COMPARATIVE ASSESSMENT OF GROUNDWATER QUALITY IN KOKRAJHAR, INDIA

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ABSTRACT

A study was carried out to analyse and compare the quality of groundwater in Kokrajhar during the pre- and post-monsoon seasons. Kokrajhar is experiencing a significant population growth and urbanisation. Groundwater is vital for the daily activities and consumption of the local population. In order to meet the needs of the local population, it is crucial to evaluate the quality of groundwater. The study involved the collection of groundwater samples from 20 different locations during the pre- and post-monsoon periods. Tests were conducted on groundwater samples to analyse 10 different test parameters. Sample points were located using geographical information system (GIS) and contour maps were generated to represent different test parameters. The assessment of groundwater quality was determined using two different methodologies: the Weighted Arithmetic Index (WAI) method and the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) method. The results obtained by both methods were compared. Minor to significant variations in various test parameters were observed during analysis of pre- and post-monsoon groundwater samples.

Keywords: *groundwater quality, WAI WQI, CCME WQI, GIS, pre- and post-monsoon groundwater*

INTRODUCTION

In order to determine various chemical and physical properties, groundwater samples are often collected from wells or other sources and then subjected to laboratory analysis using various procedures. Studies [1] have shown that the most frequently examined parameters are pH, total dissolved solids (TDS), conductivity, and main cations and anions, such as calcium, magnesium, sodium, chloride, sulphate, and nitrate. Many human activities can have an impact on groundwater, including residential, municipal, commercial, industrial, and agricultural activity [2]. In recent years, India's reliance on groundwater has increased dramatically [3]. Due to the increased use of fertilisers, pesticides, and other chemicals in agriculture, as well as the release of contaminants from industrial and sewage disposal facilities, there is increasing concern about how human activities affect groundwater quality [4, 5]. Regular monitoring of groundwater quality is necessary to solve these problems, and efficient management methods must be created to reduce the risk of contamination and protect this priceless resource [6, 7]. Understanding the condition and health of groundwater resources and ensuring that this valuable resource is maintained sustainably depends on groundwater quality studies.

Several studies have been conducted using GIS for groundwater quality assessment [8 - 12] in recent years to create new and improved methods for analysing groundwater quality. Reference [13] provides a fuzzy comprehensive evaluation approach to assess groundwater quality in China. In order to provide an integrated and comprehensive assessment of groundwater quality, the technique takes into account various elements, such as groundwater quality parameters, geological and hydrological conditions, and human activities. Similarly, [14] the current examination methods have been used to evaluate groundwater quality and contamination risk in metropolitan areas. The study recognised the shortcomings of existing methodologies and advocated for the application of new technologies, such as remote sensing and artificial intelligence to improve groundwater quality evaluation.

In short, groundwater quality analysis is critical for assessing the condition and health of groundwater resources, as well as ensuring that this precious resource is managed in a sustainable manner. In order to solve the problems caused by human activities and changing environmental circumstances, new and improved methodologies for groundwater quality analysis are needed. As a result, additional research is needed to create more efficient, cost-effective, and reliable methods for measuring groundwater quality and preservation of this vital resource.

Groundwater quality analysis usually involves the collection of groundwater samples from wells or other sources, followed by laboratory analysis using various techniques to determine different chemical and physical parameters. The most commonly analysed parameters include pH, total dissolved solids (TDS), conductivity, and major cations and anions, such as calcium, magnesium, sodium, chloride, sulphate, and nitrate. There is increased concern about the impact of human activities on groundwater quality [15], particularly due to the increased use of fertilizers, pesticides, and other chemicals in agriculture, and the release of contaminants from industrial and sewage disposal facilities [16]. In order to solve these issues, regular monitoring of groundwater quality is necessary, and effective management strategies must be developed to minimize the risk of contamination and protect this valuable resource [17]. The Water Quality Index (WQI) is important in decision-making and resource management because it provides a simplified and comprehensive assessment of water quality [18]. It facilitates effective management of water sources and determines their suitability for various purposes [19]. WQI facilitates the reduction of a large amount of data into a simple expression and enables the comparison of water quality status in different locations [20].

Water can be found both on the surface and below the surface of the earth, however, only a limited amount of surface water is safe for consumption. In India, a significant portion of the population relies on groundwater for their drinking needs in both rural and urban areas [21]. However, with increasing urbanization and inadequate waste management practices, the groundwater is facing a high risk of contamination. If the source of pollution is not effectively controlled, groundwater can be contaminated, which can lead to health hazards if consumed untreated. It is also reported that in many parts of India, groundwater is contaminated with lots of hazardous chemical due to industrial waste as well as the use of pesticides in agriculture [22, 23].

The current study focuses on the quality of groundwater in the Kokrajhar district, located in the Bodoland Territorial Region of India. Groundwater from sources, such as tube wells and bore wells is the primary source of drinking water in the region. As the population continues to grow, there is a corresponding increase in dependence on groundwater to meet the daily needs of residents. In order to assess the quality of groundwater in Kokrajhar, a study was conducted by collecting groundwater samples during pre-monsoon season in the month of May and post-monsoon season in the month of November. The samples were then subjected to laboratory tests to determine various test parameters for calculating the Groundwater Quality Index (GWQI).

STUDY AREA

The study was conducted in the Kokrajhar District, which is located in the Bodoland Territorial Region in Assam, India. According to the 2020-21 land use statistics, the district has a total forest area of 1734.65 km^2 and a total area under crops of 1405.51 km^2 [24]. Kokrajhar has an average annual rainfall of 2400 to 3000 mm, and the highest rainfall occurs from April to August [25]. The town of Kokrajhar is located on the banks of the Gaurang River and serves as the headquarters for the District and the Bodoland Territorial Region (BTR) authorities. According to the 2011 census, Kokrajhar has 887142 inhabitants, and by 2024, it is predicted that the number of inhabitants will be around 935300. The town is divided into 10 wards, and the majority of the district consists of residential areas, public/semi-public spaces, commercial areas, and recreational areas. Figure 1 shows the map of the study area.

