Water quality index assessment of groundwater in the Central Ganga Plain with reference to Raebareli district, Uttar Pradesh, India

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The major problem of groundwater contamination primarily in the Indo-Gangetic alluvium is of fluoride, nitrate, arsenic, iron and salinity. One such area is Raebareli district, Uttar Pradesh, India representing the central Indo-Gangetic alluvium, where groundwater contamination through fluoride, nitrate and salinity has already been reported. However, a comprehensive picture pertaining to water quality as a whole has not been published yet. The present study deals with the changes in water quality parameters in groundwater samples of Raebareli district to present a wholesome picture. The results for water quality index (WQI) show that 7% samples in the study area are in the class of 'unsuitable for drinking' purposes, with WQI value as high as 411.5. Moreover, the results suggest that 57% and 43% of the samples in the pre-monsoon and post-monsoon period respectively, are under the category of 'poor' water. This study will enable the government authorities to suggest alternate drinking water sources in the affected area.

Keywords: Alluvium, fluoride, groundwater pollution, nitrate, salinity, water quality index.

GROUNDWATER is adversely affected by various pollutants, making it unsuitable for various domestic uses[1]. The qualitative and quantitative deterioration is primarily due to rapid urbanization, economic development and subsequent industrialization, which have led to unmonitored withdrawal of groundwater[2]. The groundwater quality deterioration also largely depends upon various anthropogenic and geogenic factors such as soil–water interaction, mineral composition of the soil, geochemistry, application of chemical fertilizers, industrial effluents, dumping of solid waste, residence time and reactions with pollutants, etc.[3–5]. There are several approaches to assess groundwater quality. However, use of water quality index (WQI) remains one of the popular methods, which confirms compliance with the standards[6] and provides sufficient information to the stakeholders[7,8]. Numerous indexing methods exist which are also used to assess groundwater quality. Some of those are, National Sanitation Foundation Water Quality Index (NSFWQI), Bureau of Indian Standards (BIS) 10,500 weighted WQI, leachate pollution index (LPI), stream health index (SHI), Oregon water quality index (OWQI) and the Canadian Council of Ministers of the Environment water quality index (CCMEWQI)[9,10]. WQI makes use of large quantities of water quality data and transforms them to a single entity to describe the status of water quality[11,12].

Various studies have confirmed the elevated concentration of major water contaminants such as nitrate, salinity and fluoride in groundwater of Raebareli district, Uttar Pradesh, India[13,14]. Although these studies analysed the variation in individual water quality parameters, no conducive study has been conducted for Raebareli district. The present study aimed at a comprehensive assessment of groundwater quality in Raebareli district. The sites in the present study are mostly rural. During field study, it was found that people are not aware about water quality standards and the compliance of water that they are consuming[1]. This study provides a WQI report for Raebareli district to assess groundwater suitability for drinking and other domestic uses.

Description of the study area

Raebareli district lies in the northern part of the Indo-Gangetic alluvial plain, between 25°80′N and 26°40′N, 80°41′E and 81°35′E (ref. 1) (Figure 1). The present study was carried out in rural areas of four blocks, viz. Khiron, Lalganj, Rahi and Amawa. The district as a whole is a fairly compact tract of gently undulating topography[1]. The elevation varies from about 120.4 m amsl in the northwest to 86.9 m amsl in the southeast, on the banks of River Ganga. The mean annual rainfall is ~1150 mm (ref. 1). The district is underlain by alluvial sediments of Quaternary age[1,15]. The sediments from older Ganga alluvium are partly undergoing denudation, while the newer alluvium is under the process of formation[15]. According to the reports by the Central Groundwater Board[16], a four-tier aquifer system exists in the study area. In general, the first aquifer group (unconfined aquifers) consists of clay sediments and occurs up to 100 m bgl. The second and third groups are characterized by the

