Applied Water Science (2020) 10:27
https://doi.org/10.1007/s13201-019-1088-4

ORIGINAL ARTICLE

Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: a case study of the Bokaro district, India

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Received: 27 May 2016 / Accepted: 30 October 2019 / Published online: 5 December 2019
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Abstract

One hundred two groundwater samples were collected from the Bokaro district of Jharkhand state, India, during the pre-and post-monsoon seasons of the year 2014–2015. In the present study, groundwater samples were analysed for pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, F^- and NO_3^- to evaluate the suitability of the groundwater for drinking purposes through geographic information system (GIS)-based water quality index (WQI) model. For quality assessment, values of analysed parameters of the groundwater samples were compared with the Bureau of Indian standards (BIS) and World Health Organization (WHO) water quality standards. The analytical results indicate slightly acidic to slightly alkaline nature of the groundwater in the study area. Concentrations of Ca^{2+}, Mg^{2+}, HCO_3^-, F^-, NO_3^-, TDS and TH exceeded the desirable as well as permissible limits of drinking water quality standards recommended by the BIS (Indian Standard Drinking Water Specification, 2012) and WHO (Guidelines for drinking water quality: training pack, WHO, Geneva, 2004) in the study area during the pre- and post-monsoon seasons, respectively. However, Na^+, K^+, Cl^- and SO_4^{2-} concentrations were within the permissible limits during both seasons. The hydrochemical analysis of the studied groundwater samples documented with ternary and Durov diagram revealed that most of the groundwater samples belong to HCO_3^- type of anions facies and no dominant type of cation facies. The GIS-based WQI maps for the study area indicate that the poor quality of water was found the maximum in the pre-monsoon season as compared to the post-monsoon season in the study area, respectively. The high values of WQI in the several groundwater samples of the Bokaro district indicate that water is not suitable for direct consumptions and it required sustainable treatment before its utilization for drinking uses.

Keywords Major ion chemistry · Water quality index · Groundwater quality · GIS · Bokaro district

Introduction

Groundwater is emerging as a critical issue for cities and towns around the world. It is estimated that approximately one-third of the world's population use groundwater for drinking uses (Nickson et al. 2005). In India, the accessibility of surface water is more than groundwater. But, owing to the decentralized availability of groundwater, it is easily accessible and forms the largest part of India's agriculture and drinking water supply. Domestic water requirements are fulfilled by groundwater about 50% of urban water requirement and 85% of rural domestic requirements (World Bank 1998). However, in recent times, India is fast moving towards a crisis of groundwater overuse and contamination. The rapid increase in population, the growth of industrialization, the use of agricultural chemicals and the disposal of urban and industrial waste have all played a major role in groundwater contamination and increased tremendously the pressure on water resources (Chandra et al. 2015). Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source, and therefore, it becomes very important to regularly monitor the quality of groundwater and to devise ways and means to protect it (Ramakrishnaiah et al. 2009). Water pollution not only affects water quality, but also threats human health,

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economic development and social prosperity (Milovanovic 2007). Scarcity of clean and potable drinking water has emerged in recent years as one of the most serious developmental issues in many parts of the West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab (Tiwari and Singh 2014). Water quality index (WQI) method is a technique of rating water quality and an effective tool to express water quality that offers a simple, stable, reproducible unit of measure and communicate information on the quality of water to the concerned citizens and policy-makers (Mishra and Patel 2001; Tiwari and Mishra 1985). The water quality index model was originally started by Horton (1965). Brown et al. (1970) developed a water quality index by assigning a proper weight for the parameters based on their analysis. It, thus, becomes an important parameter for the assessment and management of groundwater (Chauhan et al. 2010). In the Jharkhand state, the quality of water is a major issue due to the public ignorance to environmental considerations, lack of provisional basic social services, indiscriminate disposal of increasing anthropogenic and mining wastes and discharges of improperly treated sewage/industrial effluents, resulting in excess accumulation of pollutants on the land surface and contamination of available water resources (Singh and Hasnain 1999; Tiwary 2001; Sarkar et al. 2007). Thus, the main objectives of the present study are to evaluate the spatial and temporal variation in groundwater quality parameters of the Bokaro district to assess its suitability for drinking purposes by using GIS-based WQI model.