METHODS AND METHODOLOGY

The methods and methodology applied in this study are discussed in the following sections.

Collection of samples

Collecting groundwater samples for laboratory testing is an important step in determining the quality of the groundwater. Samples should be collected using appropriate techniques to ensure that they are representative of the groundwater and are not contaminated. Groundwater samples were taken in the town of Kokrajhar, where efforts were made to collect samples from all 10 wards of the town. Since groundwater was collected from existing bore wells and dug wells, the depth of the wells varied. A total of 20 samples were collected to cover the entire area. The samples were collected in 500 ml polyethylene bottles, ensuring proper storage to avoid contamination, and each bottle was labelled with a sample number (such as S1, S2, etc.) corresponding to its location. Water samples were collected during the post-monsoon and pre-monsoon periods.

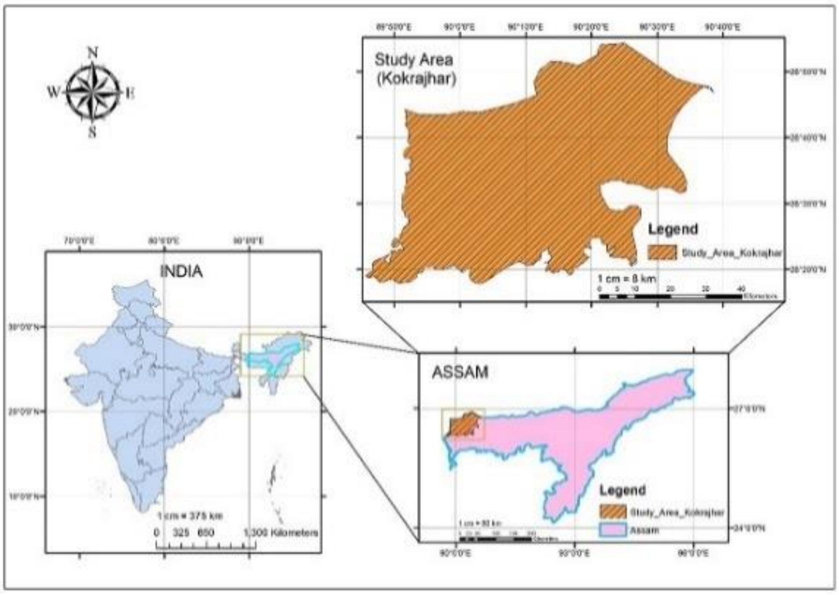

Figure 1. Map of study area (Kokrajhar)

Laboratory tests of groundwater samples

Laboratory tests of groundwater samples were carried out for 10 different parameters, which included pH, TDS, alkalinity, hardness, iron, calcium, magnesium content, electrical conductivity, nitrate, and arsenic. Laboratory testing of groundwater is a crucial process for assessing the quality of water resources. The pH test measures the acidity or basicity of water, which affects the water's ability to neutralize pollutants. pH of groundwater is an indicator of the quality and suitability for various purposes. In [26] it was found that pH, together with other factors, can indicate local contamination. Research conducted in [27] emphasized the need for pH within specific ranges for drinking and irrigation purposes. Reference [28] emphasizes the importance of pH in determining the suitability of groundwater for domestic and agricultural use. TDS measures the amount of inorganic and organic substances dissolved in water. Reference [26] emphasizes the importance of TDS in groundwater pollution assessment, especially in the context of hydrochemical properties. The alkalinity test determines the water's ability to neutralize acid, while hardness test measures the concentration of calcium and magnesium ions. Reference [29] states that the alkalinity test can help in identifying the potential sources of contamination, such as rock-water interaction, geogenic factors and human-induced pollution. The iron content test measures the amount of iron present in the groundwater. Calcium and magnesium tests determine the concentration of these essential minerals in groundwater, which can affect the hardness and taste of water. The nitrate test measures the amount of nitrates in the water, which can indicate contamination from fertilizer or animal waste. The arsenic content in groundwater samples was also examined. These tests provide valuable information about groundwater quality and help ensure that it is safe for drinking, irrigation, and other purposes.

Analysis for Groundwater Quality Index (GWQI)

The analysis for GWQI was done to study the quality of water during post- and pre-monsoon seasons. The GWQI was calculated using Weighted Arithmetic Index (WAI) method developed by [3] and the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (2001) [9]. The permissible limits of all the test parameters for drinking water according to the Bureau of Indian Standard (BIS) are given in Table 1.

Table 1. Permissible limits of tested parameters of drinking water according to Indian standard IS 10500: 2012 [30]

Test parameter	Permissible limit according to IS 10500: 2012
Iron	< 1.0 mg/l
Arsenic	< 0.05 mg/l
Nitrate	< 45 mg/l
Electrical conductivity	< 3000 μS/cm
pH	6.5 - 8.5
TDS	500 mg/l
Alkalinity	200 mg/l
Calcium	75 mg/l
Magnesium	30 mg/l
Hardness	200 mg/l

Weighted Arithmetic Index (WAI) method

The WAI method is a frequently used tool for groundwater quality analysis. This method is based on the concept of assigning weights to different water quality parameters based on their relative importance and then using these weights to calculate an overall index value for each sample. The weights are based on various factors, including the concentration of the parameter in the water sample, the toxicity of the parameter, and the presence of relevant water quality guidelines or standards. The weighted values of each parameter are then summed up to calculate the overall WAI score for each sample. The WAI is widely used in groundwater quality analysis for a variety of purposes, including assessing the suitability of water for different uses, such as irrigation, drinking and industrial purposes, identifying potential sources of contamination, and the monitoring water quality trends over time. Table 2 shows the categorization of water quality according to weighted arithmetic water quality index.