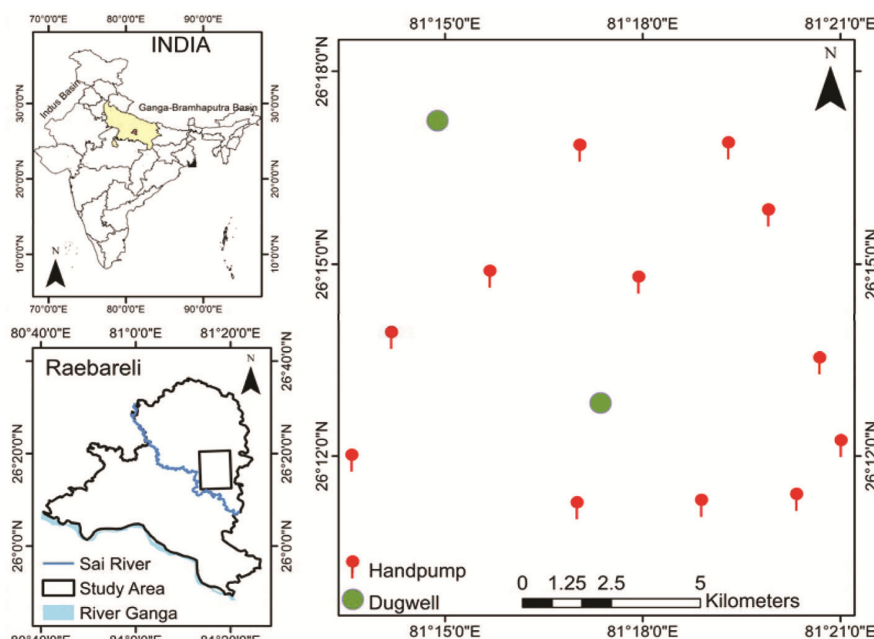*For correspondence. (e-mail: abhishek.ce@srmu.ac.in)

Figure 1. Location of the study area in Raebareli district, Uttar Pradesh, India.

presence of clay and kankar, with occasional sandy layers. The fourth aquifer group exists below 420 m and continues till 550–600 m bgl (refs 15, 16).

Methodology

Based on previous research and government reports, initially 35 water samples were collected to identify groundwater contamination. These samples were collected from hand pumps and dugwells used for domestic purposes (Figure 1). Based on the preliminary results, groundwater samples were collected for physico-chemical analysis during the pre-monsoon period (May 2016), monsoon period (August 2016) and post-monsoon period (December 2016) spread across the four blocks of Raebareli district. These samples were collected in high-density polyethylene (HDPE) bottles (1 litre capacity), which were washed and rinsed before sample collection. The samples were stored at 4°C until the analysis was completed. The pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured at the field after sample collection. Cations, viz. calcium, potassium, magnesium and sodium, and anions, viz. nitrate, chloride, sulphate and fluoride were analysed using ion chromatography (Metrohm850 Professional IC). Total hardness (TH) and bicarbonates were analysed using titration method[17].

The ionic accuracy of the analytical data was validated by (a) calculating the charge balance (CB) between cations and anions using eq. (1) below[1] and (b) calculating the EC/TDS ratio.

$$\% \text{ CB} = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum \text{Cations} + \sum \text{Anions}} \times 100. \tag{1}$$

The concentration of cations and anions was expressed in meq/l. All the groundwater samples exhibited good charge balance, less than 10%, which is within the acceptable limit for groundwater[4,17]. The EC/TDS ratio was in the range 0.55–0.7, indicating that the analytical data had good precision[1,17].

Pearson's linear correlation analysis was also done for the 14 physico-chemical parameters. The correlation matrix uses the values of correlation coefficient r, which signifies the strength of linear association between two parameters[4]. Values of r ranged between –1 (strongest negative linear correlation) to +1 (strongest positive linear correlation). Pearson's correlation matrix and other statistical analyses were done using Origin Pro 2019b software[1].

