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Research article

Investigation of groundwater and its seasonal variation in a rural region in Natore, Bangladesh

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ABSTRACT

In Bangladesh, groundwater is the most widely used source of drinking water for rural communities. However, the groundwater quality is degraded by natural contaminants and anthropogenic pollution. Groundwater is a reliable and sustainable source of safe water for irrigation and domestic purposes, especially during the dry season. The water quality assessment data for the study area was not found in the literature. This study aims to assess groundwater quality and seasonal variation in a rural area of five unions of Bagatipara Upazila, Natore, and its suitability for drinking purposes by measuring the Water Quality Index (WQI). The groundwater of five unions, namely Dayarampur, Bagatipara, Faguardiar, Jamnagar, and Pacca, has been selected for investigation. The electrical conductivity (EC), color, and turbidity exceeded the ECR guidelines. EC showed a positive correlation with total dissolved solids (TDS), total solids (TS), and turbidity. On the other hand, dissolved oxygen (DO), hardness, chloride, carbon-di-oxide (CO_2), and iron (Fe) concentrations varied based on the location of the sampling points. The bacteriological parameters TC and *E. coli* were found in most of the samples, which indicate the potential sources of contaminants such as septic tank leakage and inadequate waste disposal systems. The groundwater quality was found not to be influenced by seasonal variation except by pH, DO, and CO_2. The Water Quality Index (WQI) spatial mapping demonstrated that during the post-monsoon period, the water quality of the central part of Bagatipara upazila was in 'good' condition, which was in Bagatipara, Fagurdiar, and Pacca unions, whereas during the pre-monsoon season, the 'good' condition was found very limited to Fagurdiar union only. The study revealed that the groundwater of Bagtipara Upazila is not suitable for drinking water due to the presence of TC and E. Coli as well as 'poor' to 'unsuitable' conditions in most of the areas based on WQI.

1. Introduction

There is no equivalent of water for universal solvent and biochemical activity. Groundwater and surface water are the two main sources of water. Groundwater contains dissolved ionic substances since it is in contact with mineral rocks deep in the soil. Gradually, the amounts of pollutants are simultaneously being introduced into the groundwater through agriculture, mining, industry, and waste disposal [1–5]. Contaminated water can deteriorate biological integrity, upset ecosystems, put human health at risk, and make ecosystem functions less readily available [6]. Nowadays, various types of contaminants are being mixed in the water supply system.

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Mentionable among them are pesticides, fertilizers, chemicals, heavy metals, detergents, and pharmaceutical products. These contaminate water sources and affect aquatic life and public health [7]. Also, groundwater is contaminated when recharged water passes through the contaminated soil [8]. Although water sources are valuable, they are being polluted by man-made wastes. Due to population growth, industrialization, and urbanization, adequate water availability and water quality are being hampered [9].

Around 1.5 billion people worldwide do not have access to safe water, and 5 million die yearly due to a lack of clean water. In developing countries, 75 % of people cannot access safe drinking water [10], and 80 % of industrial waste is discharged into water, which pollutes water bodies [11,12]. The pressure on the water supply system is constantly increasing. Significant reasons behind this are a high standard of life, population growth, increasing industry and development, water use policy, and other external forces [13]. As the main source of pure water, more than half of the world's population depends on the characteristics of surface and groundwater. The availability of safe water is one of the major concerns, as water quality is directly linked to human health [14]. Many diseases spread through water, such as cholera, typhoid, viral hepatitis, etc., which are the major cause of global mortality [15].

Groundwater is an important safe water source, especially in dry climatic regions of the world [16]. Groundwater use for drinking, washing, and irrigation is significant [17]. It is a reliable and sustainable source of safe water as well as for irrigation and domestic purposes, especially during the dry season [18]. To ensure groundwater is useable, its quality must be assessed, which is primarily influenced by the region's physical and chemical parameters [6]. Around the world, numerous researchers have looked into the quality of groundwater [19–25]. However, it was reported that groundwater is being polluted due to natural and anthropogenic activities around the world [14,26–29]. This leads to various waterborne diseases, which cause one-third of deaths in developing countries, including children [15,30].

Ensuring sustainable groundwater quality is a major concern in many parts of the world, including Bangladesh; however, this country also faces serious water pollution due to urbanization and industrial pollution [31,32]. According to the World Health Organization and Bangladesh guidelines, groundwater research in Bangladesh has shown that it is very good quality water for human consumption and has no significant health risks [33]. In Bangladesh, groundwater from the alluvial aquifer system supplies 90–99 % of drinking water and 70–90 % of irrigation water [21,34]. Of the three types of groundwater aquifers, the middle-confined aquifer is the main source; the upper shallow unconfined aquifer is used by most people for agriculture and drinking [35]. It was reported that 10 million shallow tube wells were installed in Bangladesh to withdraw groundwater [15]. The groundwater quality varied among the country. In some districts, water is suitable for irrigation purposes, whereas in some districts, there is a shortage of safe drinking water during the dry season. Heavy metals or metalloids and salinity intrusion are also sometimes found in groundwater [36–38]. To ensure safe drinking water, knowledge of water pollution is important, as water, sanitation, and hygiene are the cause of 8.5 % of deaths in Bangladesh [39]. Several researchers used the Water Quality Index (WQI) method to evaluate whether Bangladesh's groundwater sources are suitable for drinking or domestic use [30,40,41].