Study groundwater sample

The Bokaro district lies between the latitudes 23° 24′ 27″ N to 23° 57′ 24″ N and longitudes 85° 34′ 30″ E to 86° 29′ 10″ E, covering a groundwater sample of 2861 km^2 in the state of Jharkhand, India (Fig. 1). It is represented in the Survey of India topographical map no. 73I/73E (1:250,000). The Bokaro district has eight administrative blocks, namely Chas, Gomia, Nawadih, Bermo, Peterwar, Kasmar, Jaridih and Chandankiyari, respectively. The district is experiencing humid with subtropical climate with three distinct seasons that include summer, monsoon and winter. Monsoon sets in the middle of June and last until the end of September. July, August and September are the most humid months of the Bokaro district. The humidity during the winter season is about 60%. Summer stretches from March to June during which the maximum temperature varies from 42 to 46 °C. The average rainfall in the district is 1363.6 mm/year. The main basin of the groundwater sample is Damodar basin and another sub-basin also occurs like the Ijri, Gobai, Konar, Bokaro, etc. The Damodar River is the main river of the study groundwater sample which flows from West to East direction in the central part of the district. Major tributaries of the Damodar River are the Konar and Jamunia rivers and minor tributaries are the Ijri, Gobai, Tasharkhan, Kadwa, Khanjo rivers, etc. Geomorphology of the study groundwater sample is part of the Chota Nagpur Plateau, which is highly undulating and hilly all over the groundwater sample. The average elevation of the undulating pediplain ranges from 200 to 350 m above mean sea level. The northern and western part of the study groundwater sample is having hilly ranges where the Gomia is the highest hill prominent block. Hydrogeology of the study groundwater sample, groundwater is mainly replenished by the atmospheric precipitation and its condition is very complicated due to the wide variety of geology, topography, drainage and mining activity. Seepages from canal, streams and other surface water bodies also contribute to the groundwater in the study groundwater sample. Groundwater occurred in the groundwater sample under confined to semiconfined conditions (CGWB 2013). Major parts of the study groundwater sample are underlain by rocks such as granite and granite gneiss. Besides these rocks, quartzites, mica schists and phyllites are also found. The oldest rock of the groundwater sample is unclassified meta-sedimentaries, which comprise quartzite and quartz schists. Three-fourths of the groundwater sample is occupied by rocks of Chota Nagpur granite gneiss. Coal, shale and sandstone deposits are found in parts of Bermo and Gomia blocks of the Bokaro district (Satapathy and Syed 2015).

Materials and methods

For the assessment of the groundwater quality of the Bokaro district, one hundred two groundwater samples (fifty-one in the pre-monsoon season and fifty-one in the post-monsoon season) were collected from bore hole and dug well during the month of December 2014 and May 2015 (Fig. 1). Care was taken to collect subsequent samples from the same location in both seasons. In the laboratory, the water samples were filtered through 0.45-μm Millipore membrane filters to separate suspended particles. The pH and EC of water samples were measured in the field immediately after the collection of the samples by using Multiparameter probe (PCSTestr 35). Major cations (Ca^{2+}, Na^+, and K^+) were analysed by using Systronics Flame Photometer 128. Magnesium, TH, bicarbonate and chloride were estimated by a titrimetric method using standard EDTA, HCl and $AgNO_3$ as titration solution (APHA 2012). Sulphate, fluoride and nitrate were estimated by using the UV–Vis spectrophotometer. Calculated ionic balance error was found within the permissible limit of $\pm 10\%$, and the ratio of TDS/EC is within acceptable limits (0.8) for confirming the reliability of the analytical results.

