of sulfate ($SO_4{}^{3-}$) in water (Shrinivasa and Venkateswaralu 2000). The $SO_4{}^{3-}$ content is likely to rise when industrial effluents and home sewage are discharged into open seas (Murhekar 2011). The average sulfate ($SO_4{}^{3-}$) content of the Gorai River in the wet season varies from 8.45 to 22.34 mg/l and in the dry season from 6.60 to 9.70 mg/l (Table 2; Fig. 2). The mean value of $SO_4{}^{3-}$ content in the water of the study area is 10.30 mg/l. The low sulfate contents show that bacterial sulfate reduction has taken place (Kirk et al. 2004). The lack of industries in the studied area is shown by the reduced sulfate level of groundwater, whereas the high sulfate content suggests anthropogenic sources and industrial processes (Mostafa et al. 2017). In the wet season, according to Alam et al. (2004), $SO_4{}^{3-}$ concentrations varied between 0.13 and 0.15, and 135 and 153 mg/l in the dry season at Demra in the Shitalakhya River. The carbonate (CO_3^{2-}) concentration of water ranged from 0.40 to 0.90 and 0.05 to 0.28 mg/l in the wet and dry seasons, respectively. The lowest average CO_3^{2-} was found at 0.05 (mg/l) at site S-1 and the highest at 0.90 (mg/l) at the S-4 site during the dry and wet seasons, respectively (Table 2; Fig. 2).

Factors influencing spatio-seasonal variations in river

Table 3 displays the results of the *T*-test value that revealed statistically significant ($p < 0.05$) seasonal fluctuations in the analyzed river water quality indicators, with the exception of TH, Mg, and Br$^-$. Based on their water quality, cluster analysis (CA) was used to organize all the sampling sites in the river into spatio-seasonal similarity groups (Barakat et al. 2016). Figure 3 shows the dendrograms of several sampling sites derived from Ward's approach throughout the wet and dry seasons. Preliminary, the CA data revealed that the sampling sites were divided into two big clusters throughout all seasons, with similar features and water contaminants originating from identical anthropogenic sources in each group. On the other hand, the clusters were generated using various sample sites at various times throughout the year. Throughout the wet and dry seasons, for example, the first cluster comprised three sample sites (St-5, St-7, and St-10), the second cluster had three sites (St-2, St-3, St-6, St-8, and St-9), and the third cluster consisted of two sites (St-1 and St-4) (Fig. 3). Cluster formation was shown to be consistent with similar land use patterns and pollution sources, while seasonal fluctuations in cluster formation can be attributed to the hydrological variability of the study area (Xu et al. 2019). The discharge of industrial, residential, and municipal waste water was referred to as the substantial sources of pollution at both St-1 and St-4 in the Gorai River grouped together throughout the seasons. Furthermore, all of the sampling locations were linked closely, and that could be owing to the consequences of heavy rain, which might also dilute the pollutants' contents and spread them widely along the river's downstream reaches.

Correlations among water quality parameters and identification of potential sources

The correlations between water quality parameters provide essential information about the likely sources and channels of parameters in the river environment (Bhuyan et al. 2019). Tables 4 and 5 show the correlation matrix of the investigated water quality metrics. The findings clearly showed that acidity-DO, K-pH, PO$_4^{3-}$-NO$_3^-$, F$^-$-DO-Ca, and alkalinity-Cl$^-$ have a substantial negative relationship. Furthermore, TDS-temperature-Cl$^-$, acidity-SO$_4^{3-}$-Mg, Mg-Cl$^-$-CO$_3^{2-}$, F$^-$-Ca, and HCO$_3^-$-CO$_3^{2-}$, showed a substantial positive relationship, while Ca-TDS, Cl$^-$-NO$_3^-$, and Mg-HCO$_3^-$-PO$_4^{3-}$ ($r = 0.918–0.953$) showed a strongly positive relation. There was also a significant positive association between TA-F$^-$, TA-Cl$^-$, TA-NO$_3^-$, and TA-SO$_4^{3-}$ and TH-Cl$^-$, TH-NO$_3^-$, and TH-SO$_4^{3-}$. Furthermore, there was a weak negative link between EC-DO-TDS-Ca-F$^-$ ($r = -0.815 – -0.872$). The lack of correlation is related to the variation of sources and geochemical features of pollutants in the aquatic environment (Adamu et al. 2015). The characteristics were derived from analogous sources, primarily industrial discharges, municipal sewage and wastes, and agricultural inputs, as evidenced by the extremely strong and strong relationships (Bhuyan et al. 2019).