WQI was calculated with reference to Indian standard for drinking water (IS1500:2012), wherein the standard value for bicarbonates was taken as specified by WHO[18]. First, all the parameters were assigned a weight (w_i) according to their importance in the overall quality criteria (Table 1). Maximum weights were assigned to fluoride and nitrate due to their importance in the overall water quality and their adverse effects on human health. Other parameters were assigned weight in the range 1–4 (ref. 4) based on their relative significance[19,20]. Secondly, the relative weight (W_i) for all the parameters was calculated using eq. (2) (Table 1)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \tag{2}$$

where W_i is the relative weight of the ith parameter, w_i the weight of the ith parameter and n is the total number

Table 1. Relative weights of water quality parameters[1]

Chemical parameters	Drinking standard (IS10500:2012)	Weight (w_i)	Relative weight (W_i)
pH	6.5–8.5	4	0.1176
Total dissolved solids (TDS)	500–2000	4	0.1176
Total hardness (TH)	200–600	2	0.0588
Chloride	250–1000	3	0.0882
Sulphate	200–400	4	0.1176
Nitrate	45–100	5	0.1471
Bicarbonates	500*	3	0.0882
Fluoride	1–1.5	5	0.1471
Calcium	75–200	2	0.0588
Magnesium	30–100	2	0.0588
		$\sum w_i = 34$	$\sum W_i = 1.000$

*WHO Standard (ref. 18). Note: All parameters are expressed in mg/l, except for pH.

Table 2. Site-wise analytical summary of physico-chemical parameters for groundwater samples during pre-monsoon period

	pH	EC	TDS	TH	F⁻	Cl⁻	SO_4^{2-}	NO_3^-	HCO_3^-	Na⁺	K⁺	Mg²⁺	Ca²⁺
RB1	7.26	1740.00	1040.00	372.50	0.82	94.00	63.74	26.86	605.00	73.00	7.12	56.21	92.00
RB2	8.69	850.00	573.00	145.61	3.95	43.00	51.36	11.77	305.00	108.00	4.06	17.30	26.46
RB3	8.56	790.00	521.00	420.67	1.54	37.00	120.00	0.00	220.00	71.00	4.24	19.00	42.00
RB4	8.65	1000.00	863.00	269.14	3.86	86.08	80.27	39.86	418.00	140.00	8.91	37.31	46.24
RB5	7.44	490.00	353.00	193.14	0.98	26.00	13.27	3.60	216.00	18.54	8.34	21.61	41.69
RB6	7.24	470.00	330.00	185.84	0.25	19.00	18.64	0.56	205.00	24.80	2.83	17.97	39.00
RB7	7.21	1750.00	1430.00	559.26	1.99	303.89	148.23	129.80	424.00	246.00	8.38	66.58	97.68
RB8	7.43	1350.00	910.00	219.04	1.85	181.90	54.20	1.49	380.00	214.00	9.73	28.36	40.93
RB9	7.26	1680.00	1180.00	427.83	2.04	224.68	107.18	14.16	478.00	228.00	10.25	48.00	67.00
RB10	7.24	700.00	535.00	348.78	1.77	73.84	18.90	17.12	285.00	21.38	4.05	46.74	62.57
RB11	7.79	4200.00	2893.00	1002.77	8.28	531.72	410.00	139.76	1012.00	529.00	18.97	195.00	50.10
RB12	7.57	420.00	284.00	178.72	0.18	26.07	13.31	0.23	171.00	43.24	5.43	20.60	11.34
RB13	7.53	1010.00	902.00	260.66	0.82	155.92	76.81	2.51	395.00	188.00	12.64	41.00	29.42
RB14	7.49	1060.00	930.00	367.20	0.13	174.34	64.34	112.34	310.00	174.00	7.46	63.00	24.51
Mean	7.67	1250.71	910.29	353.65	2.03	141.25	88.59	35.72	387.43	148.50	8.03	48.48	47.92
Minimum	7.21	420.00	284.00	145.61	0.13	19.00	13.27	0.00	171.00	18.54	2.83	17.30	11.34
Maximum	8.69	4200.00	2893.00	1002.77	8.28	531.72	410.00	139.76	1012.00	529.00	18.97	195.00	97.68
SD	0.55	964.47	664.44	221.17	2.16	141.61	101.25	51.22	216.41	135.86	4.21	45.51	24.65

Note: Electrical conductivity (EC) in µS/cm; all other parameters in mg/l, except pH. SD, Standard deviation.

of parameters. Next, a quality rating value (q_i) was assigned to each parameter, which was calculated using eq. (3):

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100, \tag{3}$$

where q_i is the quality rating of the ith parameter, C_i the concentration of the ith parameter in each water sample and S_i is the standard value for each chemical parameter according to IS10500:2012. Further, sub-index (SI) for each parameter was calculated, which was used to calculate WQI using the following equations

$$SI_i = W_i \times q_i, \tag{4}$$

$$WQI = \sum SI_{i-n}, \tag{5}$$

where SI_i is the sub-index for the ith parameter.