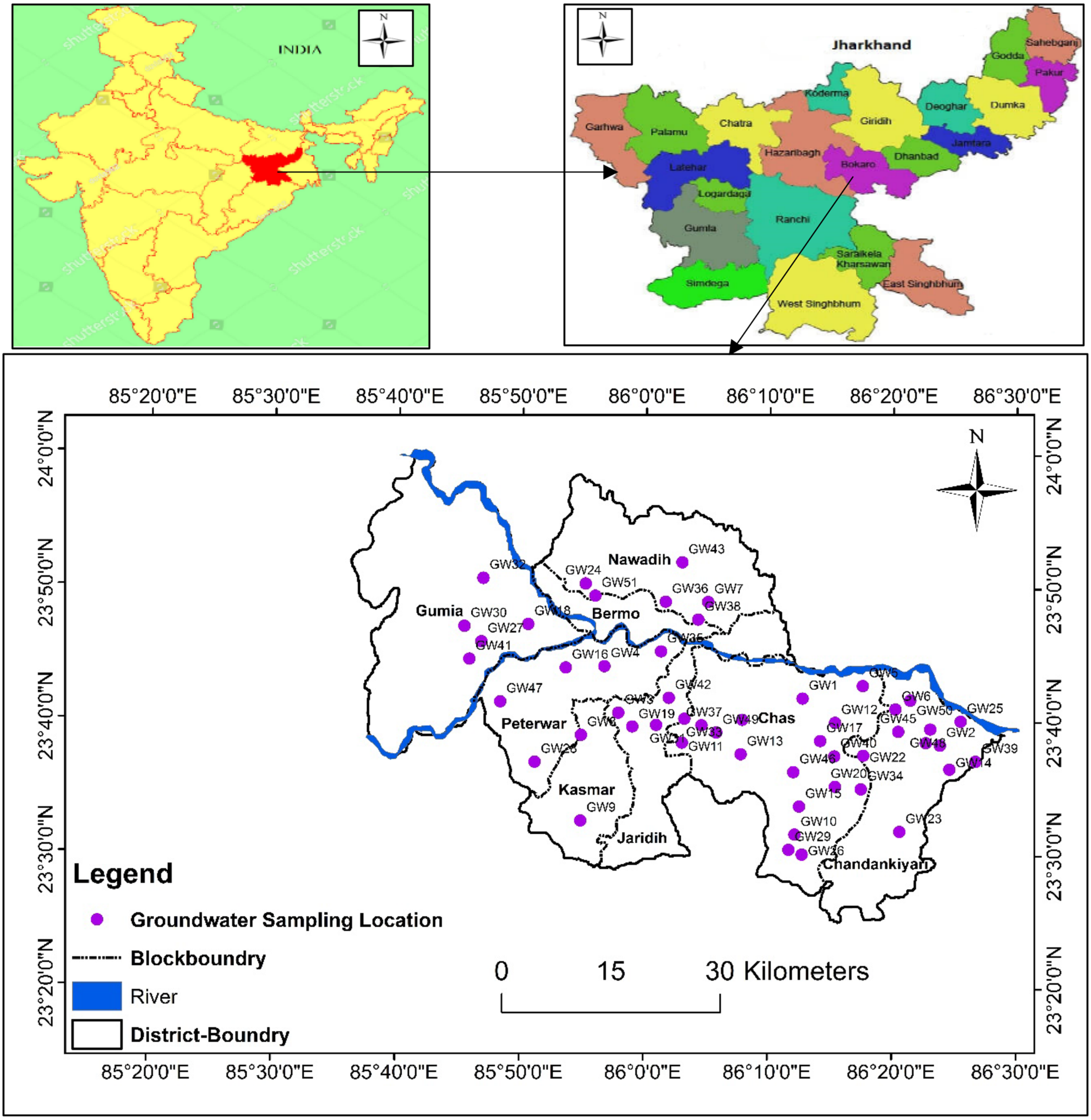

Fig. 1 Groundwater sample location in the Bokaro district

Water quality index computing

Water quality index (WQI) was used for evaluating the composite influence of individual water quality parameter on the overall quality of water (Mitra et al. 2006; Yadav et al. 2015). WQI is a mathematical equation used to summarize a large number of water quality data into a single number and understandable format (Štambuk-Giljanovic 1999). In assessing the suitability of drinking water, the water quality data of the analysed samples were compared with the recommended drinking water standard of BIS (2012) which have been considered for the calculation of WQI are given in Table 1. In computing WQI, three steps are followed. In the first step, each of the 13 parameters (pH, TDS, F^-, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, TH) has been allotted a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes are listed in Table 1. The maximum weight of 5 has been allotted to the parameters like

Table 1 Relative weight of chemical parameters

Parameters	Weight (w_i)	Relative weight ($W_i = k/S_i$)	BIS (IS:10500) (2012)
pH	4	0.108	6.5–8.5
TDS (mg/L)	5	0.135	500
Total hardness (mg/L)	2	0.054	200
F^- (mg/L)	5	0.135	1.0
Cl^- (mg/L)	5	0.135	250
NO_3^- (mg/L)	5	0.108	45
SO_4^{2-}(mg/L)	4	0.108	200
HCO_3^- (mg/L)	1	0.081	200
Ca^{2+} (mg/L)	3	0.081	75
Mg^{2+} (mg/L)	3	0.081	30
	$w_i = 37$	$W_i = 1.0$	

TDS, F^-, Cl^- and NO_3^- owing to main significance in water quality assessment (Vasanthavigar et al. 2010; Tiwari et al. 2017). HCO_3^- and TH are given the minimum weight of 1 and 2 assigned. Other parameters like Ca^{2+}, Mg^{2+}, Na^+ and HCO_3^- were assigned a weight (W_i) between 3 and 4 depending on their importance in water quality determination. In the second step, the relative weight (W_i) is computed from the following equation as it plays an insignificant role in the water quality assessment.

$$W_i = \frac{W_i}{\sum_{i=1}^{n} W_i}$$

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

In the third step, a quality rating scale (q_i) for each parameter was computed by dividing its concentration in each water sample by its respective standard concentration prescribed by the guidelines of BIS (2012) and the result is multiplied by 100:

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

where the q_i is the quality rating scale, C_i is the concentration of each chemical parameters in each water sample in mg/L and S_i is the BIS for each chemical parameter in mg/L according to the guidelines of the BIS (2012).

$$\mathrm{SI}_i = w_i \times q_i$$

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

Table 2 Classification of WQI range and category of water

WQI	Status
< 50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
> 300	Unfit for drinking purpose

For computing the WQI, the SI_i is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation, where the SI_i is the sub-index of ith parameter, q_i is the rating based on concentration of ith parameter and n is the number of parameters.

Calculated water quality index was classified into five groups excellent water to water unsuitable for drinking purpose of range water quality index for drinking purpose and is given in Table 2.

Spatial analysis

The spatial analysis of various physicochemical parameters was carried out by using GIS contouring methods with ArcGIS 10.3. The inverse distance weighted (IDW) interpolation techniques have been used for preparing the spatial distribution maps for each physicochemical parameter. The spatial distribution map of the pH, EC, TDS, TH, cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (Cl^-, SO_4^{2-}, HCO_3^-, F^-, and NO_3^-) have been generated for Bokaro district. The methodology in Fig. 2 was involved in the mapping of physicochemical parameters and development of drinking water quality index map for the pre-and post-monsoon seasons based on the BIS (2012) for drinking water.