The principal component analysis (PCA) was also used to better understand the interrelationships between the water quality metrics and to determine the possible origins of the variables analyzed in the Gorai River water (Barakat et al. 2016). Moderate positive loading was observed for EC, TH, and TDS, as well as strong positive loadings were also perceived on TH, K, Ca, Mg, F$^-$, Cl$^-$, NO$_3^-$, and SO$_4^{3-}$ during the wet season (Fig. 4; Table S5). Anthropogenic point and nonpoint pollution sources, primarily wastewater discharge from city areas and the fertilizer industry, as well as agricultural runoff of inorganic fertilizers, are responsible for this PC. During the dry season, significant positive loadings were detected on temperature, EC, acidity, TDS, K, Ca, Mg, F$^-$, Cl$^-$, Br$^-$, PO$_4^{3-}$, NO$_3^-$, SO$_4^{3-}$, HCO$_3^-$, and CO$_3^{2-}$, along with high negative loadings on pH, DO, alkalinity, and Na (Fig. 4; Table S5). As a result, such PC can be interpreted using mixed contamination of organic and nutritional factors caused by anthropogenic interventions as well as geogenic processes.

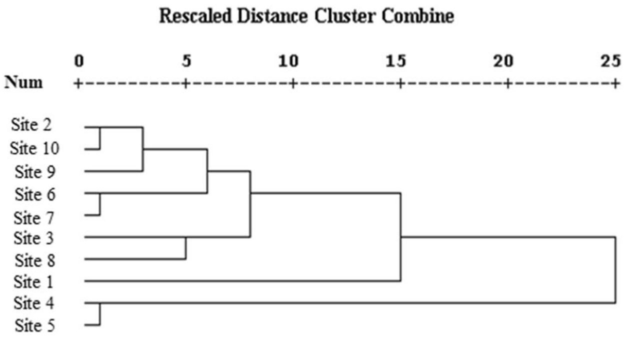

Fig. 3 Rescaled cluster of water quality parameters from 10 different sampling sites of Gorai River

Assessment of water quality

The water quality index (WQI) values and spatiotemporal fluctuations in acceptability of the Gorai river water are shown in Fig. 5 and Table S6. Brown et al. (1972), ECR (1997), and WHO (2011) aquatic environment standards were used to calculate the WQI scores for drinking water quality. In addition, the WQI was used to assess the suitability of water for fisheries or aquatic environments and ranged from 56.34 to 86.21 in the rainy season and 43.85 to 52.41 in the dry season, respectively (Table S6). As a result, the data suggested that the water quality along with

Table 4 Pearson correlation matrix water parameters during the dry season

	Temp	pH	EC	DO	Acidity	Alkalinity	TH	TDS	Na	K	Ca	Mg	F^-	Cl^-	Br^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	HCO_3^-	CO_3^{2-}
Temp	1																			
pH	−0.528	1																		
EC	0.155	−0.485	1																	
DO	−0.665*	0.811**	−0.217	1																
Acidity	0.499	−0.724*	0.535	−0.631	1															
Alkalinity	−0.089	0.295	−0.257	0.129	−0.551	1														
TH	0.456	−0.119	0.369	−0.01	0.208	−0.088	1													
TDS	0.862**	−0.449	0.122	−0.596	0.45	0.231	0.522	1												
Na	0.396	0.042	−0.096	0.237	−0.117	0.316	0.646*	0.51	1											
K	0.722*	−0.719*	0.425	−0.523	0.493	−0.316	0.68*	0.583	0.44	1										
Ca	0.701*	−0.738*	0.641*	−0.546	0.537	−0.237	0.661*	0.571	0.354	0.917**	1									
Mg	0.751*	−0.581	0.293	−0.461	0.601	−0.639*	0.547	0.452	0.292	0.862**	0.775*	1								
F^-	0.552	−0.461	0.699*	−0.287	0.487	−0.09	0.487	0.487	0.316	0.511	0.778*	0.484	1							
Cl^-	0.812**	−0.559	0.395	−0.457	0.641*	−0.555	0.630*	0.600*	0.339	0.844**	0.797*	0.949**	0.611*	1						
Br^-	0.342	−0.279	0.662*	−0.227	0.204	−0.411	0.495	0.104	−0.109	0.568	0.633*	0.533	0.449	0.589	1					
NO_3^-	0.731*	−0.769*	0.423	−0.630*	0.688*	−0.607*	0.469	0.505	0.141	0.870**	0.836**	0.925**	0.568	0.932**	0.581	1				
PO_4^{3-}	0.588	−0.796*	0.238	−0.678*	0.770*	−0.509	0.117	0.369	0.038	0.618*	0.636*	0.748*	0.465	0.640*	0.089	0.767*	1			
SO_4^{2-}	0.572	−0.663*	0.413	−0.432	0.847**	−0.717*	0.429	0.389	0.191	0.709*	0.679*	0.873**	0.540	0.853**	0.303	0.863**	0.846**	1		
HCO_3^-	0.686*	−0.466	0.185	−0.319	0.431	−0.424	0.649*	0.594	0.474	0.828**	0.646*	0.818**	0.337	0.888**	0.471	0.823**	0.409	0.690*	1	
CO_3^{2-}	0.616*	−0.441	0.245	−0.213	0.232	−0.444	0.566	0.362	0.447	0.845**	0.715*	0.843**	0.409	0.845**	0.622*	0.814**	0.405	0.609*	0.892**	1