Table 2. Categorization of water quality according to WAI and CCME WQI

WAI method		CCME WQI	
WQI value	Water quality status	WQI value	Water quality status
0 - 25	Excellent	95 - 100	Excellent
26 - 50	Good	80 - 94	Good
51 - 75	Poor	65 - 79	Fair
76 - 100	Very poor	45 - 64	Poor
> 100	Not suitable for drinking	0 - 44	Very poor

Steps according to the WAI method for calculating the WQI:

Step 1: Unit weight (W_n) factor for each parameter is calculated using the following formula:

$$W_n = \frac{K}{S_n} \qquad (1)$$

and

$$K = \frac{1}{\frac{1}{S_1} + \frac{1}{S_2} + \ldots + \frac{1}{S_n}} = \frac{1}{\Sigma \frac{1}{S_n}} \qquad (2)$$

where is: S_n - standard desirable value of the nth parameters. On summation of all unit weight factors of selected parameters, $W_n = 1$.

Step 2: Calculate the sub-index (Q_n) value using following formula:

$$Q_n = \frac{[V_n - V_o]}{[S_n - V_o]} \times 100 \qquad (3)$$

where is: V_n - mean concentration of the nth parameters, V_o - actual values of parameters in pure water, generally $V_o = 0$ for most parameter except pH:

$$Q_{pH} = \frac{[(V_{pH} - 7)]}{[(8.5 - 7)]} \times 100 \qquad (4)$$

Step 3: Combining step 1 and step 2, the WQI is calculated as follows:

$$\text{Overall } WQI = \frac{\Sigma W_n Q_n}{\Sigma W_n} \qquad (5)$$

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI)

In 1997, the Canadian Council of Ministers of the Environment (CCME) modified the British Colombia Water Quality Index (WQI) to create the CCME WQI, which could be applied by many water agencies in various countries with minor modification [13]. The CCME WQI was developed as a water quality assessment and reporting tool for management institutions and the public. The WQI provides a comprehensive and integrated assessment of water quality based on multiple parameters. The WQI ranges from 0 to 100, with higher scores indicating higher water quality and lower scores indicating lower water quality. The WQI is designed to be simple, transparent, and easy to understand by a wide range of stakeholders, including government agencies, industry, and the general public. The CCME WQI is used to support water management and decision-making by providing a consistent and comprehensive assessment of water quality across different regions and jurisdictions in Canada. The WQI is also used as an indicator of progress towards achieving water quality objectives, and as a tool for communication and reporting on water quality status and trends. Table 2 shows the categorization of water quality according to the CCME WQI.

Steps according to the method developed by CCME for calculating the WQI:

Step 1: Calculation of F_1 value (scope):

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \qquad (6)$$

Step 2: Calculation of F_2 value (frequency):

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \qquad (7)$$

Step 3: Calculation of F_3 value (amplitude):

3.1. Excursion

$$\text{excursion}_i = \frac{\text{Failed test value}_i}{\text{Objective}_i} - 1 \quad (8)$$

3.2. Normalised sum of excursion (nse)

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}}{\text{Total number of test}} \quad (9)$$

3.3. F_3 value

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01} \quad (10)$$

$$\text{Overall CCME WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (11)$$

RESULTS AND DISCUSSION

Results of laboratory tests of pre- and post-monsoon groundwater samples

The results of the laboratory tests for all 10 test parameters are presented in Table 3. All samples were within the limits prescribed by the BIS standard, which makes the groundwater in Kokrajhar suitable for consumption. After examining the influence of the monsoon on various groundwater parameters, no significant differences were observed. The pH showed a decrease of 4 % in sample S8 and an increase of 3 % in sample S1. The TDS decreased during the post-monsoon period in all samples, and the highest decrease of 91 % was observed in sample S12. The alkalinity of the water samples also decreased during the post-monsoon, and the highest decrease of 51 % was observed in sample S10. The changes in hardness varied among samples, with the highest increase of 42 % in sample S5 and the highest decrease of 33 % in sample S20. The changes in the NO_3-, Ca, and Mg contents also varied slightly in different samples.

Contour maps showing the variations of all the test parameters were created using the Inverse Distance Weighted (IDW) method by using ArcGIS software. Figures 2 to 11 show the contour maps generated for various test parameters and give a clear understanding of the changes in the parameters during the pre- and post-monsoon periods.

Table 3. Results of testing the parameters of groundwater samples collected during pre- and post-monsoon

Sample No.	Type of source	Monsoon period	pH	TDS (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Fe (mg/l)	Ca (mg/l)	Mg (mg/l)	EC (µS/Cm)	NO_3 (mg/l)	As (mg/l)
1	Bore well	Pre	6.7	109.5	90	78	0.08	17.61	6.8	20.2	8.1	0
		Post	6.89	107.3	84	72	0.12	20.02	6.8	19.93	11.4	0
2	Tube well	Pre	6.3	210.8	102	110	0.68	27.23	10.2	35.5	11.2	0.001
		Post	6.25	204.1	94	102	0.66	28.83	7.29	36.1	13.5	0
3	Bore well	Pre	6.31	195.6	84	104	0.25	25.63	9.72	34.4	13.5	0
		Post	6.28	191.8	78	98	0.12	27.23	7.29	35	15.7	0.001
4	Bore well	Pre	6.37	58.4	68	56	0.25	20.02	1.46	9.8	10.2	0
		Post	6.26	43.79	40	62	0.21	19.23	3.4	8.67	9.3	0
5	Tube well	Pre	6.06	110.4	68	48	2.37	16.82	1.46	21.1	13.4	0.004
		Post	5.98	95.78	44	68	2.26	22.42	2.92	18.34	14.3	0.005
6	Bore well	Pre	7.08	118.8	128	86	2.3	19.22	9.23	20.9	14.4	0.005
		Post	7.14	112.9	94	102	2.27	24.02	10.21	21.3	12.3	0.005
7	Tube well	Pre	6.12	96.5	66	70	0.35	20.82	4.37	16.41	0	0
		Post	6.02	88.23	50	78	0.29	20.02	6.8	13.34	0	0
8	Tube well	Pre	6.35	236	128	80	0.25	30.43	0.97	42.1	0.01	0
		Post	6.07	166.5	54	80	0.23	24.82	4.37	31.1	0.02	0

Table 3 (continued). Results of testing the parameters of groundwater samples collected during pre- and post-monsoon