Results and discussion

The analysed parameters of the groundwater samples were compared with drinking water quality standards established by the WHO (2004) and BIS (2012) for drinking and public health purpose (Table 3). Moreover, the statistical analysis of the groundwater samples and consequences of the elements beyond the drinking water limit are presented in Table 3.

Drinking water quality mapping

Spatial analysis of pH, TDS, TH, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, F^- and NO_3^- parameters in the groundwater samples of the Bokaro district during the pre- and post-monsoon seasons is shown in Figs. 3, 4 and 5. pH of the analysed water samples varied from 5.67 to 8.09 in the pre-monsoon season and from 6.88 to 7.92 in the post-monsoon

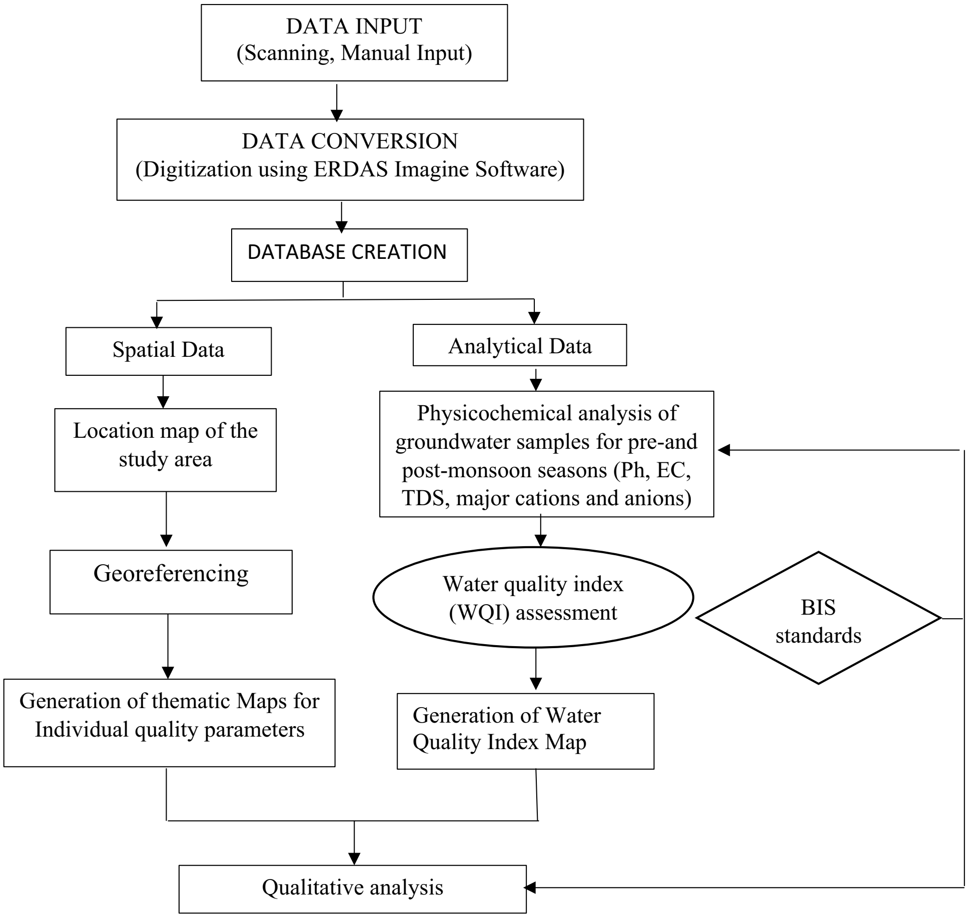

Fig. 2 Flowchart for the method adopted (Chatterjee et al. 2010)