*Significant difference at the 0.05 level; **statistical significance at the 0.01 level

Table 5 Pearson correlation matrix water parameters during the wet season

	Temp	pH	EC	DO	Acidity	Alkalinity	TH	TDS	Na	K	Ca	Mg	F^-	Cl^-	Br^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	HCO_3^-	CO_3^{2-}
Temp	1																			
pH	−0.024	1																		
EC	−0.343	−0.261	1																	
DO	0.428	0.041	−0.815	1																
Acidity	−0.42	−0.052	0.612	−0.836	1															
Alkalinity	0.333	−0.569	−0.358	0.344	−0.24	1														
TH	−0.576	0.603*	0.401	−0.633	0.453	−0.674	1													
TDS	−0.593	0.11	0.651*	−0.854**	0.799**	−0.435	0.64	1												
Na	−0.464	0.576	0.164	−0.421	0.306	−0.775	0.826**	0.455	1											
K	−0.572	0.013	0.622	−0.872*	0.657*	−0.471	0.674*	0.789*	0.686*	1										
Ca	−0.594	0.09	0.809*	−0.871*	0.703*	−0.634*	0.724*	0.918**	0.562	0.830*	1									
Mg	−0.329	0.212	0.398	−0.692*	0.531	−0.53	0.609*	0.618*	0.801*	0.900**	0.642*	1								
F^-	−0.496	0.213	0.671*	−0.826*	0.842*	−0.683*	0.679*	0.816**	0.566	0.735*	0.867**	0.608*	1							
Cl^-	−0.63	0.335	0.651	−0.761*	0.545	−0.781*	0.885**	0.795*	0.809**	0.843**	0.926**	0.744*	0.804**	1						
Br^-	0.052	−0.502	−0.467	0.395	−0.294	0.509	−0.452	−0.261	−0.273	−0.228	−0.343	−0.281	−0.475	−0.404	1					
NO_3^-	−0.551	0.237	0.476	−0.725	0.682*	−0.703*	0.724*	0.703*	0.859**	0.888**	0.772*	0.897**	0.829**	0.856**	−0.292	1				
PO_4^{3-}	−0.568	−0.017	0.517	−0.720*	0.600*	−0.482	0.547	0.658*	0.717*	0.937**	0.699*	0.930**	0.650*	0.754*	−0.221	0.911**	1			
SO_4^{2-}	−0.579	0.02	0.568	−0.714*	0.597	−0.49	0.539	0.806**	0.646*	0.887**	0.796*	0.866**	0.632*	0.793*	−0.206	0.829**	0.922**	1		
HCO_3^-	−0.5	−0.034	0.559	−0.763*	0.646*	−0.501	0.529	0.773*	0.68*	0.94**	0.791*	0.922**	0.694*	0.786*	−0.134	0.901**	0.958**	0.961**	1	
CO_3^{2-}	−0.524	0.207	0.528	−0.774	0.865**	−0.641	0.664*	0.782*	0.662*	0.767*	0.795*	0.700*	0.960**	0.771*	−0.333	0.910**	0.737*	0.683*	0.766*	1

*Significant difference at the 0.05 level; **statistical significance at the 0.01 level