Sample No.	Type of source	Monsoon period	pH	TDS (mg/l)	Alkalinity (mg/l)	Hardness (mg/l)	Fe (mg/l)	Ca (mg/l)	Mg (mg/l)	EC (μS/Cm)	NO_3 (mg/l)	As (mg/l)
9	Tube well	Pre	6.16	165.9	92	60	0.28	20.02	2.43	28.2	0	0
		Post	6.08	156.2	52	82	0.27	32.03	0.49	28.5	0	0
10	Tube well	Pre	6.22	240	102	80	0.35	22.42	5.83	40.5	0	0
		Post	6.2	205.8	50	106	0.24	24.02	11.18	38.5	0	0
11	Tube well	Pre	6.15	156.7	90	70	2.5	16.02	7.29	26.7	0	0.004
		Post	6.06	145.5	56	86	2.64	16.82	10.69	22.3	0	0.004
12	Bore well	Pre	6.2	146.2	90	90	2.3	25.63	6.32	24.8	0	0.005
		Post	6.23	12.8	60	84	2.21	23.22	6.32	25	0	0.005
13	Bore well	Pre	6.33	151.8	78	110	2.15	23.22	12.64	27.1	5.1	0.004
		Post	6.34	193.8	52	90	2.21	13.61	13.61	27	4.6	0.004
14	Bore well	Pre	6.2	105.6	60	70	2.1	15.22	7.78	20.1	8.5	0.003
		Post	6.14	99.34	52	64	2.26	12.81	7.78	19.2	9.2	0.003
15	Tube well	Pre	6.4	250.8	100	114	2.52	32.03	8.26	38.3	8	0.003
		Post	6.31	249.7	110	112	2.77	30.43	18.47	39.5	8.5	0.005
16	Bore well	Pre	6.91	108.9	80	88	0.37	28.03	4.37	18.96	3.5	0
		Post	6.63	100.6	64	72	0.23	26.43	1.46	19.12	4.6	0
17	Tube well	Pre	5.89	100.2	42	70	1.8	20.02	4.86	16.31	1	0.005
		Post	5.78	78.94	22	66	2.29	20.82	3.4	15.05	0	0.005
18	Tube well	Pre	6.16	165.9	86	100	0.45	16.02	14.58	28.5	0	0
		Post	6.15	139.7	62	88	0.22	14.41	12.64	25.9	0	0
19	Bore well	Pre	6.44	97.5	60	74	2.15	24.02	3.4	16.05	0	0.004
		Post	6.36	80.92	32	78	2.26	28.02	1.94	15.73	0	0.005
20	Tube well	Pre	5.89	88.5	44	104	2.12	23.22	11.18	14.44	0	0.003
		Post	5.83	70.91	22	70	2.26	19.22	5.35	13.66	0	0.004