The computed WQI values were classified into five categories as follows[21]: excellent water (WQI < 50), good water (WQI: 50–100), poor water (WQI: 101–200), very poor water (WQI: 201–300) and not suitable for drinking purposes (WQI > 300)[22].

Results and discussion

Tables 2–4 summarize the results of various physico-chemical parameters. The pH value ranged from 7.16 to 8.69, which suggests that groundwater in the study area is slightly alkaline. TDS was recorded at a minimum of 260 mg/l during monsoon and a maximum of 3060 mg/l during the post-monsoon period. Increased levels of sodium and bicarbonate ions might be the reason for increase in TDS during post-monsoon period. Consuming water with high concentration of TDS may result in undesirable taste and gastrointestinal irritation[12]. The high

Table 3. Site-wise analytical summary of physico-chemical parameters for groundwater samples during monsoon period

	pH	EC	TDS	TH	F^-	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	Na^+	K^+	Mg^{2+}	Ca^{2+}
RB1	7.14	1480.00	990.00	320.45	0.63	96.00	51.24	16.51	595.00	78.00	7.42	57.00	84.00
RB2	8.54	767.00	575.00	105.90	4.12	49.00	53.00	0.00	308.00	113.00	3.61	19.00	24.56
RB3	8.49	710.00	561.00	319.40	1.16	42.00	136.00	0.00	238.00	79.00	2.54	24.00	39.00
RB4	8.48	892.00	786.00	256.63	3.46	92.00	79.00	41.68	374.00	117.00	3.77	36.00	39.00
RB5	7.31	431.00	305.00	163.01	0.73	4.47	8.13	4.21	216.00	12.34	6.27	18.64	34.52
RB6	7.16	415.00	300.00	167.46	0.13	3.46	12.54	0.24	205.00	18.92	1.54	16.43	39.94
RB7	7.12	1482.00	1180.00	473.36	1.21	218.00	124.43	86.44	396.00	221.00	8.12	49.00	76.00
RB8	7.32	1220.00	954.00	222.29	1.12	156.84	42.34	0.86	469.00	208.00	7.45	31.61	36.89
RB9	7.16	1519.00	1200.00	374.23	2.30	246.00	73.24	8.46	502.00	253.00	9.84	47.00	59.00
RB10	7.18	629.00	525.00	305.01	1.54	46.24	8.84	21.57	312.00	30.31	6.62	39.84	56.42
RB11	7.63	4100.00	3010.00	866.44	6.34	571.00	424.00	164.26	990.00	584.00	11.24	174.60	42.64
RB12	7.43	360.00	260.00	130.49	0.13	4.28	5.46	0.00	189.00	29.00	2.41	21.00	8.51
RB13	7.38	956.00	850.00	266.97	0.57	154.31	59.52	1.74	374.00	165.24	9.54	48.20	27.45
RB14	7.43	986.00	870.00	267.75	0.12	166.24	48.21	101.15	310.00	152.37	5.21	54.34	17.65
Mean	7.56	1139.07	883.29	302.81	1.68	132.13	80.43	31.94	391.29	147.23	6.11	45.48	41.83
Minimum	7.12	360.00	260.00	105.90	0.12	3.46	5.46	0.00	189.00	12.34	1.54	16.43	8.51
Maximum	8.54	4100.00	3010.00	866.44	6.34	571.00	424.00	164.26	990.00	584.00	11.24	174.60	84.00
SD	0.53	939.93	686.62	190.13	1.81	149.29	106.78	50.36	209.13	148.14	3.03	39.75	21.03

Note: EC in μS/cm; all other parameters in mg/l, except pH.