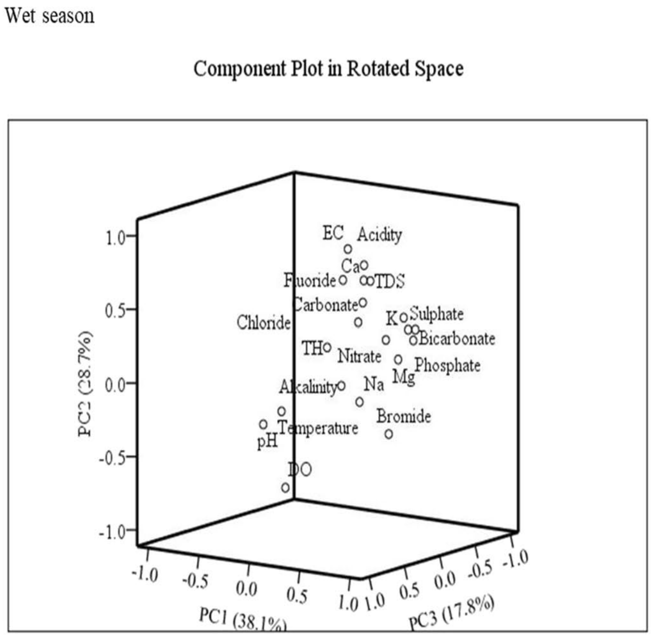

Fig. 4 Principal component analysis (PCA) of the water quality variables of wet and dry seasons

the Gorai River was very low (during the wet season) to poor (during the dry season). Furthermore, the data show that St-1 has the lowest (dry season) WQI score, indicating less contamination of water, whereas St-4 showed the highest level (wet) of WQI values during all the seasons (Fig. 5). Because of the large interventions by industrial and commercial activities, the WQI analysis revealed that St-3, St-4, and St-5 were the two most polluted locations in the study area, and thus were found to be unsuitable for any types of human uses, including drinking, fish culture, irrigation, and industrial uses throughout all sampling periods. Several anthropogenic actions, such as sewerage from domestic and commercial formations, direct release of untreated effluents from small-scale industries and factories, agricultural run-off, and dumping of solid wastes by local communities dwelling near a river, all contribute to the higher WQI values of all sampling sites (Bora and Goswami 2017).

Evaluation of water quality for irrigation

Sodium adsorption ratio

The SAR is shown in Fig. 5 to be a reasonable estimate of the degree to which irrigation water tends to undergo cation-exchange reactions in the soil. High SAR values indicate a risk of salt replacing absorbed calcium and magnesium, resulting in a state that eventually destroys soil structure (Khan and Abbasi 2013; Elbeltagi et al. 2022). In the wet season, the SAR values of the Gorai River water ranged from 4.86 to 7.99, with a mean value of 6.15, while in the dry season, the SAR values ranged from 3.27 to 5.34, with a mean value of 4.17 (Fig. 5; Table S7). The SAR value for all of the samples (both wet and dry seasons) suggests that the irrigation water is of outstanding quality.

Potential salinity

The appropriateness of water for irrigation is not reliant on the total concentration of soluble salts because low-solubility salts precipitate off and are deposited on the soil (Doneen 1964). Water with a low salt content is actually appropriate for irrigation. The PS of water samples from the Gorai River ranged from 5 to 7.18 in the rainy season, with a mean of 5.96, and from 3.45 to 4.59 in the dry season, with a mean of 3.92 (Fig. 5; Table S6), and was judged moderate.

Soluble sodium percentage

The soluble sodium percent is a measure of water's proclivity for cation exchange processes (Khan and Abbasi 2013). Na ions make up a certain percentage of total cations. The SSP is an important element in irrigation water classification. For appropriate plant nutrition and growth, a certain ratio of air and water in the pore spaces of the soil is required. For irrigation water, the maximum SSP allowed value is 60%. The calculated SSP value in this study varied from 4.22 to 5.74 in the wet season, with a mean value of 4.97, and 4.69 to 6.36 in the dry season, with a mean value of 5.55 (Fig. 5; Table S7), showing that the water from the study river is suitable for irrigation in both seasons.