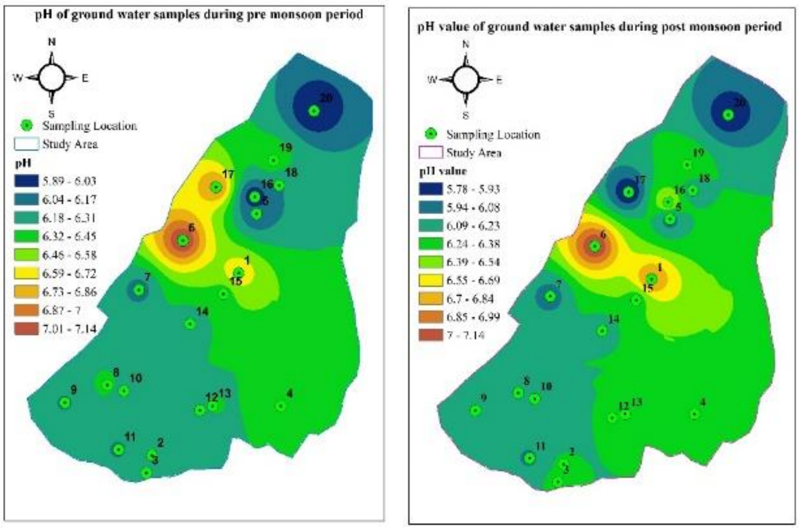

Figure 2. Variations of pH of groundwater during pre- and post-monsoon periods

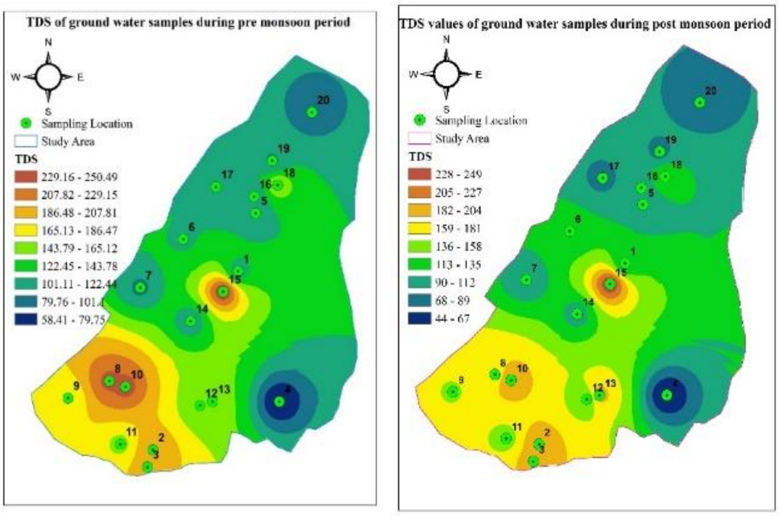

Figure 3. Variations of TDS in groundwater during pre- and post-monsoon periods

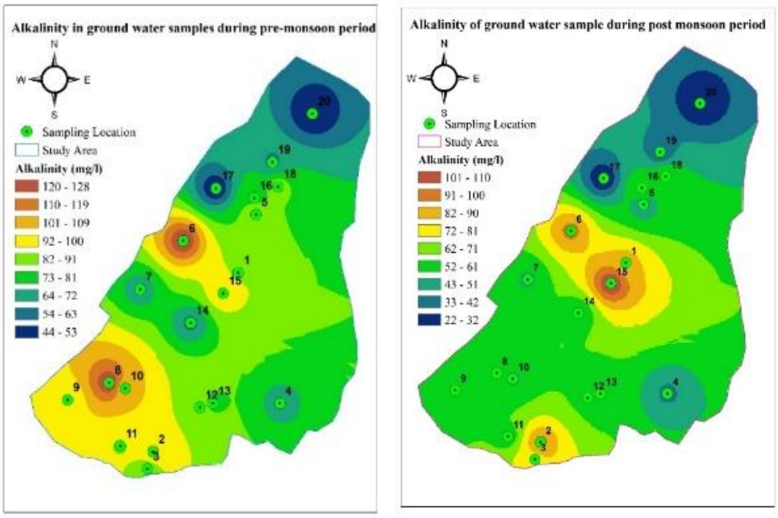

Figure 4. Variations of alkalinity of groundwater during pre- and post-monsoon periods

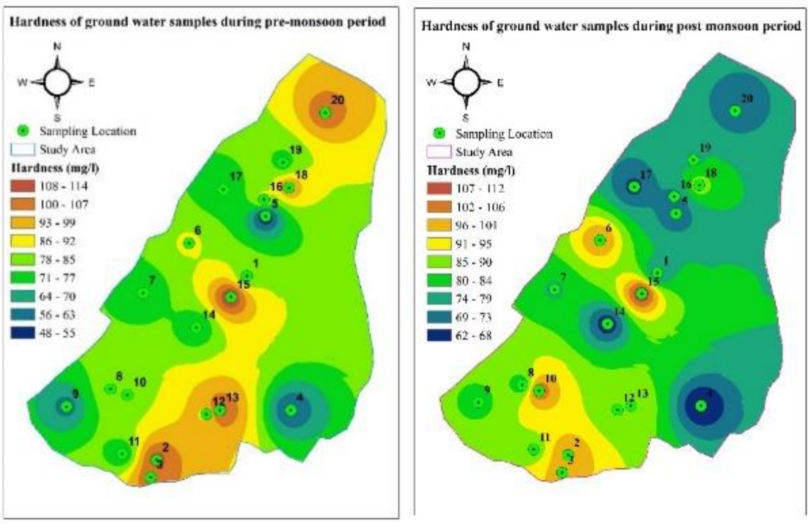

Figure 5. Variations of hardness of groundwater during pre- and post-monsoon periods

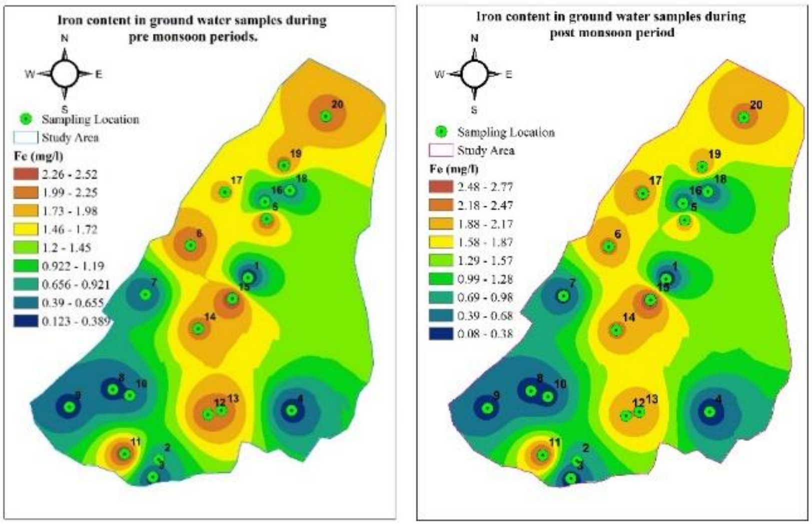

Figure 6. Variations of iron content in groundwater during pre- and post-monsoon periods

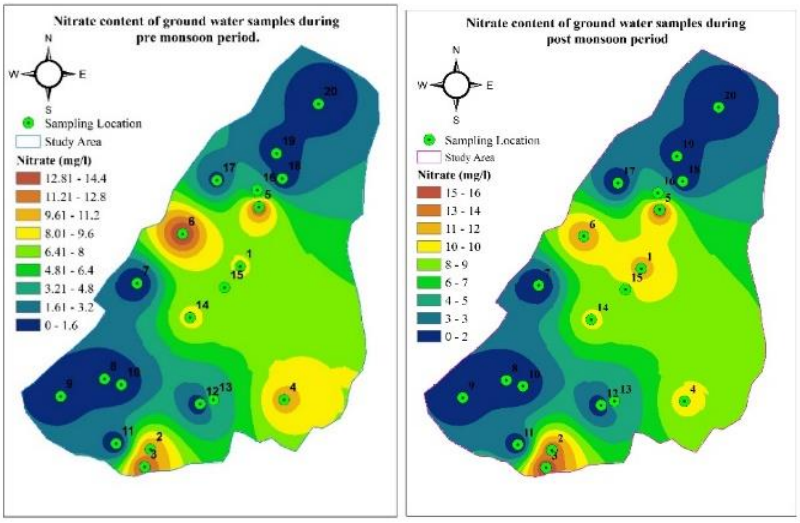

Figure 7. Variations of nitrate content in groundwater during pre- and post-monsoon periods