The Natore District has mostly swampy and plain areas and falls into the western climate zone with annual rainfall below 150 cm. Also, during the summer season (March–May), this area becomes driest and hottest [42]. According to the Köppen-Geiger climatic classification, the Natore district falls into the humid subtropical climate zone criteria [43]. Presently, groundwater is mainly used for purposes in the Natore district as protected ponds and dug wells were abandoned or dried up during the dry season, and it was used for rural water supply before tubewell installation in this area [44]. Assessment of the groundwater quality plays a vital role in policy-making as this can assist the policymaker in the possible use of groundwater. According to the Department of Public Health Engineering (DPHE) of Natore, efforts are being made to bring about positive changes in drinking water and sanitation in different parts of the Natore district. Success is being achieved by working to prevent groundwater pollution [45]. People here are equally dependent on groundwater and surface water [46,47]. They depend on groundwater for drinking. The water quality assessment of Barigram Upzila of Natore district found that the groundwater was safe for drinking and domestic purposes [44]. Meanwhile, the water quality assessment of Lalpur Upzilla showed that it is not suitable for drinking purposes as coliform (*E. coli*) bacteria are found in groundwater [48].

Bagatipara Upazila still has no water supply by the local authority. According to DPHE, Natore's future plan is to provide a water supply system to Bagatipara Upzila [45]. To install a new water supply system in Bagatipara, water quality information in this area will benefit the local authority for policy making. Also, no water quality assessment was done for Bagatipara Upzila, as properties of groundwater in the Bagatipara region have received inadequate interest in research, and people are not aware of the quality of water. However, they use it for various purposes like drinking, cooking, bathing, etc. For this reason, groundwater water quality assessment is required. A novel aspect of this research is the distribution of groundwater constituents in the study area. This study aims to assess the groundwater quality of the rural area of five unions of Bagatipara Upazila, Natore, for use as a drinking water source by measuring the Water Quality Index (WQI). Also, assess the seasonal variation of groundwater in this area. This study was carried out at Bagatipara Upazila in the Natore district of the Rajshahi division of Bangladesh from 2021 to 2022. This research will function as a knowledge base to combat public health issues by better planning, implementing environmentally friendly infrastructure, and providing sufficient drinking to safeguard local economies and communities.

2. Materials and methods

2.1. Description of the study area and context

Natore is one of the largest districts in the Rajshahi Division of Bangladesh. This large district consists of 7 Upazilas. Bagatipara was selected for the study (Fig. 1). The total area of Bagatipara Upazila is 34560.159 acres. This Upazila consists of five unions which were Dayarampur Union (denoted as D), Bagatipara Union (denoted as B), Faguardiar Union (denoted as F), Jamnagar Union (denoted as J) and Pacca Union (denoted as K). Among the study areas, Dayarampur Union (denoted as D) has 12 villages and a population of 31254 people; Bagatipara Union (denoted as B) has 26 villages and a population of 25900 people; Faguardiar Union (denoted as F) has 13 villages and a population of 2562 people; Jamnagar Union (denoted as J) has 41 villages, and a population of 34835 people and Pacca Union (denoted as K) has 23 villages and 31007 people. Except for Fagurdiar all four unions were situated on the banks of the Boral River. Bagatipara Upazila has Natore Sadar on the north, Lalpur and Bagha Upazilas on the south, Baraigram Upazila on the east, and Charghat Upazila on the west. Bagatipara is located between 24°15′ and 24°22′ north latitudes and in between 89°13′ and 89°26′ east longitudes [49].

2.1.1. *Water secsampling laboratory testing*

A total of 14 samples were collected from tube wells (T) among five unions of Bagatipara Upazila. All samples were taken in both the periods of Post-Monsoon (Oct–Nov 2021) and Pre-Monsoon (May–June 2022). However, in the Pre-Monsoon season, the FT1 water sample could not be collected due to the abundance of the tube well. Sample coordinates were recorded with a GPS device (GARMIN eTrex 10). The tube wells were pumped continuously for one to 2 min while water was collected from the tube wells. Sample collection bottles were washed two to three times with sample water. Water collection bottles were labeled with the sample ID.

2.1.2. *Laboratory testing*

All water quality parameters were tested in the Environmental Engineering Laboratory of the Civil Engineering Department at university premises. pH and electrical conductivity (EC) were measured using Lutron pH/ORP, DO, and CD/TDS meters (Model: WA-2015). The temperature was recorded at the sampling place by immersing the corresponding water sample (bottle) with the thermometer for about 1 min. The color and iron were determined by using a spectrophotometer made by HACH (Model: DR 3900). Turbidity was measured in a Turbidity Meter (Model: TUB-430). The hardness of water was determined through titration with EDTA