season, indicating slightly acidic to alkaline nature of the groundwater samples, respectively. Spatial analysis of pH value of the groundwater samples (Fig. 3a) indicates all of the water samples were within the permissible limits (6.5–8.5) of the BIS (2012) except at one site in the western side of the study area during the pre-monsoon season. The electrical conductivity (EC) value of the groundwater samples ranged from 520.00 to 1961.00 µs/cm (avg. 1142.22 µs/cm) during the pre-monsoon season and from 304.00 to 1620.00 µs/cm (avg. 860.80 µs/cm) in the post-monsoon season, respectively. Spatial analysis of EC (Fig. 3b) of the groundwater shows that the major part of the study area had higher EC values (> 1000 µs/cm) during both seasons. The concentration of TDS in the groundwater of the study area ranged from 414.00 to 1735.00 mg/L (avg. 961.69 mg/L) in the pre-monsoon and from 258.00 to 1454.00 mg/L (avg. 702.96 mg/L) in the post-monsoon season. Spatial analysis of TDS concentrations of the groundwater (Fig. 3c) shows that 11.76, 76.48 and 11.76% of the groundwater sample falls within the acceptable (< 500 mg/L), permissible (500–1500 mg/L) and above the permissible (> 1500 mg/L) limit, respectively, during the pre-monsoon period as per the WHO (2004) standard, while 31.37 and 68.63% of the groundwater sample falls within the acceptable and permissible limit during the post-monsoon season. The high concentrations of TDS beyond the acceptable and permissible limit were observed during the pre-monsoon period in the eastern side and some portion of the western side of the study area (Fig. 3c). Moreover, during the post-monsoon season, the TDS values were within the maximum permissible limit as per the WHO (2004) and BIS (2012) drinking water standards (Fig. 3c). We found the level of TDS concentrations was less high in the post-monsoon season as compared to the pre-monsoon season, and this may be due to the dilution with rainwater (Jasmin and Mallikarjuna, 2014). Total hardness in the groundwater samples ranged from 172.62 to 973.73 mg/L and 121.30 to 817.77 mg/L with the average value of 488.49 and 371.07 mg/L during the pre-and post-monsoon season, respectively. The spatial distribution map of TH (Fig. 3d) shows that 3.92, 64.73 and 31.35% of the groundwater sample falls within the acceptable (< 200 mg/L), permissible (200–600 mg/L) and above the permissible (> 600 mg/L) limit, respectively, recommended by the BIS (2012) during the pre-monsoon season, while during the post-monsoon season, 19.60, 68.64 and 11.76% of the samples were within the acceptable, permissible and above the permissible limit. The high concentrations of TH beyond permissible limit were observed during

Table 3 Descriptive statistics of the groundwater quality of Bokaro district and drinking water quality standards with probable effects (Latha and Rao 2012)

Parameters	Pre-monsoon			Post-monsoon			WHO (2004)		BIS (2012)		Risks or effects
	Min	Max	Avg.	Min	Max	Avg.	Acceptable limit	Permissible limit	Acceptable limit	Permissible limit	
pH	5.67	8.09	7.42	6.88	7.92	7.44	7.0–8.5	9.2	6.5–8.5		Low pH—corrosion, metallic taste High pH—bitter/soda taste, deposits
EC	520.00	1961.00	1142.22	304.00	1620.00	860.80	–	–	–	–	–
TDS	414.00	1735.00	961.69	258.00	1454.00	702.96	500	1500	500	2000	Salty or bitter taste, corrosion of pipes and fittings, constipation effects gastrointestinal irritation,
F^-	0.34	1.89	1.08	0.24	1.64	0.84	–	1.5	1.0	1.5	Crippling skeletal fluorosis, dental mottling, bone diseases and cancer
Cl^-	43.99	328.99	151.37	23.99	288.93	105.70	200	600	250	1000	High blood pressure, salty taste, corroded pipes, blackening and pitting of stainless steel
HCO_3^-	155.00	750.00	428.33	138.00	654.00	330.92	–	500	–	–	–
SO_4^{2-}	21.83	157.76	68.03	10.42	125.69	44.57	200	400	200	400	Cause gastrointestinal irritation when Mg and Na sulphate
NO_3^-	5.09	103.42	38.06	1.44	73.43	22.92	–	45	45	No relaxation	Methaemoglobinemia-Blue baby disease
TH	172.62	973.73	488.49	121.30	817.77	371.07	100	500	200	600	Encrustation in water supply structure and adverse effects on domestic use
Ca^{2+}	31.80	218.74	101.80	24.20	196.72	83.47	75	200	75	200	Gastrointestinal irritation and stone formations
Mg^{2+}	21.35	106.93	56.93	13.60	87.95	39.51	50	150	30	100	Adverse effects on domestic use
Na^+	39.70	235.90	102.56	14.20	172.80	65.57	–	200	–	–	–
K^+	3.60	24.70	10.33	1.10	14.20	5.50	–	12	–	–	–