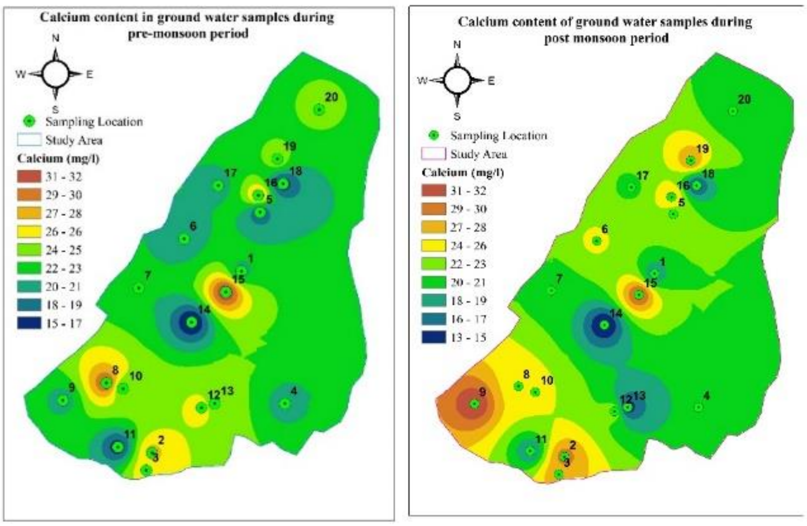

Figure 8. Variations of calcium content in groundwater during pre- and post-monsoon periods

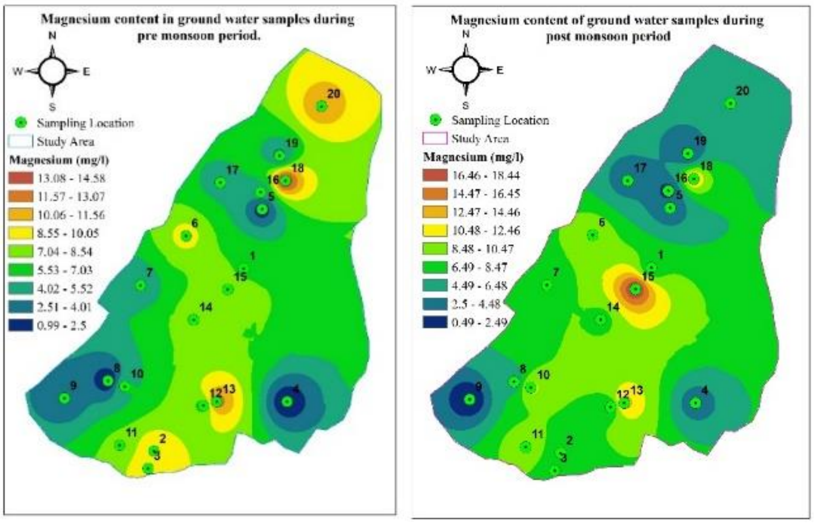

Figure 9. Variations of magnesium content in groundwater during pre- and post-monsoon periods

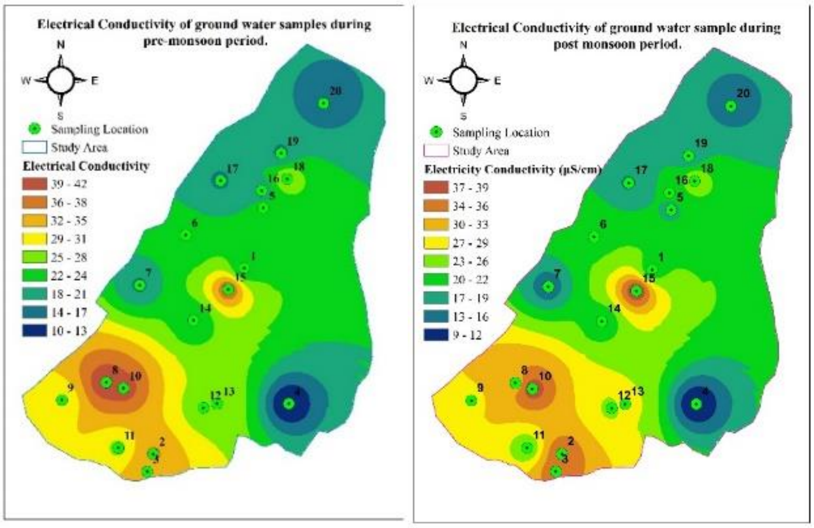

Figure 10. Variations of electrical conductivity of groundwater during pre- and post-monsoon periods

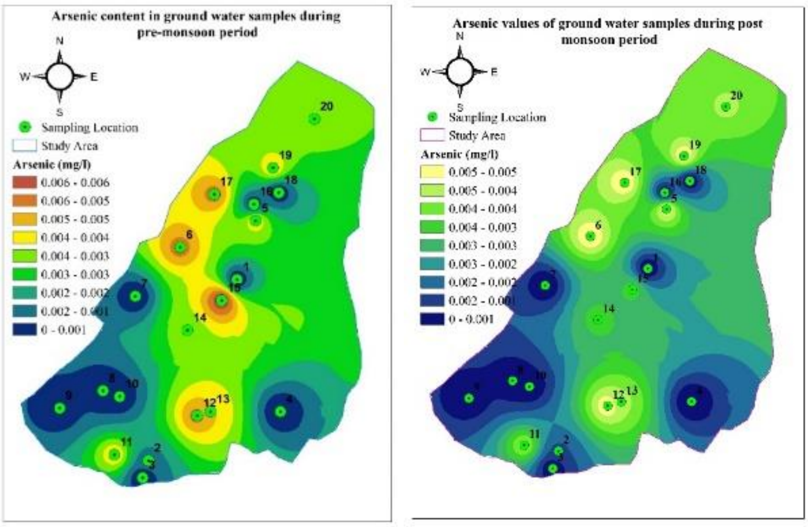

Figure 11. Variations of arsenic content in groundwater during pre- and post-monsoon periods

Groundwater quality index (GWQI)

As shown in Table 4, out of 20 samples, the groundwater quality was excellent in 16 samples and good in 4 samples when determined by the WAI method. When the CCME WQI was used, all samples showed excellent quality, as shown in Table 5. Therefore, it can be concluded that the groundwater in the researched area is suitable for consumption and other uses.