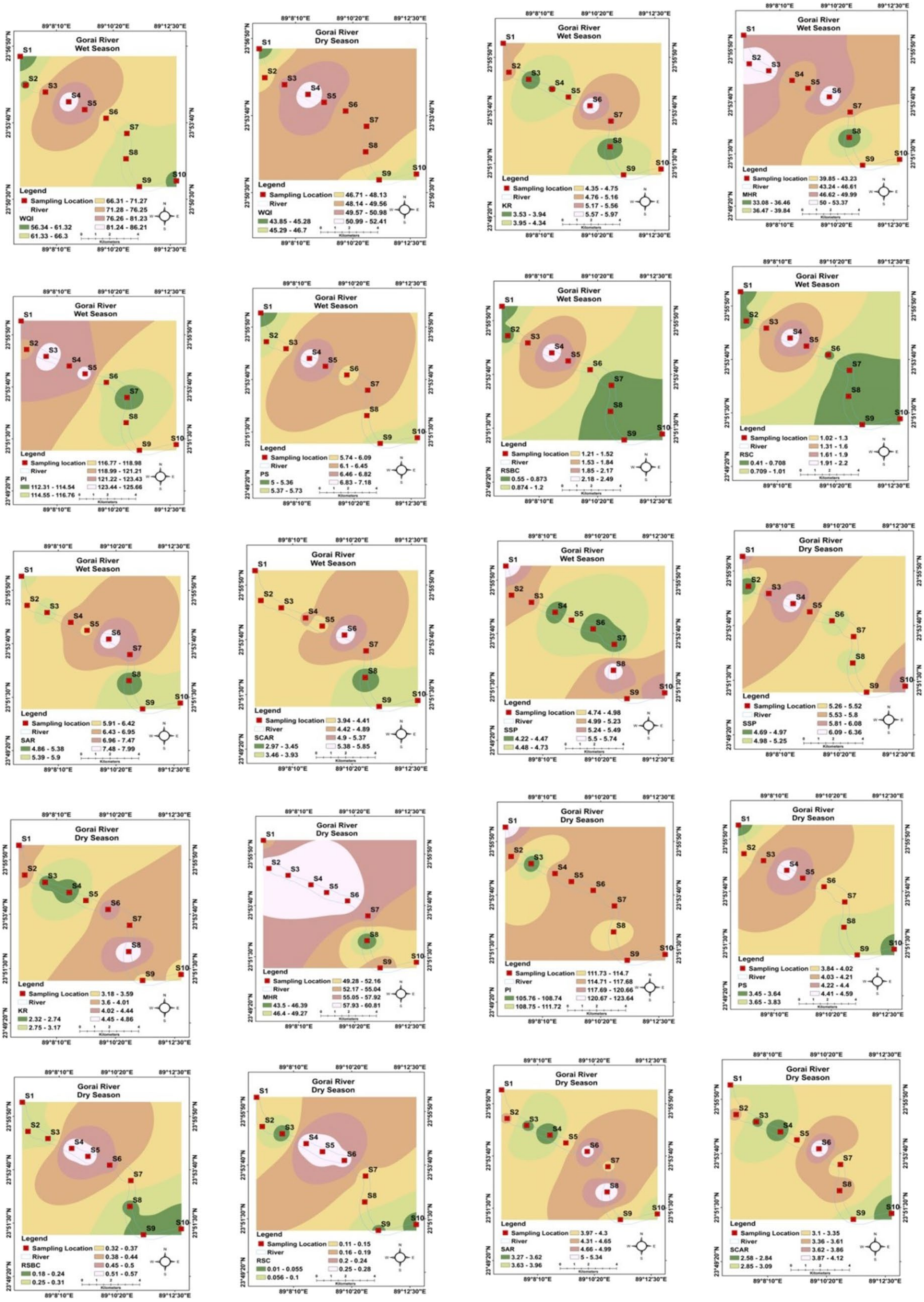

Fig. 5 Spatial distribution of WQI and irrigation indices of Gorai River, Bangladesh

Kelly's ratio

KR is the amount of Na^+ ions measured against Ca^{2+} and Mg^{2+}. Kelly's index indicates that there is too much sodium in the water. As a result, water with a Kelly's index value of less than 1 is suitable for irrigation, whereas water with a value larger than 1 (KI > 1) contains too much sodium, and water with a value of less than 2 has too little sodium (Kelly 1940). In the rainy season, the KR values of the Gorai River water ranged from 3.53 to 5.97, with a mean value of 4.50, whereas in the dry season, the KR values ranged from 2.32 to 4.86, with a mean value of 3.58 (Fig. 5; Table S7). The KR value for all of the water samples (both wet and dry seasons) was greater than 1, suggesting that this water is unfit for irrigation.

Magnesium hazard ratio

The magnesium ratio is used to quantify the negative impact of magnesium in irrigated water. Paliwal (1972) devised a "magnesium hazard" index to assess the negative effects of magnesium in irrigation water. The link between calcium and magnesium concentration in river water is expressed as the magnesium adsorption ratio (Ayuba et al. 2013). Irrigation water with high calcium and magnesium concentrations can raise the pH of the soil, causing phosphorus loss. Magnesium ions are also necessary for soil fertility. If the numerical value of magnesium hazard (MH) is less than 50%, the water is safe and suited for irrigation (Szabolcs and Darab 1964). In the wet season, the MHR values of the Gorai River water ranged from 33.08 to 53.37, with a mean value of 45.50, indicating that the water is suitable for irrigation, and in the dry season, the MHR values ranged from 43.5 to 60.81, with a mean value of 55.62 (Fig. 5; Table S7), indicating that the water is unsuitable for irrigation.