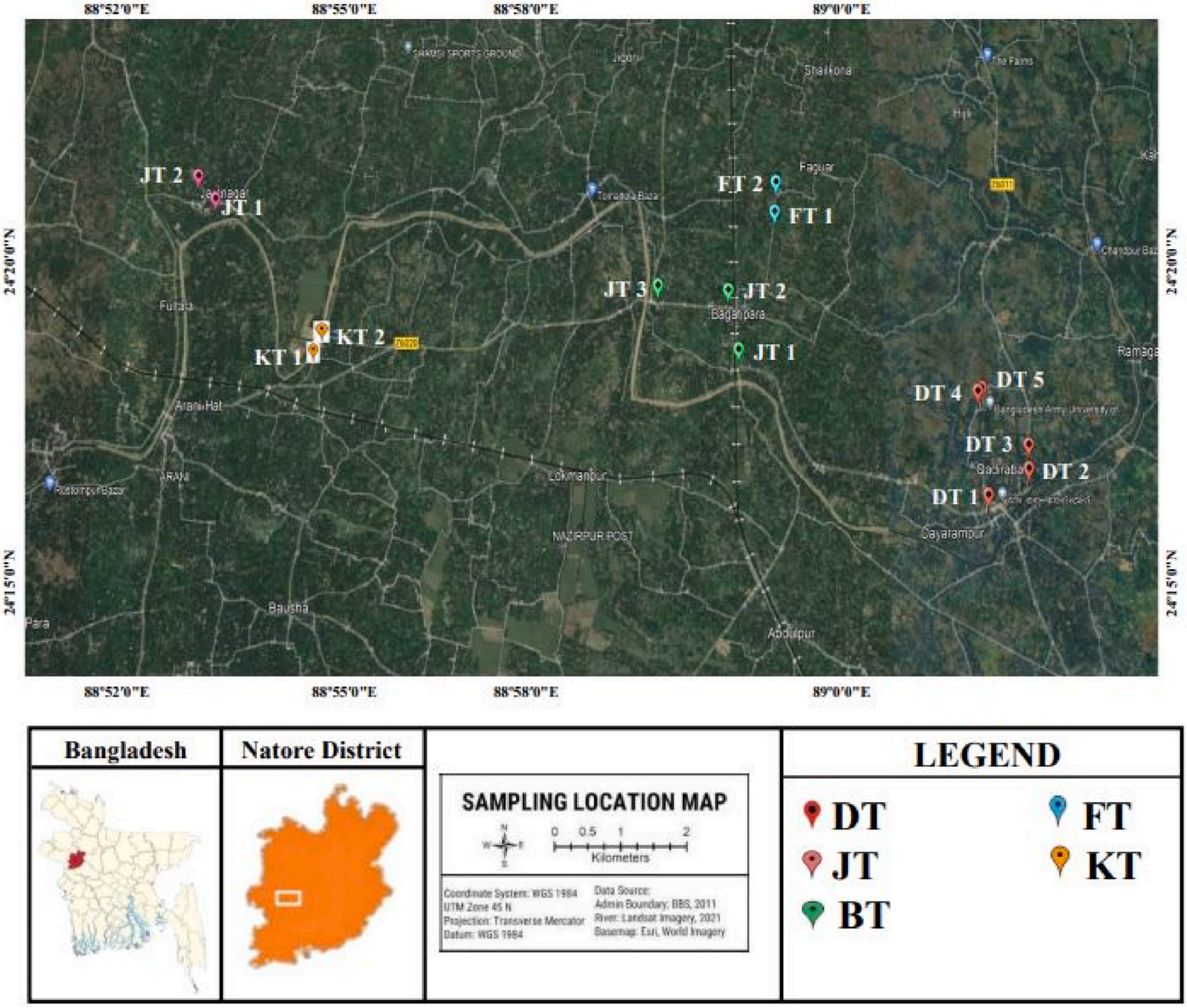

Fig. 1. Map showing the geographic location of the study area and sampling locations.

(HI 3812 Hardness Test Kit). Chloride was determined through titration with Mercuric Nitrate (HI 3815 Chloride Test Kit). Dissolved oxygen (DO), carbon dioxide (CO_2), total solids (TS), total dissolved solids (TDS), and microbiological tests (coliform group) were carried out according to APHA [50] method.

DO was measured by the Azide Modification method (Method no: 4500-O C). Biochemical Oxygen Demand (BOD) was measured by the 5-Day BOD Test (Method no: 5210 B). Carbon dioxide (CO_2) was determined through the Titrimetric Method for Free Carbon Dioxide (Method no: 4500-CO2 C). For measuring Total Solids (TS) and Total Dissolved Solids (TDS), Method no: 2540 was used. The coliform group (Total Coliform & *Escherichia Coli*) was tested using a membrane filter technique (Method no: 9222) and XM-G Agar (Nissui Pharmaceutical, Japan) as media.

2.2. Data analysis

Analysis is an essential means of obtaining results from any data collected. Data processing and analysis were done using Microsoft Office Excel 2019 and IBM SPSS Statistics version 26. The results obtained were compared with Environment Conservation Rules (ECR) [51], Environment Conservation Rules (ECR) [52], and the World Health Organization (WHO) [53] standard threshold for drinking water quality. Statistical analysis was carried out to check the mean, standard deviation, maximum, minimum, arithmetic mean, coefficient of variation, correlation, and *t*-test. The study area map and spatial distribution of WQI of groundwater were prepared by using ArcGIS 10.8.

2.2.1. Weighted arithmetic water quality index (WQI) method

The water quality index (WQI) of groundwater was studied to ascertain the suitability of the water for drinking purposes because WQI was widely used to compare the water quality in different areas [54]. The study used ten (10) parameters to calculate the water quality index. The WQI was calculated using the standard for drinking water quality approved by the ECR [51]. The weighted arithmetic index method used by Akter et al. [55] in a similar study in line with Brown et al. [56] was applied to calculate the WQI of the water samples. Further quality rating or sub-index (qn) was calculated using the following formula Ochuko et al. [57] used. The Water Quality Index (WQI) and water quality status were adopted from Iloba et al. [58], as shown in Table 1.

3. Results and discussion

3.1. Physical characteristics

3.1.1. pH levels in groundwater

The pH values of the groundwater were found to be between 7.20 and 7.44, which indicates slightly alkaline, which may be caused by the presence of a considerable amount of sodium, calcium, magnesium, carbonate, and bicarbonate ions [27,59], as shown in Fig. 2 (a). These findings partially agreed with the pH of nearby Baraigram Upzila [Rasheduzzaman. (2020)] and Lalpur Upzila [48], which were 7.14–7.45 and 6.99–7.26, respectively. According to ECR [51] guidelines, the standard pH of groundwater is 6.5–8.5, which met our tested results. Although different pH values of groundwater were also found by Chowdhury & Chowdhury [60] and Shahidullah et al. [59], which were 6.34–6.88 and 8.1 to 8.3, respectively, do not agree with the current findings because Naogaon and Mymensingh districts were far from the Natore districts. Groundwater was found to be 7.25–7.68 during pre-monsoon season. Also, it was found that the pH of post-monsoon has a significant difference from that of the pH of pre-monsoon ($P < 0.05$), indicating that the groundwater becomes slightly more alkaline during pre-monsoon which may be caused by evaporation or reduced dilution pre-monsoon high temperature and low rainfall occurred which increase alkalinity concentration. Because the pH levels remain within the ECR [51] permissible range for groundwater quality, this minor rise in alkalinity has no significant impact on the environment.