Table 4. Water quality index according to WAI method

Sample No.	Monsoon	WQI value	Water quality status	Sample No.	Monsoon	WQI value	Water quality status
S1	Post	7.39	Excellent	S11	Post	23.25	Excellent
	Pre	10.86	Excellent		Pre	20.65	Excellent
S2	Post	21.19	Excellent	S12	Post	18.98	Excellent
	Pre	20.77	Excellent		Pre	19.92	Excellent
S3	Post	20.66	Excellent	S13	Post	19.05	Excellent
	Pre	20.48	Excellent		Pre	19.72	Excellent
S4	Post	17.60	Excellent	S14	Post	21.62	Excellent
	Pre	15.79	Excellent		Pre	20.56	Excellent
S5	Post	24.46	Excellent	S15	Post	32.82	Excellent
	Pre	22.29	Excellent		Pre	18.13	Excellent
S6	Post	9.54	Excellent	S16	Post	10.40	Excellent
	Pre	9.42	Excellent		Pre	25.91	Good
S7	Post	22.96	Excellent	S17	Post	26.5	Good
	Pre	20.43	Excellent		Pre	4.96	Excellent
S8	Post	21.64	Excellent	S18	Post	21.99	Excellent
	Pre	15.95	Excellent		Pre	22.64	Excellent
S9	Post	20.66	Excellent	S19	Post	15.17	Excellent
	Pre	19.22	Excellent		Pre	13.97	Excellent
S10	Post	21.01	Excellent	S20	Post	26.02	Good
	Pre	19.36	Excellent		Pre	27.01	Good

Table 5. Water quality index according to CCME WQI method

Sample No.	CCME WQI value	Water quality status	Sample No.	CCME WQI value	Water quality status
S1	96.13	Excellent	S11	96.13	Excellent
S2	96.13	Excellent	S12	96.13	Excellent
S3	96.13	Excellent	S13	96.13	Excellent
S4	96.13	Excellent	S14	96.13	Excellent
S5	96.13	Excellent	S15	96.13	Excellent
S6	96.13	Excellent	S16	96.13	Excellent
S7	96.13	Excellent	S17	96.13	Excellent
S8	96.13	Excellent	S18	96.13	Excellent
S9	96.13	Excellent	S19	96.13	Excellent
S10	96.13	Excellent	S20	96.13	Excellent

CONCLUSION

In this study, groundwater parameters tested showed no significant changes during pre- and post-monsoon periods, only minor variations. The groundwater was within the limits prescribed by the BIS standard, which makes it suitable for consumption and other purposes. The GWQI obtained using CCME WQI and WAI method showed that most of the groundwater samples had excellent quality, and a few samples had good quality. Adequate groundwater quality in this region is probably due to the low levels of pollution from industries and a lack of significant sources of pollution. Results may also vary depending on the depth of the groundwater source in some locations. The presence of rice fields near some water sources had little to moderate impact on groundwater quality during the post-monsoon period. This could be due to the rainwater percolating through the surface and reaching the groundwater, resulting in a small change in the groundwater quality.

In this study, the depth of the sample collection point was not considered. Therefore, it will be useful to make a study taking into account the depth of the sample collection point and the long-term effect of rainfall variations.

REFERENCES

[1] S. Anbazhagan, A.M. Nair, Geographic information system and groundwater quality mapping in Panvel Basin, Maharashtra, India, Environmental Geology 45(2004), 753-761. https://doi.org/10.1007/s00254-003-0932-9

[2] A. Bayram, H. Önsoy, Sand and gravel mining impact on the surface water quality: a case study from the city of Tirebolu (Giresun Province, NE Turkey), Environmental Earth Sciences 73(2015), 1997-2011. https://doi.org/10.1007/s12665-014-3549-2

[3] R.M. Brown, N.I. McClelland, R.A. Deininger, M.F. O'Connor, A Water Quality Index - Crashing the Psychological Barrier, in: Indicators of Environmental Quality, Environmental Science Research, ed.: W.A. Thomas, vol. 1, Springer, Boston, MA, 173-182. https://doi.org/10.1007/978-1-4684-2856-8_15

[4] A. Saraswat, T. Nath, M.E. Omeka, C.O. Unigwe, I.E. Anyanwu, S.I. Ugar, A. Latare, M.B. Raza, B. Behera, P.P. Adhikary, A. Scopa, M.A.E. Abdel Rahman, Irrigation suitability and health risk assessment of groundwater resources in the Firozabad industrial area of north-central India: An integrated indexical, statistical, and geospatial approach, Frontiers in Environmental Science 11(2023), 1-30. https://doi.org/10.3389/fenvs.2023.1116220

[5] G.V. Ratnalu, R. Dhakate, S. More, Aqueous geochemistry and non-carcinogenic health risk through chloride and nitrate enriched groundwater of cosmopolitan Bangalore city, India, International Journal of Environmental Analytical Chemistry (2023), 1-25. https://doi.org/10.1080/03067319.2023.2173007

[6] S.K. Abanyie, O.B. Apea, S.A. Abagale, E.E.Y. Amuah, E.D. Sunkari, Sources and factors influencing groundwater quality and associated health implications: A review, Emerging Contaminants 9(2023) 2, Article ID: 100207. https://doi.org/10.1016/j.emcon.2023.100207

[7] B. Pradhan, S. Chand, S. Chand, P.R. Rout, S.K. Naik, Emerging groundwater contaminants: A comprehensive review on their health hazards and remediation technologies, Groundwater for Sustainable Development 20(2023), Article ID: 100868. https://doi.org/10.1016/j.gsd.2022.100868

[8] H.H. Khan, A. Khan, S. Ahmed, J. Perrin, GIS-based impact assessment of land-use changes on groundwater

quality: study from a rapidly urbanizing region of South India, Environmental Earth Sciences 63(2011), 1289-1302. https://doi.org/10.1007/s12665-010-0801-2

[9] R. Damo, P. Icka, Evaluation of Water Quality Index for Drinking Water, Polish Journal of Environmental Studies 22(2013) 4, 1045-1051.