Sodium-to-calcium activity ratio

The SCAR was computed using the Na^+ and Ca^{2+} concentrations in water samples (Gupta and Gupta, 1987). The SCAR can be classified as: non-sodic (S-0: SCAR = 5), normal (S-1: SCAR = 5–10), low (S-2: SCAR = 10–20), medium (S-3: SCAR = 20–30), high (S-4: SCAR = 30–40), and extremely high (S-5: SCAR > 40). In the rainy season, the SCAR of water samples ranged from 2.97 to 5.85, with a mean value of 4.20, and in the dry season, it ranged from 2.58 to 4.12, with a mean value of 3.14 (Fig. 5; Table S7).

Residual sodium carbonate

Excess sodium bicarbonate and carbonate have an impact on the physical characteristics of soil related to the irrigation water. RSC occurs when excess CO_3^{2-} combines with Na^+ to create $NaHCO_3$. If irrigation water remains at a high RSC value, then it solidifies the agricultural soils and makes saline (Zaidi et al. 2015). According to Wilcox (1955), if the RSC value of any water is lower than 1.25 meq/l then the water is safe for irrigation; a value of 1.25–2.5 meq/l is moderately suitable; and a value larger than 2.5 meq/l is unsuitable for irrigation. The RSC values of the water samples in this study ranged from 0.41 to 2.2 in the wet season, with a mean value of 0.89, and from 0.01 to 0.28 in the dry season, with a mean value of 0.14 (Fig. 5; Table S7). The RSC mean value for all samples (including wet and dry seasons) suggests that the water used for irrigation is of acceptable quality.

Residual sodium bicarbonate

The RSBC index was proposed by Gupta and Gupta (1987) to express the alkalinity danger. Bicarbonate concentrations of more than 10.0 meq/l are anticipated to have a variety of effects on plant growth. The RSBC index values of less than 5 mg/l were deemed acceptable (Ravikumar et al. 2011). The RSBC values in this study varied from 0.55 to 2.49 meq/l in the wet season, with a mean of 1.09 meq/l, and 0.18 to 0.57 meq/l in the dry season, with a mean of 0.33 meq/l (Fig. 5; Table S7). All of the RSBC values from both seasons are far below the acceptable level, indicating that they can be utilized safely for irrigation.

Permeability index

The constant use of irrigation water has an impact on soil permeability. The use of irrigation water increases the amount of sodium, calcium, magnesium, and bicarbonate ions in the soil (Chandu et al. 1995). The permeability index (PI) is a metric that determines whether water is suitable for irrigation. Class I (> 75%; appropriate), class II (25–75%; fairly suitable), and class III (25%; unsuitable) permeability indexes are used. In the rainy season, the PI values of the Gorai River water ranged from 112.3 to 125.6, with a mean value of 119.4, and in the dry season, the PI values ranged from 105.7 to 123.6, with a mean value of 115.4 (Fig. 5; Table S6). The PI value for all the samples (wet and dry seasons) indicates the water quality is suitable for irrigation purposes.

Suitability of water quality for industrial application

Langelier saturation index

The LSI method was used to determine if water was corroding or depositing. The LSI values ranged from 0.07

(at S-1) to 0.85 (at S-7) during the wet season, whereas they ranged from – 0.24 (at S-9) to 0.09 (at S-7) (Fig. 6; Table S8). The study's findings revealed that in nature, water tends to be under-saturated to supersaturate. In most sectors, supersaturated water is favored for its applications. Shil et al. 2019 observed the LSI values of 1.6 to 0.8 in the pre-monsoon season and 1.5 to 0.1 in the post-monsoon season of the Mahananda River.

Ryzner stability index

RSI offers better corrosion resistance, as well as the ability to withstand increased Ca hardness and pH values. The scale thickness monitoring index is the RSI. Scale formation begins once the Ca hardness reaches its maximum value, protecting the equipment against corrosion. However, the equipment's efficiency may suffer as a result of the scale formation (Shah et al. 2019). The waters of the Gorai River showed an alternation between high and severe corrosion classes, according to our RSI data (Fig. 6; Table S8). During the rainy season, the heavy corrosion class outnumbered the corrosion unacceptable class. The occurrence of the corrosion unacceptable class, which implies significant corrosion, increased throughout the dry season. As a result, the tested waters had corrosive potential ranging from heavy to unbearable, making them unfit for pipe transit (Haritash et al.