Table 4. Site-wise analytical summary of physico-chemical parameters for groundwater samples during post-monsoon period

	pH	EC	TDS	TH	F^-	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	Na^+	K^+	Mg^{2+}	Ca^{2+}
RB1	7.21	1676.00	1050.00	338.11	0.76	104.00	59.43	20.55	588.00	93.00	6.00	51.09	89.00
RB2	8.63	780.00	595.00	127.42	3.63	41.00	49.00	8.43	326.00	125.00	2.59	16.84	23.24
RB3	8.51	764.00	620.00	360.03	1.25	15.69	143.13	0.00	309.00	79.00	4.69	26.00	42.00
RB4	8.53	926.00	685.00	256.05	3.72	73.16	71.83	27.92	328.00	115.00	3.77	24.00	38.00
RB5	7.38	463.00	292.00	178.05	0.84	5.31	10.44	2.14	205.00	15.73	8.34	17.00	28.00
RB6	7.19	434.00	314.00	179.64	0.27	4.53	14.85	0.46	218.00	21.37	2.83	15.00	37.00
RB7	7.16	1576.00	1260.00	523.14	1.43	288.35	134.92	112.05	359.00	227.00	5.81	51.00	84.00
RB8	7.38	1265.00	910.00	196.08	1.73	172.34	49.84	1.24	406.00	218.00	3.80	24.12	38.73
RB9	7.19	1563.00	1140.00	439.93	1.87	234.21	84.37	10.61	487.00	234.00	5.67	42.00	51.00
RB10	7.21	674.00	560.00	326.76	1.71	64.31	14.26	19.10	326.00	24.15	3.84	43.24	59.53
RB11	7.73	4150.00	3060.00	937.47	7.62	509.83	396.14	123.43	1145.00	636.00	15.26	161.00	43.41
RB12	7.49	396.00	285.00	159.36	0.21	5.43	7.26	0.43	204.00	40.05	3.45	13.00	9.27
RB13	7.43	975.00	790.00	251.13	0.67	166.29	64.24	2.34	326.00	153.00	4.75	45.47	25.61
RB14	7.46	1024.00	860.00	337.12	0.16	173.14	55.63	108.26	281.00	160.00	5.48	49.00	20.74
Mean	7.61	1190.43	887.21	329.31	1.85	132.69	82.52	31.21	393.43	152.95	5.45	41.34	42.11
Minimum	7.16	396.00	285.00	127.42	0.16	4.53	7.26	0.00	204.00	15.73	2.59	13.00	9.27
Maximum	8.63	4150.00	3060.00	937.47	7.62	509.83	396.14	123.43	1145.00	636.00	15.26	161.00	89.00
SD	0.54	951.98	696.77	208.46	2.00	141.72	99.53	46.11	240.62	158.46	3.20	37.32	22.79

Note: EC in μS/cm, all other parameters in mg/l, except pH.

TDS value observed at site RB11 (dugwell), located in the vicinity of agricultural fields (Amawa block), may be associated with percolation of irrigation water which contains fertilizers and animal waste. The EC values varied between 420 and 4200 μS/cm during pre-monsoon and between 396 and 4150 μS/cm during the post-monsoon period. The high values of EC are proportional to the ionic strength of water and chiefly contribute towards the salinity in groundwater. Moreover, alkaline earth metals are exceeded by alkali earth metals in majority of the groundwater samples. The association of sodium and high chloride concentration suggests that the study area has been adversely affected by groundwater salinity. The weak acids also show dominance over the strong acids, which suggests slightly alkaline nature of water, and is in coherence with mean values of pH.