3.1.2. Electrical conductivity (EC) level in groundwater

According to WHO [53] standards, EC value should not exceed 400 μS/cm [61]. However, from Fig. 2(b) it was found that EC values ranged from 585 to 1047 μS/cm, which exceeded the standard values of 400 μS/cm but fell into the "permissible" group, which is < 1500 μS/cm as reported by Bozdağ & Göçmez [62]. Similar results were found in nearby Baraigram Upzila [44] and Lalpur Upazila [48], which were higher than 400 μS/cm, concluding that the groundwater of Natore district has a high EC value. A similar study was done in the southwestern region of Bangladesh, where the EC value varied from 434 to 990 μS/cm, which agreed with the current findings that the high EC value of the study area is a common phenomenon in this region. The maximum amount of EC was found at Jamnagar Union, which was more than 1000 μS/cm. The higher EC values of the studied area indicate that the water has higher soluble

Table 1
Water quality index (WQI) level (adopted from Ref. [58]).

WQI Level	Status of Water Quality
>100	Unsuitable
76–100	Very poor
51–75	Poor
26–50	Good
0–25	Excellent

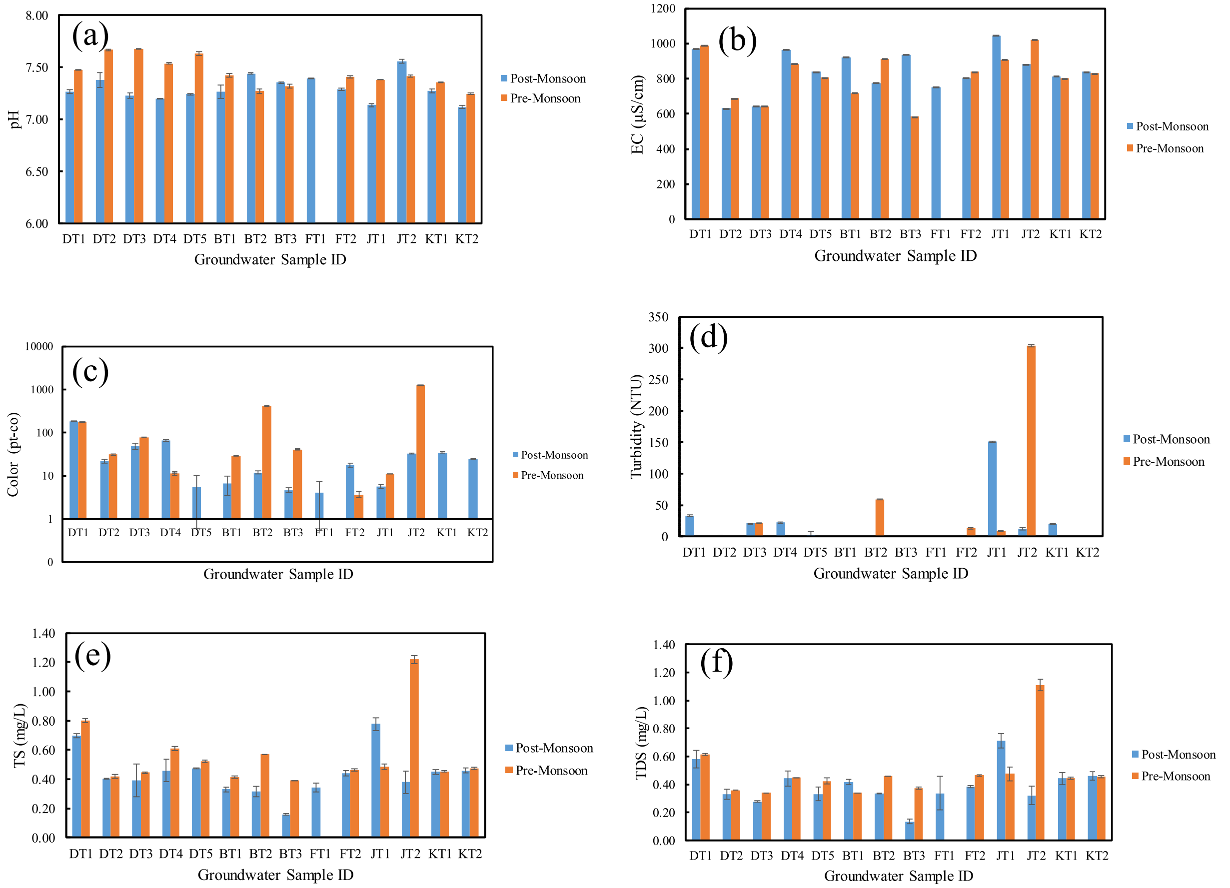

Fig. 2. Physical concentration of groundwater samples during pre-monsoon and post-monsoon (a) pH, (b) EC, (c) color, (d) turbidity, (e) TS, and (f) TDS concentrations.

salts as well as dissolved solids, a higher level of ionic concentration, and the presence of high inorganic pollutants such as dissolved salts, sewage water, agricultural runoff [61,63–66]. Also, it was found that EC has a positive correlation with TDS (0.574), TS (0.538), and turbidity (0.461), with $p < 0$ 0.05 indicating EC value increase as TDS, TS, and turbidity increase. However, no significant difference was found during post- and pre-monsoon EC levels ($P > 0.05$), suggesting that groundwater has consistent sources of ion input and relatively stable seasonal fluctuation throughout the year.