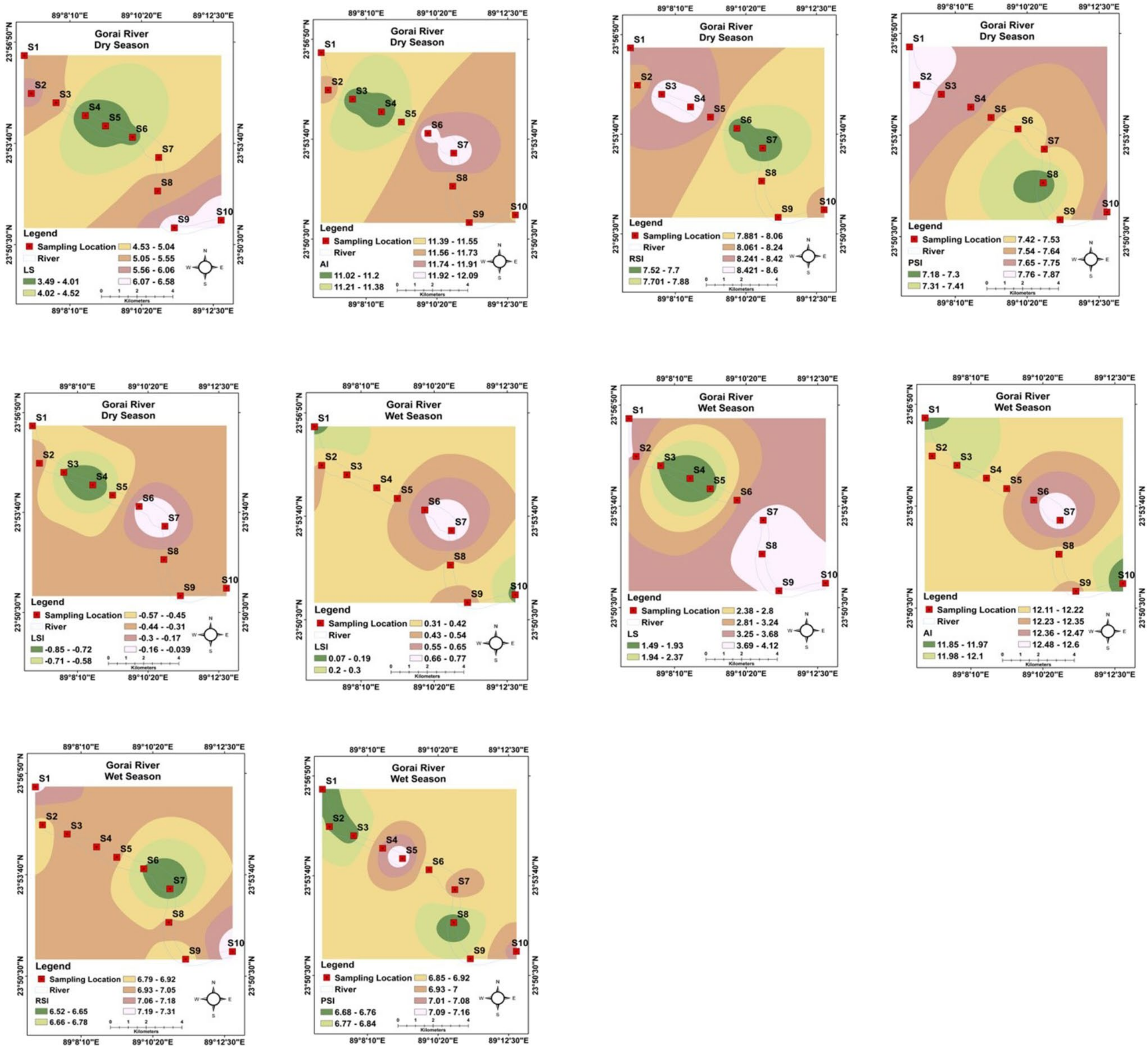

Fig. 6 Spatial distribution of industrial indices of Gorai River, Bangladesh

2016). RSI values larger than 7 indicate that the creation of calcium carbonate will not result in a corrosion-preventing coating (Shah et al. 2019; Souza et al. 2020).

Puckorius or practical scaling index

The PSI determined that the tested waters had a corrosive propensity regardless of the time period studied, and it also calibrates the relationship between saturation state and scale formation by combining an estimate of the water's buffering capacity into the index (Puckorius and Strauss 1983). If the water has a high calcium concentration but low alkalinity and buffering ability, it has a high calcite saturation level. Due to a lack of buffering ability, calcium precipitates, causing a fast drop in pH. There is a chance that the water will have a strong inclination to produce scale as a result of the driving force, but the scale formed will be quite small. Our collected samples had PSI values greater than 6 (Fig. 6; Table S8). On the scale, a PSI greater than 6 indicates dissolving water action. The PSI values of our obtained samples show a strong corrosion tendency (Souza et al. 2020).