The results from ion chemistry show that HCO_3^- is the leading anion and Na^+ is the leading cation in all the groundwater samples during all seasons. HCO_3^- varied between 171 and 1145 mg/l. High values of bicarbonates are associated with kankar (calcrete) formation[22]. The higher bicarbonate values during post-monsoon period may be attributed to dissolution of rocks during heavy rainfall and groundwater movement[22,23]. Among the cations, the compliance of Mg^{2+} was very low, viz. 28.57% during all seasons. It has been reported that elevated magnesium levels (>100 mg/l) are associated with cardiovascular diseases and hypertension, which may also cause death[24,25]. Moreover, concentration of Na^+ varied from 12.34 mg/l (monsoon) to 636 mg/l (post-monsoon). The high values of sodium indicate high sodicity of the soil. Among the anions, chloride concentration varied
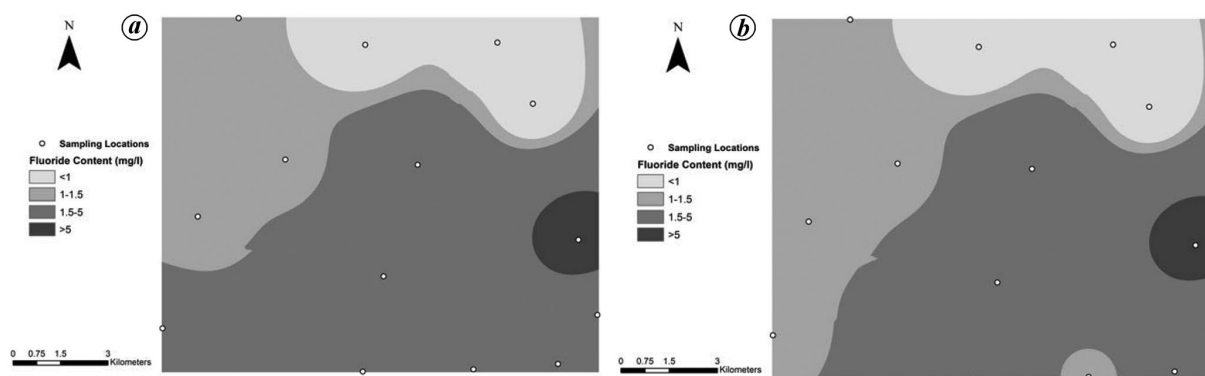
Figure 2. Spatial variation of fluoride content during (*a*) pre-monsoon and (*b*) post-monsoon periods.
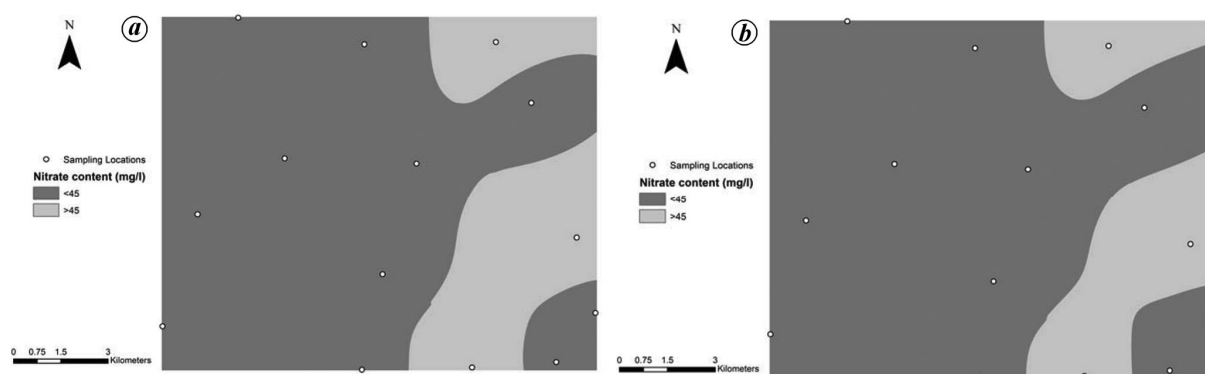

Figure 3. Spatial variation of nitrate content during (*a*) pre-monsoon and (*b*) post-monsoon periods.