3.1.3. Color level in groundwater

In Fig. 2(c), it was found that eight samples' colors from post-monsoon and seven samples' colors from pre-monsoon exceeded the ECR [51] standards for drinking water, which is 15 pt-co. The reason behind having a higher color value in groundwater may be the presence of irons and minerals, as color showed a positive correlation with iron (0.923), TDS (0.785), and TS (0.781) with $p < 0.05$ [48]. However, no significant seasonal variation was found ($p > 0.05$) during the pre-monsoon season, which indicates the dissolved organic matter and minerals, which caused the color substances to remain the same in both seasons.

3.1.4. Turbidity level in groundwater

It was seen that the seven samples' turbidity during post-monsoon and four samples' turbidity during pre-monsoon exceeded the ECR [51] standards for drinking water, which is 10 NTU (Fig. 2(d)). High turbidity indicates that there are a lot of suspended particulates in the water, which raises issues about contamination, pollution, and water safety [67,68]. The high turbidity in Dayarampur Union was caused by the presence of iron, as explained by Tong et al. [69]. However, no significant variation was observed in the post- and pre-monsoon seasons ($P > 0.05$), suggesting that the turbidity has no impact on seasonal changes.

3.1.5. Total solids (TS) and total dissolved solids (TDS) levels in groundwater

From Fig. 2(e) and (f), it was found that TS ranged from 0.17 to 0.8 mg/L and TDS ranged from 0.14 to 0.56 mg/L during the post-monsoon season, which was very negligible in amounts and within the standard range of ECR [51] standards for drinking water. The TS & TDS values indicate that water has a very low amount of minerals, as Kumar et al. [70] found that water having a higher quantity of minerals has higher EC. Also, it was observed that in the post- and pre-monsoon seasons, no significant variation of TS and TDS was found ($p > 0.05$) because the level of TS and TDS remains stable throughout the year and possesses no seasonal effect. However, the value of TS and TDS increased pre-monsoon.

3.1.6. Chemical characteristics

3.1.6.1. Dissolved oxygen (DO) level in groundwater. DO was found to be 0.8–6.63 mg/L during post-monsoon, as shown in Fig. 3(a). Similar results were found by Ref. [71], which was 3.98–5.5 mg/L. According to ECR [52], the standard value of DO for drinking water is 6 mg/L. Also, DO was found by Ahmmed & Kibria [48] in the nearest Lalpur Upazila, which was 6.20–7.40 mg/L, while it is beside Dayarampur Union. The DO value significantly increased in pre-monsoon season ($p < 0.001$). The increase in DO during the pre-monsoon season may be influenced by several environmental factors, such as surface water infiltration from rivers or rain, permeable rocks and soils enhancing oxygen diffusion from the surface, and vegetation and root systems further aiding in oxygen delivery into the soil. The possible reason for high DO in groundwater may be that oxygen is rapidly absorbed from the atmosphere into the groundwater by microbial respiration and decomposition of organic matter in soil and unsaturated areas [72].

3.1.7. Hardness level in groundwater

According to ECR [51], the hardness of drinking water is 500 mg/L as $CaCO_3$. Fig. 3(b) showed that hardness was found between 249 and 498 mg/L as $CaCO_3$ during the post-monsoon season. Similar results were found by Chowdhury & Chowdhury [60], which was 97–449 mg/L as $CaCO_3$. According to Hung et al. [73], hardness ranges from 0 to 75 mg/L as $CaCO_3$ is considered soft water, 75–150 mg/L as $CaCO_3$ is moderately hard, 150–300 mg/L as $CaCO_3$ is hard, and more than 300 mg/L as $CaCO_3$ is very hard. The water of the Dayarampur, Bagatipara, and Jamnagar union was very hard, whereas the Faguardiar and Pacca union was hard. The higher hardness of groundwater may be related to the presence of anions and cations of bicarbonate, sulfate, chloride, calcium, magnesium, and carbonate minerals such as calcite, dolomite, aragonite, and evaporates [62,74]. In the pre-monsoon season, the hardness of eight samples was increased, although no significant variation was found ($p > 0.05$).