Unit: concentrations are in mg/L except EC (µS/cm), and pH

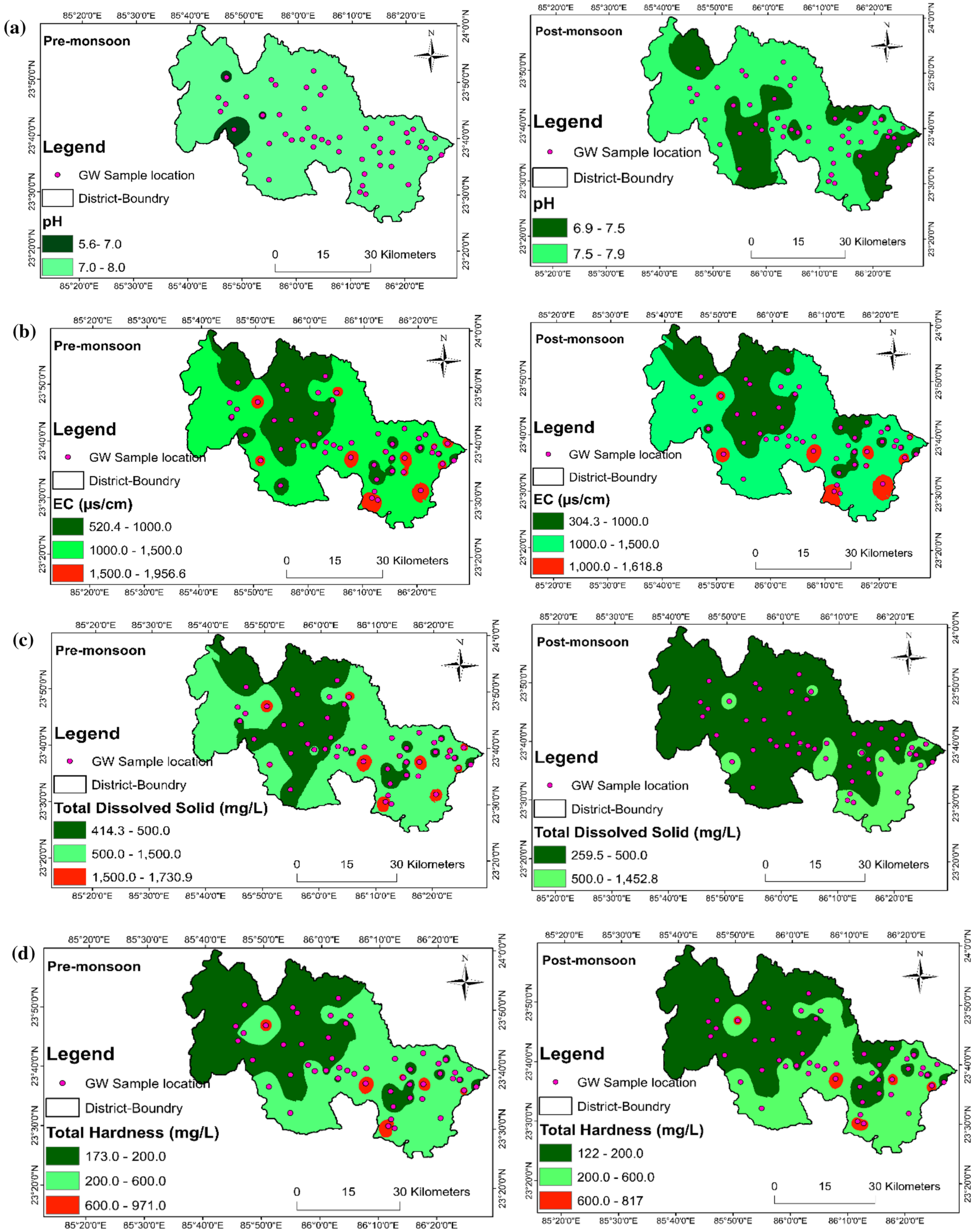

Fig. 3 Spatial variations in pH, EC, TDS and TH

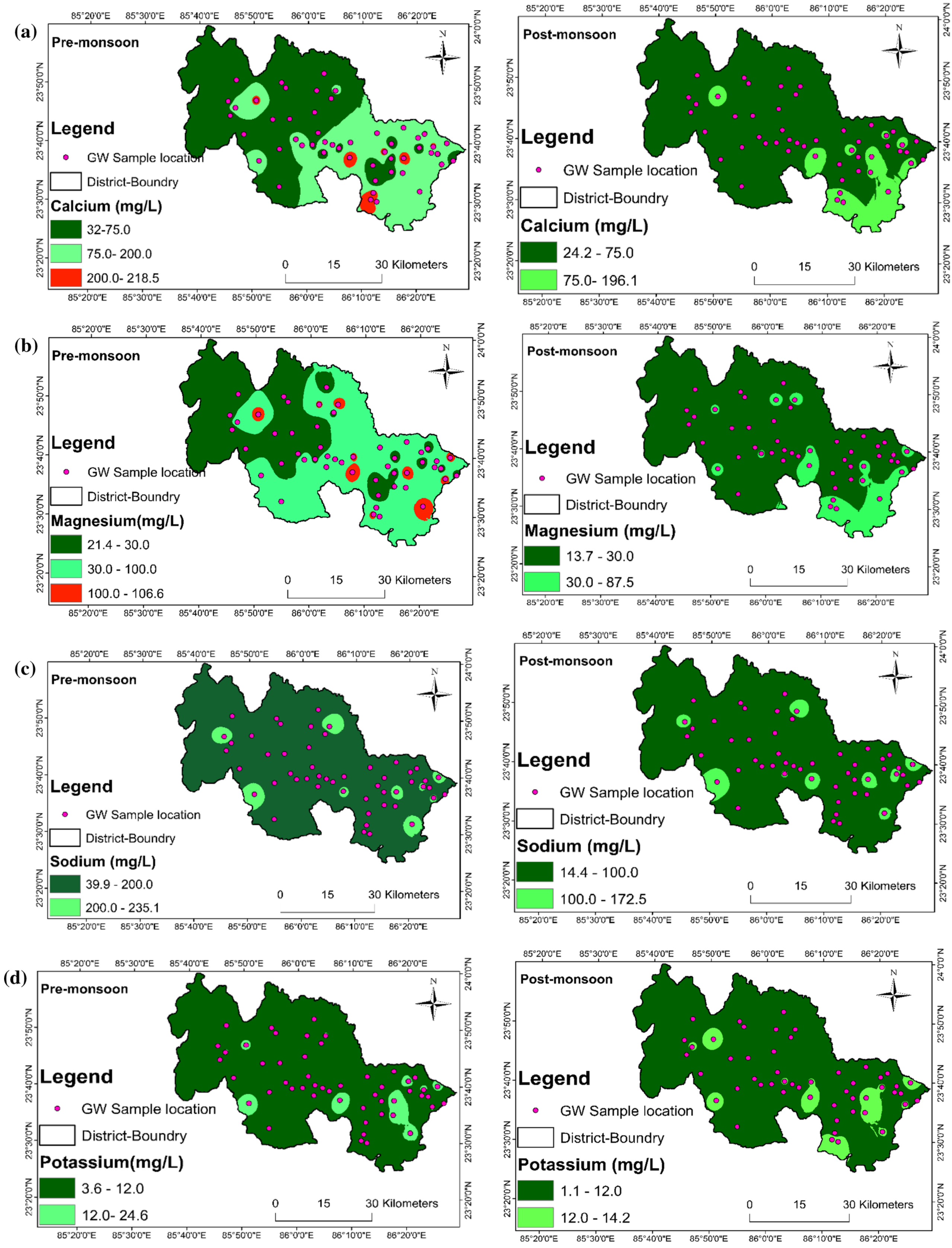

Fig. 4 Spatial variation in cations

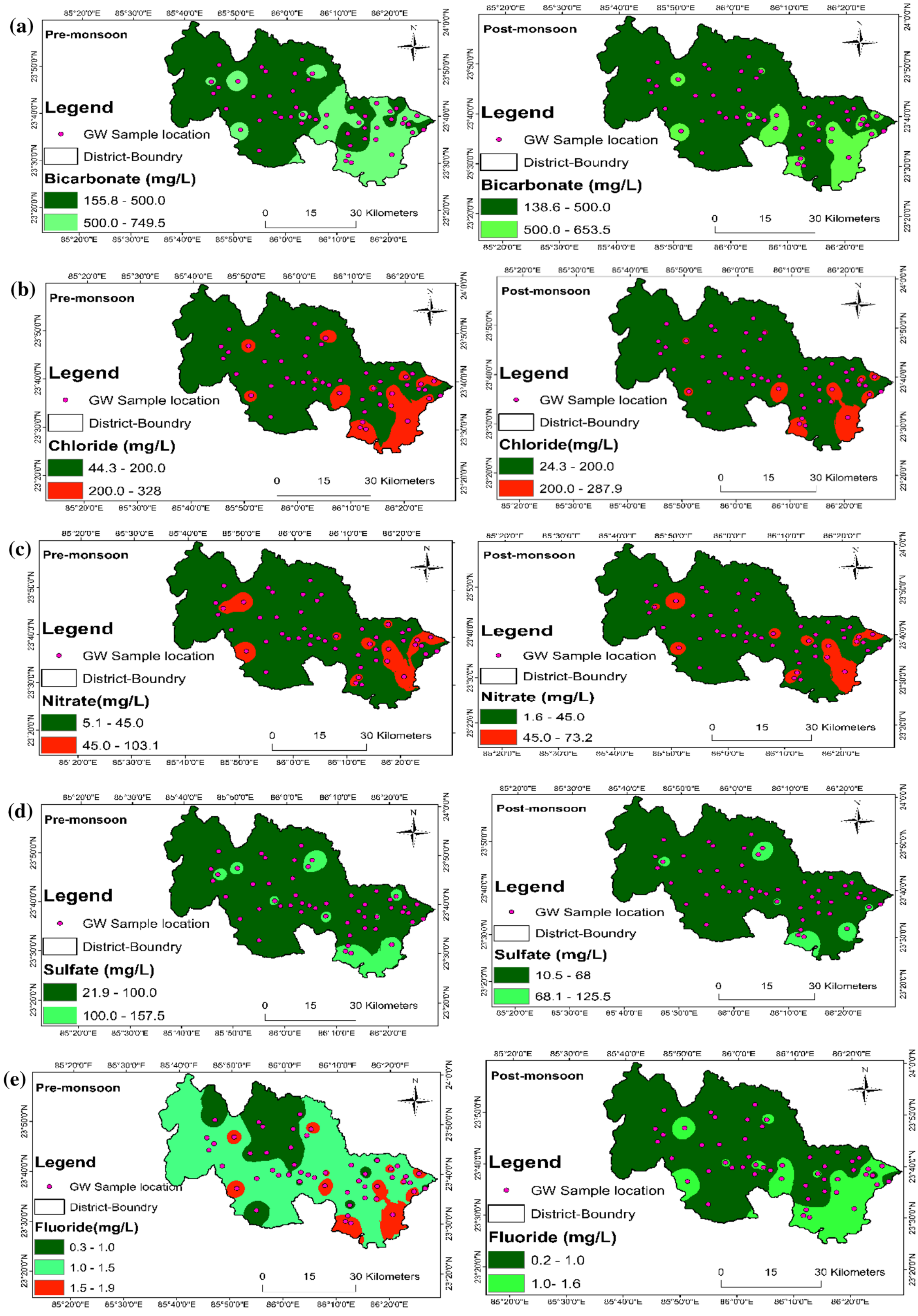

Fig. 5 Spatial variation in anions

both seasons in the study area (Fig. 3d). Ca^{2+} in the groundwater samples of the study area varied from 31.80 to 218.74 mg/L with an average value of 101.80 mg/L in the pre-monsoon season and from 24.20 to 196.72 mg/L with an average value of 83.47 mg/L in the post-monsoon season, respectively. The spatial analysis of Ca^{2+} (Fig. 4a) shows that the groundwater samples fall within the acceptable (< 75 mg/L), permissible (75–200 mg/L) and above permissible (> 200 mg/L) limits affect to 39.21, 54.91 and 5.88%, respectively, during the pre-monsoon season, recommended by the BIS (2012) and WHO (2004) standards, while 47.06 and 52.94% of the groundwater sample falls within the acceptable and permissible limit during the post-monsoon season in the study area. However, none of the groundwater samples falls above permissible limit during the post-monsoon, may be due to the influence of monsoon. Concentration of Mg^{2+} in the study area ranged from 21.35 to 106.93 mg/L (avg. 56.93 mg/L) and 13.60 to 87.95 mg/L (avg. 39.51 mg/L) in the pre- and post-monsoon seasons, respectively. The spatial analysis of Mg^{2+} (Fig. 4b) shows that 15.1, 81.1 and 3.8% of the groundwater