from 3.46 mg/l (monsoon) at site RB6 to 571 mg/l (monsoon) at site RB11. Moreover, it was observed that three samples during pre-monsoon and two samples during monsoon and post-monsoon periods were not within the permissible limit with respect to chloride. Also, chloride is an important inorganic anion and its presence in groundwater is often related with improper sanitary conditions, irrigation practices and mismanagement of industrial discharge[26]. Among the anions, compliance of F⁻ (42.86%) ion was the lowest. Figure 2 shows the spatial variation of fluoride contamination in groundwater. Maximum fluoride concentration of 8.28 mg/l was found at RB11 during pre-monsoon period. This fact is also coherent with a health impact survey done in the study area, where many people were found to be suffering from dental fluorosis. Moreover, elevated nitrate levels were also found in the study area. The maximum value of nitrate was 164.26 mg/l in the sample collected from a dugwell in Amawa block (RB11) during monsoon, and the mean value was 35.72 and 31.21 mg/l during pre-monsoon and post-monsoon periods respectively. Figure 3 shows the spatial variation of nitrate in groundwater. Higher nitrate values (>10 mg/l) in groundwater suggest interventions from anthropogenic sources[27]. Since the area is mostly agriculture-dominated, excessive fertilizer use might be the reason for nitrate in groundwater[1,27]. The

presence of nitrate in groundwater also indicates poor sanitary conditions in the surrounding areas. There has been an emphasis on 'toilet for every home' under the 'Swachh Bharat Mission' in India. It may be possible that lack of technical supervision in the study area might have resulted in faulty design of septic tanks and leaching pits, leading to leaching out of sewage. Moreover, since the soil is of sandy type, sewage might have percolated into the groundwater causing higher nitrate content in it. However, sporadic occurrence of nitrate in the study area also suggests the possible contribution of geogenic factors[27]. Consuming water with high nitrate content (>45 mg/l) might cause 'blue baby syndrome', cancer and thyroid problems[28,29].

The value of WQI was in the range 43.27–411.55 during pre-monsoon, 37.75–382.70 during monsoon and 40.36–390.01 during post-monsoon periods. It is noteworthy that percentage of samples in 'excellent' and 'unsuitable for drinking' categories remained the same throughout the duration of the study. However, the number of samples in 'good' category increased during monsoon and post-monsoon periods due to the probability of dilution factor in groundwater (Table 5).

Figure 4 shows the WQI values for all the sampling locations. It can be observed that WQI largely depends upon the concentration of nitrate and fluoride in the

Table 5. Water quality index (WQI) and per cent compliance with different water types

		Per cent compliance		
WQI range	Water type	Pre-monsoon	Monsoon	Post-monsoon
<50	Excellent	14	14	14
51–100	Good	21	36	36
101–200	Poor	57	43	43
201–300	Very poor	0	0	0
>300	Unsuitable for drinking	7	7	7
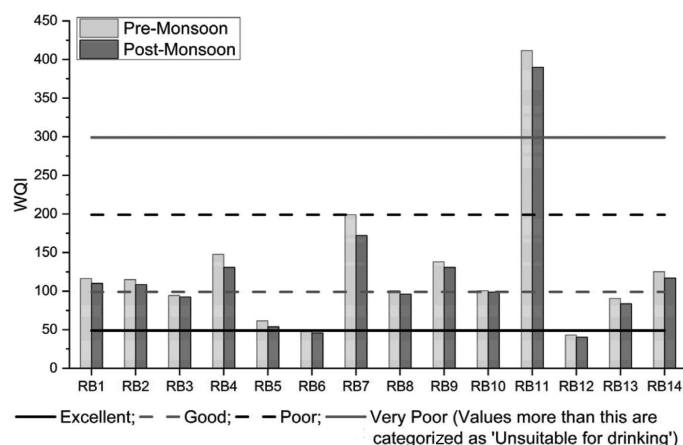
Figure 4. Site-wise variation of water quality index for pre-monsoon and post-monsoon periods.

groundwater. The site RB11, where both nitrate and fluoride were recorded in excess of the permissible limits, also recorded an alarmingly high WQI value of 411.5. Water samples showing high values of WQI (>300) were categorized as 'unsuitable' not only for drinking and domestic purposes, but also for cattle feeding. Moreover, in the sites where concentration of nitrate was high but fluoride was within the permissible limits, water quality was under the 'poor' category, i.e. not suitable for domestic purposes but can be used for cleaning and other such purposes. Site location RB7 (Mark-II handpump) exhibited 'poor' category of drinking water, associated with higher values of nitrate and TDS in the study area. Few other sites (RB1, RB2, RB4, RB9 and RB14) were categorized as 'poor' with respect to WQI. However, these sites were under 'poor' category due to high TDS and fluoride concentration, which resulted in higher WQI values. Incorporating the WQI values in the correlation matrix enables us to identify the importance of analysed parameters in influencing WQI (Table 6). The correlation matrix verifies that WQI shows good correlation with EC, TH, TDS, SO_4^{2-}, Cl^-, HCO_3^-, F^-, Na^+, NO_3^-, Mg^{2+} and K^+, suggesting the importance of these parameters in shaping the drinking water quality.