Larson–Skold index

LS describes how corrosive water is to mild steel and cast iron pipes, affecting industrial process efficiency. The increase in chloride and sulfate causes the aggressiveness of cooling water with suitable buffering capacity and alkalinity. Their presence also causes interference with the creation of the film. For water with extremely high or extremely low alkalinity, the LS calculation will not yield accurate results (Larson and Skold 1958). Figure 6 and Table S7 show the LS values of the gathered samples, together with their ranges of 1.2. According to the guidelines, all of the samples will have exceptionally high corrosion rates and no film formation. The presence of a very high LS value and a sulfate concentration within allowed limits implies that the chlorine content of the samples is significantly higher than desired (Alsaqqar et al. 2014). As a result of employing such water, the efficiency of the process equipment was reduced (Haritash et al. 2016). The concentrations of Cl^- and SO_4^{2-} in proportion to HCO_3^- are closely connected to the observed metallic corrosion. According to Agatemor and Okolo (2008), adding Cl and SO_4^{2-} anions to saline increases the corrosive tendency.

Aggressive index

The AI values are likewise very similar to the LSI values. During the wet season, the lowest AI value was recorded at S-10, while the highest was found at S-7 (12.62). During the dry season, AI values ranged from 11.02 (at S-4) to 12.09 (at S-7) (Fig. 6; Table S8). According to the findings, the Gorai River water was moderately hostile to non-aggressive. The pre-monsoon AI values ranged from 10.14 to 12.4 while the post-monsoon AI values ranged from 10.40 to 11.90, indicating that the Mahananda River's water is moderately aggressive and non-aggressive (Shil et al. 2019).

Assessment of water quality for livestock permissibility

Water is a critical nutrient for all living things. Production of healthy livestock and poultry requires a reliable and safe water supply (Saha et al. 2019). Water that has a detrimental effect on livestock and poultry growth, reproduction, or performance cannot be regarded as acceptable (Breede 2006). Despite the lack of research on the economic implications of water quality on livestock performance, logic dictates that farm water supplies, whether surface or groundwater, be protected from microbes, chemicals, and other pollutants (Islam et al. 2015). Nitrates, bacteria, organic materials, and suspended solids are all substances that originate on animal farms and frequently contaminate water systems. Surface water supplies to which livestock have ready access are always potential candidates for contamination (Pfost et al. 2001). Water facilitates the flow of food through the gastrointestinal tract by transporting nutrients, waste products, hormones, and other electrolytes (Lardner et al. 2005). To protect livestock from illnesses, salt imbalances, and toxic component poisoning, high-quality water should be provided (Saha et al. 2019). Although the total allowable limits for total suspended particles and salinity level may be higher, most of the water quality characteristics for livestock use would be the same as for drinking water (Bhardwaj and Singh 2011). According to Australian, UNESCO, and University of Minnesota Extension Division (MUE) recommendations, the desired pH, TDS (mg/l), alkalinity (mg/l), sulfate (mg/l), and phosphate (mg/l) values are 6.8 to 7.5, < 500, < 400, < 250, and < 1, respectively. On the other hand, problem range of pH, TDS (mg/l), alkalinity (mg/l), sulfate (mg/l), and phosphate (mg/l) values are < 5.5 or > 8.5, > 3000, > 5000, > 2000, and not established, respectively (Hamill and Bell 1986; Pfost et al., 2001). Results of the study revealed that the surface water of the Gorai River is suitable for livestock because the desired levels of the investigated parameters are within a safe range (Figure S1).

Conclusions

The present study dealt with the water quality assessment in the Gorai River, Bangladesh during the wet and dry seasons using GIS, various indices, and multivariate statistical approaches. The PCA revealed that the main contributors to water quality parameters were geogenic, domestic, and agricultural runoffs and the application of fertilizers and agrochemicals. On the other hand, CA categorized the spatio-temporal similarity groups for all of the sampling locations and validated the relationship between water quality parameters and associated influencing factors, whereas the *T*-test revealed statistically significant ($p < 0.05$) seasonal fluctuations in the analyzed water quality indicators, with the exception of TH, Mg, and Br^-. The WQI assessment showed that the river water was not suitable for human consumption. The MHR and KR showed that the water was unsuitable for irrigation, although PS and SCAR values indicated the somewhat useable condition of river water, and the remaining index values indicated the suitability of river water for agricultural use. LSI and AI analysis designated the water of the study river as moderately aggressive to non-aggressive, but restricted the uses for industries. The values of RSI, PSI, and LS also expressed their unsuitability for industrial uses. The findings of the study showed that the water quality of the study river was generally acceptable, with a few exceptions in the urban areas. After appropriate treatment, the surrounding industries can use the river water for industrial operations. The water of the river is not recommended for drinking and irrigation purposes. Future in-depth monitoring of water quality is required to protect and manage the whole riverine ecosystem.

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