sample, respectively, falls within the acceptable (< 30 mg/L), permissible (30–100 mg/L) and above permissible (> 100 mg/L) limit during the pre-monsoon season, recommended by the BIS (2012), while 41.17 and 58.83% of the groundwater sample falls within the acceptable and permissible limit during the post-monsoon season. Concentrations of Na^{+} ranged from 39.70 to 235.90 mg/L (avg. 102.56 mg/L) and from 14.20 to 172.80 mg/L (avg. 65.57 mg/L), in the pre-and post-monsoon seasons, respectively. The spatial analysis of Na^{+} (Fig. 4c) reveals that 96.1% of the groundwater sample falls within permissible limit, and only 3.9% of the groundwater sample falls above permissible limit (> 200 mg/L) during the pre-monsoon period recommended by the WHO (2004) standard, while the total groundwater sample of the Bokaro district falls within the permissible limit (< 200 mg/L) during the post-monsoon season. Concentration of K^{+} varied from 3.60 to 24.70 mg/L (avg. 10.33 mg/L) in the pre-monsoon season and from 1.10 to 14.20 mg/L (avg. 5.50 mg/L) in the post-monsoon season, respectively. The spatial analysis of K^{+} (Fig. 4d) indicates that 70.58% of the groundwater sample falls within permissible limit (< 12 mg/L) and 23.52% of the groundwater sample exceeding permissible limit (> 12 mg/L) during the pre-monsoon season, while 96.07% of the groundwater sample falls within permissible limit, and only 3.9% of the groundwater sample falls above permissible limit during the