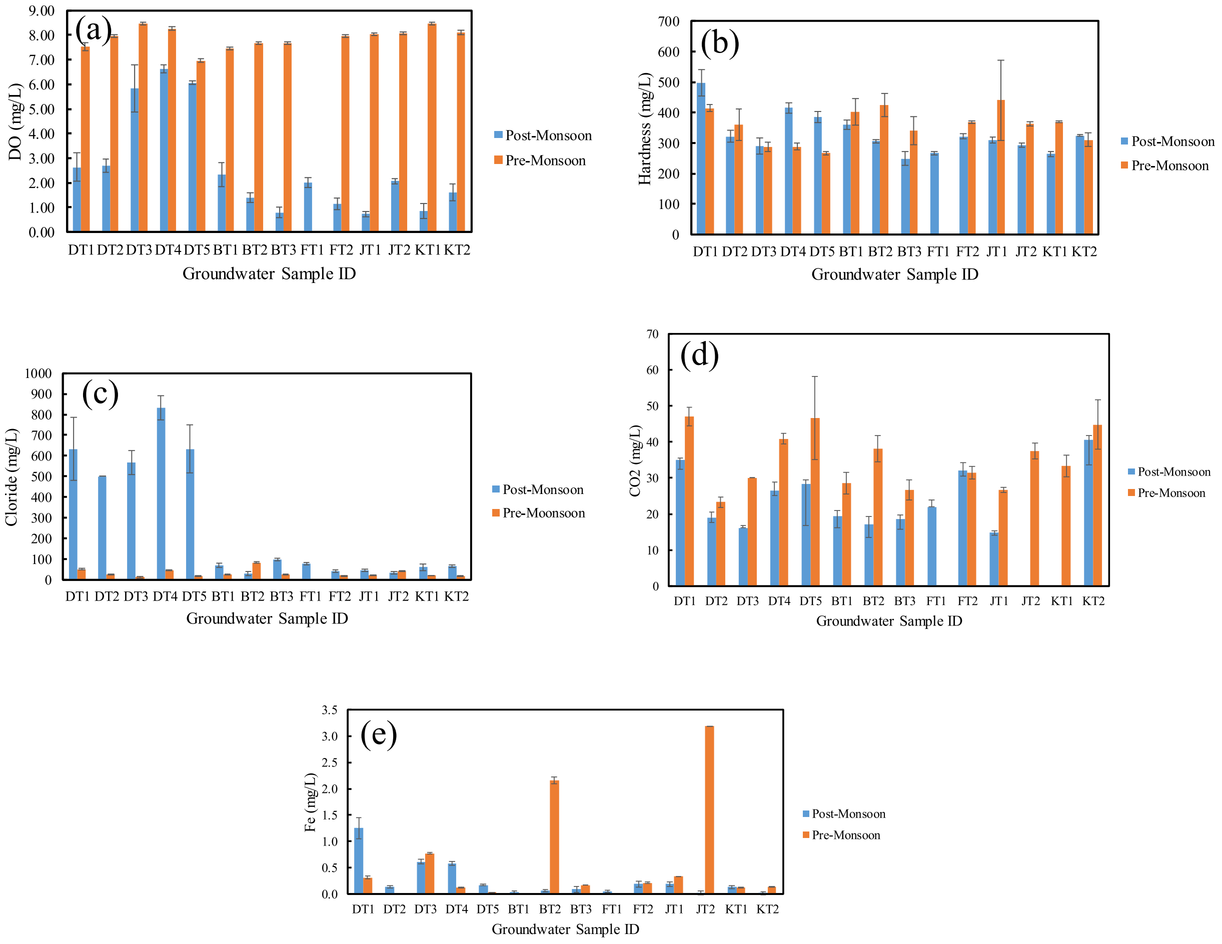

Fig. 3. Chemical concentration of groundwater samples during pre-monsoon and post-monsoon: (a) DO, (b) hardness, (c) chloride, (d) CO_2, and (e) Fe concentration.

3.1.7.1. Chloride level in groundwater. Chloride was found between 30 and 633.33 mg/L in the groundwater during the post-monsoon season, as shown in Fig. 3(c). In the Dayarampur union, the chloride content was found very high than in other unions during the post-monsoon season. Ahmmed & Kibria [48] showed chloride was found in the nearest Lalpur Upazila, which was 17.75–172 mg/L. Other researchers also found similar chloride values, ranging from 8.47 to 1324 mg/L which partially agreed with the current findings [33,60,63,74]. According to ECR [51], the ideal range of chloride drinking water is 250 mg/L. On the other hand, continuous use of high chloride-containing water negatively impacts digestion and heart and kidney functioning [64]. The possible reason for having a higher amount of chloride in groundwater mainly indicates the presence of table salt (NaCl) derived from the dissolution of hydrochloric acid salt, Na_2CO_3 [48]. No significant ($p > 0.05$) seasonal variation was observed, which indicates that the anthropogenic inputs and mineral dissolution, which are the principal sources of chloride in groundwater, remain the same throughout the year, although chloride content was decreased during the pre-monsoon season except for BT2 and JT2.

3.1.8. Carbon dioxide (CO_2) level in groundwater

CO_2 was found in the groundwater from 17.17 to 35 mg/L during the post-monsoon season, as shown in Fig. 3(d). According to WHO [53], the CO_2 standard is 0.001 mg/L for drinking water. But no such standard value has been set in Bangladesh yet. The tested water contained higher levels of carbon dioxide than the standard. The presence of high levels of CO_2 in groundwater may be caused by the reaction of groundwater with soil, minerals, and bacteria, which have been storing CO_2 for hundreds or thousands of years [75]. During the pre-monsoon season, the amount of CO_2 was significantly increased ($p < 0.001$), which may lead to the corrosion of metal and lowering of pH, which was confirmed by the results discussed in “pH levels in groundwater.” The reason for the increase in CO_2 amount during the pre-monsoon season depended on several interrelated factors, such as a decrease in water tables causing less dilution of CO_2, leading to higher concentration; increased temperatures facilitating microbial activity and root respiration in the soil, producing more CO_2 that percolates in the groundwater.

3.1.8.1. Iron (Fe) level in groundwater. Iron was found to be 0.03–1.25 mg/L during the post-monsoon season, as shown in Fig. 3(e). Similar results were found by Islam et al. [33], Ahmmed & Kibria [48], and Shahidullah et al. [59], which were 0.21–2.45 mg/L, 0.4–1.90 mg/L and 0.2–1.97 mg/L respectively. According to ECR [51], drinking water should contain iron from 0.3 to 1 mg/L. The iron concentration of DT1 during the post-monsoon season and BT2 and JT1 during the pre-monsoon season exceeded the ECR [51] standard for drinking water. No seasonal significant ($P > 0.05$) seasonal variation was found because, despite seasonal changes, the iron content is mostly determined by the steady geological composition and mineral dissolution.