Conclusion

The water quality analysis of groundwater in this study enables us to evaluate the groundwater quality of Raebareli

district through computation of WQI. Also, WQI can be used as a good tool to authenticate and present the comprehensive status of groundwater contamination and its potential adverse impacts on residents of the study area. The important findings of this study are as follows:

- The maximum WQI value of 411.5 was reported from the water sample collected from a dugwell in Amawa block (site RB11). Also, 58% and 43% of the samples were reported under 'poor' and 'very poor' categories of WQI respectively, throughout the year.
- The detailed WQI analysis suggests that the area is mainly affected by fluoride, nitrate and salinity. Detailed analysis reflects sporadic occurrence of these parameters in the study area. High values of these parameters result in overall poor water quality which makes the groundwater unsuitable for drinking.
- The source of elevated fluoride concentration appears to be geogenic in nature (possible weathering of mica minerals)[8]. Whereas the reason for high nitrate concentration in groundwater may be because of anthropogenic factors such as heavy fertilizer application, improper sewer design, industrial discharge, etc.[14,28].
- Continuous consumption of groundwater with high WQI values by people living in the area, may result in dental fluorosis, skeletal fluorosis, blue baby syndrome, etc.

This study could help bring awareness among the people and present a wholesome picture pertaining to

Table 6. Pearson's linear correlation matrix for water quality parameters in the study area

	pH	EC	TDS	TH	F⁻	Cl⁻	SO_4^{2-}	NO_3^-	HCO_3^-	Na⁺	K⁺	Mg^{2+}	Ca^{2+}	WQI
pH	1													
EC	-0.06284	1												
TDS	-0.05372	0.993245	1											
TH	-0.09544	0.925986	0.937638	1										
F⁻	0.438023	0.766837	0.76598	0.672067	1									
Cl⁻	-0.16938	0.944189	0.970026	0.906723	0.672102	1								
SO_4^{2-}	0.17068	0.929321	0.937004	0.935566	0.8054	0.875993	1							
NO_3^-	-0.09107	0.722973	0.767467	0.790302	0.495252	0.789908	0.716726	1						
HCO_3^-	-0.05688	0.977664	0.957481	0.865696	0.764425	0.880659	0.867521	0.617525	1					
Na⁺	0.002598	0.945861	0.966517	0.865866	0.764162	0.975041	0.910813	0.72526	0.8859804	1				
K⁺	-0.22493	0.872168	0.8818	0.805059	0.599317	0.889626	0.780259	0.602604	0.8528385	0.862678	1			
Mg^{2+}	-0.10615	0.956136	0.96153	0.938991	0.721529	0.915078	0.912992	0.790916	0.9261339	0.894164	0.862918	1		
Ca^{2+}	-0.36579	0.332587	0.307595	0.405399	0.065817	0.277777	0.188735	0.237896	0.3717608	0.142761	0.227248	0.235227	1	
WQI	0.10035	0.959243	0.971206	0.932665	0.862947	0.921902	0.953695	0.801112	0.9152207	0.933012	0.811934	0.94889	0.262876	1

groundwater quality problems of the study area. Moreover, WQI can also be used to categorize the sources (hand pumps, dugwells, etc.) of drinking water. The sources with high WQI should be demarcated and not recommended for use. In addition, proper treatment methods such as cost-effective filters may be proposed in the study area. Moreover, this study could be important for policymakers and the involved stakeholders in shaping policies and may also assist the various government officials towards better groundwater management. It is also recommended that the concept of WQI should be adopted for areas affected by similar problems, which would help in providing the population access to safe drinking water.

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