[10] R. Vijay, P. Khobragade, P.K. Mohapatra, Assessment of groundwater quality in Puri City, India: an impact of anthropogenic activities, Environmental Monitoring and Assessment 177(2011), 409-418. https://doi.org/10.1007/s10661-010-1643-9

[11] B.S. Kamble, P.R. Saxena, R.M. Kurakalva, K. Shankar, Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar municipal solid waste dumpsite of Hyderabad city, India, SN Applied Sciences 2(2020), Article number: 498. https://doi.org/10.1007/s42452-020-2199-0

[12] R.K. Rai, A. Upadhyay, C.S. Ojha, V.P. Singh The Yamuna river basin: water resources and environment, Springer Dordrecht, 2011. https://doi.org/10.1007/978-94-007-2001-5

[13] V. Dao Thi Bich, Modification of the Canadian Water Quality Index : Case Study Assessment of Groundwater Quality in Mekong Delta, Vietnam, Ph.D. Thesis, Technische Universität, Darmstadt, 2020. https://doi:10.25534/tuprints-00014394

[14] J.C. Egbueri, C.O. Unigwe, M.E. Omeka, D.A. Ayejoto, Urban groundwater quality assessment using pollution indicators and multivariate statistical tools: a case study in southeast Nigeria, International Journal of Environmental Analytical Chemistry 103(2023) 14, 3324-3350. https://doi.org/10.1080/03067319.2021.1907359

[15] A.R. Finotti, R. Finkler, N. Susin, V.E. Schneider, Use of water quality index as a tool for urban water resources management, International Journal of Sustainable Development and Planning, 10(2015) 6, 781-794. https://doi:10.2495/SDP-V10-N6-781-794

[16] S.K. Gupta, R.D. Deshpande, Water for India in 2050: first-order assessment of available options, Current Science 86(2004) 9, 1216-1224.

[17] A.S. Jasrotia, A.K. Taloor, U. Andotra, B.D. Bhagat, Geoinformatics based groundwater quality assessment for domestic and irrigation uses of the Western Doon valley, Uttarakhand, India, Groundwater and Sustainable Development 6(2018), 200-212. https://doi.org/10.1016/j.gsd.2018.01.003

[18] N. Akhtar, M.I.S. Ishak, M.I. Ahmad, K. Umar, M.S. Md Yusuff, M.T. Anees, A. Qadir, Y.K.A. Almanasir, Modification of the Water Quality Index (WQI) Process for Simple Calculation Using the Multi-Criteria Decision-Making (MCDM) Method: A Review, Water 13(2021) 7, Article ID: 905. https://doi.org/10.3390/w13070905

[19] R. Rana, R. Ganguly, Water quality indices: challenges and applications - an overview, Arabian Journal of Geosciences 13(2020), Article number: 1190. https://doi.org/10.1007/s12517-020-06135-7

[20] Z.Z. Aljanabi, A.-H. M.J. Al-Obaidy, F.M. Hassan, A brief review of water quality indices and their applications, IOP Conference Series: Earth and Environmental Science 779(2021), Article ID: 012088. https://doi:10.1088/1755-1315/779/1/012088

[21] B. Nas, A. Berktay, Groundwater quality mapping in urban groundwater using GIS, Environmental Monitoring and Assessment 160(2010) 1, 215-227. https://doi.org/10.1007/s10661-008-0689-4

[22] N. Boraah, S. Chakma, P. Kaushal, Remediation of toxic contaminants from groundwater using low-cost adsorbent, EGU General Assembly 2023, Vienna, Austria, April 23 - 28, 2023, EGU23-

559. https://doi.org/10.5194/egusphere-egu23-559

[23] A. Nayak, G. Matta, D.P. Uniyal, A. Kumar, P. Kumar, G. Pant, Assessment of potentially toxic elements in groundwater through interpolation, pollution indices, and chemometric techniques in Dehradun in Uttarakhand State, Environmental Science and Pollution Research 31(2024), 36241-36263, (2024) https://doi.org/10.1007/s11356-023-27419-x

[24] Land use Statistics 2020-21, Government of Assam, India. https://des.assam.gov.in/documents-detail/land-utilisation-statistics, Accessed: December 10, 2023.

[25] Government of Assam, Kokrajhar District, General information about district, India. https://kokrajhar.assam.gov.in/about-district/district-glance, Accessed: December 10, 2023.

[26] A.F. Bon, S.D. Aoudou, A.M. Ndam, E.A. Bineli, E.D. Fita, Groundwater Pollution Index Evaluation Test Using Electrical Conductivity in a Semi-arid Quaternary Aquifer (Kousseri-Cameroon, Lake Chad Basin): Multivariate Statistical Analysis Approach, in: Advances in Sustainable and Environmental Hydrology, Hydrogeology, Hydrochemistry and Water Resources, Proceedings of the 1st Springer Conference of the Arabian Journal of Geosciences (CAJG-1), Tunisia 2018, eds: H.I. Chaminé, M. Barbieri, O. Kisi, M. Chen, B.J. Merkel, CAJG 2018, Springer, Cham, 2019, 295-297. https://doi.org/10.1007/978-3-030-01572-5_70

[27] K.S. Rawat, T.G.A. Jacintha, S.K. Singh, Hydro-chemical Survey and Quantifying Spatial Variations in Groundwater Quality in Coastal Region of Chennai, Tamilnadu, India - a case study, Indonesian Journal of Geography 50(2018) 1, 57-69. https://doi.org/10.22146/ijg.27443

[28] J. Iqbal, C. Su, A. Rashid, N. Yang, M.Y.J. Baloch, S.A. Talpur, Z. Ullah, G. Rahman, N. Ur Rahman, Earjh, M.M. Sajjad, Hydrogeochemical Assessment of Groundwater and Suitability Analysis for Domestic and Agricultural Utility in Southern Punjab, Pakistan, Water 13(2021) 24, Article ID: 3589. https://doi.org/10.3390/w13243589

[29] J. Chen, Q. Huang, Y. Lin, Y. Fang, H. Qian, R. Liu, H. Ma, Hydrogeochemical Characteristics and Quality Assessment of Groundwater in an Irrigated Region, Northwest China, Water 11(2019) 1, Article ID: 96. https://doi.org/10.3390/w11010096

[30] IS 10500: 2012, Drinking water - Specification, Indian Standard, Bureau of Indian Standards, New Delhi, 2012.