3.2. Bacteriological parameters

3.2.1. Total coliform (TC) & Escherichia coliform (E. coli) levels in groundwater

TC was found in fourteen samples except for DT1, and *E. coli* was found in nine samples except for DT1, BT2, BT3, FT1, and FT2 during the post-monsoon season, as shown in Fig. 4. Ahmmed & Kibria [48] also found TC & *E. coli* in the nearest Lalpur Upazila. According to ECR [51], the amount of TC and *E. coli* in drinking water is 0. TC and *E. coli* should not be present in water bodies. The leading causes of TC and *E. coli* in groundwater may be leakage from septic tanks, lack of sewerage lines, and solid waste disposal systems, which are significant threats [73].

3.2.2. Generalized quality of groundwater

Table 2 shows the statistical summary of physical (pH, EC, color, turbidity, TS, and TDS), chemical (DO, hardness, chloride, CO2, and Fe), and bacteriological (TC and E. Coli) parameters. This information is used to assess the influence of individual parameters on drinking water. The pH was found to be 7.30 ± 0.12 during the post-monsoon season and 7.45 ± 0.14 during the pre-monsoon season, which indicates the alkaline condition of groundwater in both seasons [27]. The EC was found to range from 585 to 1046 μS/cm with an average of 844.31 ± 120.59 during the post-monsoon season and 817.79 ± 130.76 μS/cm during the pre-monsoon season, which falls into category Type I, where the salts concentration was low [76]. The chloride concentration was found to be 263.57 ± 294.75 mg/L during the post-monsoon season and 31.32 ± 19.29 mg/L during the pre-monsoon season, with a range of 12–833.33 mg/L, which may be caused by domestic waste, septic tank leakage, irrigation return flow, etc. [16]. The pathogenic bacteria *E. coli* was found in the range of 0–47.50 with an average of 9.94 ± 14.53 and 5 ± 9.60 during post-monsoon and pre-monsoon seasons, respectively. In Table 2, the coefficient of variations of color, turbidity, Chloride (Cl), iron (Fe), Total Coliform (TC), and *Escherichia coli* (E. Coli) was

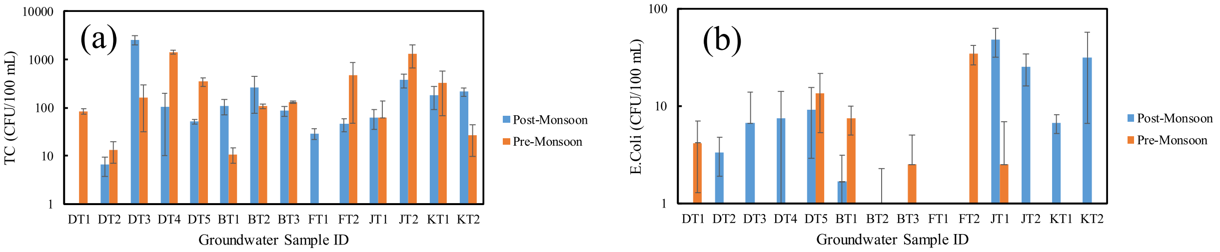

Fig. 4. Physical concentration of groundwater samples during pre-monsoon and post-monsoon: (a) TC and (b) *E. coli* concentration.

Table 2
Statistical summary of seasonal groundwater composition of the study area.

Particulars	Post-Monsoon (Post)		Pre-Monsoon (Pre)		Arithmatic mean		Standard Daviation		Coefficient of Variation (%)	
	Min	Max	Min	Max	Post	Pre	Post	Pre	Post	Pre
Physical parameters										
pH	7.12	7.56	7.25	7.68	7.30	7.45	0.12	0.14	1.64	1.93
EC (mS/cm)	0.63	1.05	0.59	1.02	0.84	0.82	0.12	0.13	14.28	15.99
Color (Pt–Co)	4.00	183.33	0.00	1250.33	33.50	157.72	46.94	348.34	140.11	220.86
Turbidity (NTU)	0.00	150.50	0.00	304.00	18.72	31.25	39.52	83.64	211.11	267.67
TS (mg/L)	0.16	0.78	0.39	1.22	0.44	0.56	0.15	0.23	35.12	40.38
TDS (mg/L)	0.14	0.71	0.34	1.11	0.39	0.49	0.14	0.20	34.92	41.42
Chemical parameters										
DO (mg/L)	0.73	6.63	6.97	8.47	2.63	7.89	2.03	0.43	77.37	5.39
Hardness (mg/L)	249.00	498.00	267.00	441.00	329.07	356.85	67.09	55.74	20.39	15.62
Chloride (mg/L)	30.00	833.33	12.00	82.50	263.57	31.32	294.75	19.29	111.83	61.59
CO_2 (mg/L)	14.83	40.50	23.33	47.00	24.14	35.00	8.29	8.08	34.34	23.10
Fe (mg/L)	0.02	1.25	0.00	3.19	0.25	0.58	0.34	0.97	136.17	167.80
Bacteriological parameters										
TC (CFU/100 mL)	0.00	2591.67	10.83	1434.17	295.24	347.05	669.81	483.16	226.87	139.22
E. coli (CFU/100 mL)	0.00	47.50	0.00	34.17	9.94	5.00	14.53	9.60	146.15	192.09

found to be more than 100 %, which indicates significantly larger spatial variation and temporal fluctuations across the different sampling locations and time. This variation may be caused by a combination of natural factors, such as geological differences and seasonal changes, as well as human activities [77], and highlights the necessity of continuous monitoring to reduce health concerns and efficiently regulate the quality of the water.

3.2.3. Water quality index (WQI)

The WQI method was generally used to check the suitability of water for drinking purposes. To provide a comprehensive understanding of the variations in water quality, the Water Quality Index (WQI) was employed. The WQI results show that, during post-monsoon, water quality at different unions of Bagatipara was different. It was found that DT1 and JT1 showed deteriorated water quality with an 'unsuitable' marking, which means this water needs to be immediately treated before use as drinking water. Also, DT3 and DT4 were found to be 'very poor,' and DT5, JT2, and KT1 were designated as 'poor,' which signifies a condition that demands immediate attention and intervention to address water quality issues. On the other hand, the remaining sampling points, namely DT2, BT1, BT2, BT3, F1, and F2, found satisfactory water quality levels with 'good' identification, which indicates these areas' water can be used for drinking purposes during the post-monsoon season.

The detailed variations of WQI for both seasons are visually depicted in the geospatial map presented in Fig. 5. This map is a valuable tool for visualizing the spatial distribution of water quality variations across the sampled points, facilitating a more in-depth interpretation of the environmental conditions and aiding in targeted mitigation strategies where needed. The map (Fig. 5) shows notable variations in water quality across the Bagatipara upazila during both the pre-monsoon and post-monsoon periods. Specifically,

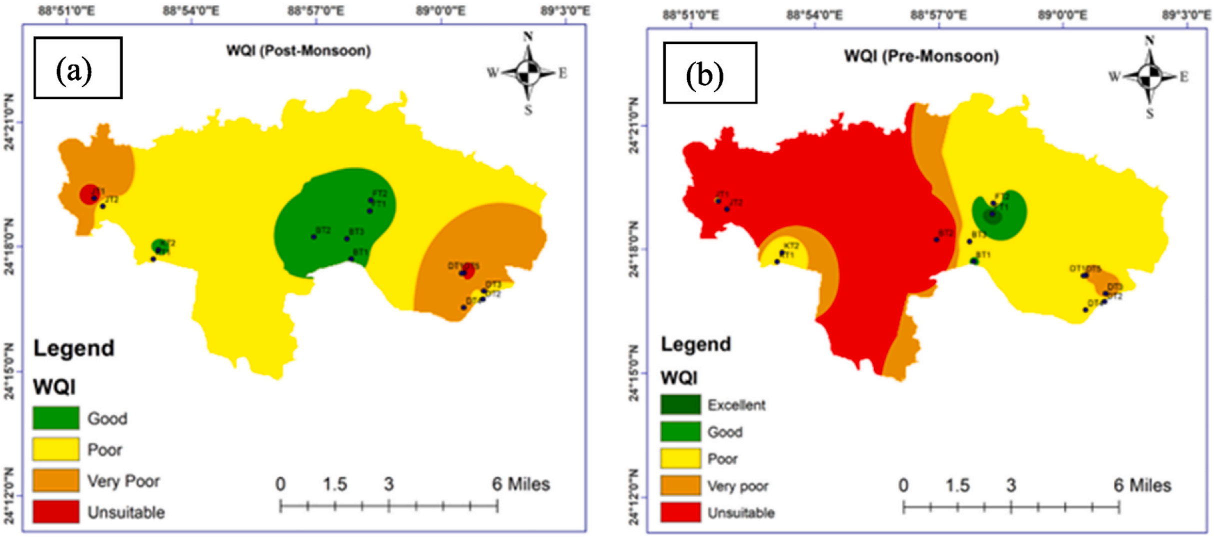

Fig. 5. Spatial distribution of water quality index (WQI) of groundwater during (a) post-monsoon season and (b) pre-monsoon season within the targeted region.

during the post-monsoon season, the central segment of Bagatipara upazila, encompassing primarily the Bagatipara and Fagurdiar areas, exhibited a ‘good’ water quality classification suitable for drinking. In contrast, the pre-monsoon period saw a more restricted zone with ‘good’ water quality, primarily confined to the Fagurdiar area. During the post-monsoon season, the remainder of the region depicted water quality ranging from ‘poor’ to ‘very poor’ conditions. This indicates a concern for water quality degradation in the areas outside Bagatipara and Fagurdiar during this period. Moreover, during the pre-monsoon phase, the middle to western sections of Bagatipara upazila experienced a significant decline in water quality, reaching an ‘unsuitable’ classification. Notably, the Pacca union remained in a condition categorized as ‘poor’ to ‘very poor’ during the pre-monsoon period.

These findings underscore the seasonal dynamics and spatial heterogeneity of water quality within Bagatipara upazila, emphasizing the critical need for targeted interventions and management strategies to address specific areas exhibiting compromised water quality. The detailed mapping information serves as a valuable resource for formulating informed decisions and implementing effective measures to enhance water quality across the region.

4. Conclusion

In conclusion, the analysis of groundwater quality of the rural region of Bagatipara, Natore indicates significant fluctuation across different parameters, seasons, and spatial locations. The study reveals that several physical and chemical parameters exceed the ECR guidelines which indicate potential contamination sources and highlight the urgency for water quality management intervention. Seasonal variations were observed with little environmental significance in pH, DO and CO_2. Spatial variability in water quality was revealed by the WQI spatial mapping showing some areas exhibited ‘excellent’ conditions that were suitable for drinking during the post-monsoon, while others showed ‘poor’ to ‘very bad’ conditions, especially during the pre-monsoon. These findings highlight the complex nature of water quality in Bagatipara Upazila, Natore and emphasize the need for targeted interventions and management strategies to address specific areas where water quality is compromised. The detailed geospatial mapping offers analytical information that may be used to make well-informed decisions and effective implementation of measures to improve water quality across the region. Overall, the study contributes novel insights into understanding the seasonal and spatial dynamics of groundwater quality which makes it an invaluable tool for guiding future water management initiatives in rural region of Natore.

Availability of data and material

Data will be made available on request.

Ethical approval

Not applicable to this manuscript.

Consent to participate

Not applicable.

CRediT authorship contribution statement

M.M. Rahman: Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **M.S. Islam:** Writing – review & editing, Project administration, Funding acquisition. **M.M. Islam:** Investigation. **T. Hasan:** Investigation. **R. Parvin:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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