post-monsoon season as per the WHO (2004) standard. Evaporate encrustations of Na^{+} and K^{+} salts, which develop due to cyclic wetting and drying of the Damodar River and cause the formation of alkaline/saline soils, also serve as a local source of Na^{+} and K^{+} (Singh et al. 2005; Tiwari et al. 2016). HCO_3^{-} is the dominant anion among the other anions, varied from 155.00 to 750.00 mg/L (avg. 428.33 mg/L) and from 138.00 to 654.00 mg/L (avg. 330.92 mg/L), in the pre- and post-monsoon seasons, respectively. The spatial analysis of HCO_3^{-} (Fig. 5a) indicates that 64.71% of the groundwater sample falls within permissible limit (< 500 mg/L), and 35.29% of groundwater sample beyond the permissible limit (> 500 mg/L), during the pre-monsoon season, while 92.8% of the groundwater sample falls within permissible limit, and 7.20% of the groundwater sample beyond permissible limit during the post-monsoon season, recommended by the WHO (2004) standards. In groundwater samples, higher concentration of HCO_3^{-} is due to the carbonate weathering as well as dissolution of carbonic acid in the aquifers and decay of organic matter in the soil zone (Canter 1997; Jeong 2001; Zilberbrand et al. 2001). Weathering of silicate minerals and Na^{+}, K^{+} feldspar additionally also increases the concentration of HCO_3^{-} in the groundwater samples. Concentration of Cl^{-} in the pre- and post-monsoon seasons varied from 43.99 to 328.99 mg/L (avg. 151.37 mg/L) and 23.99 to 288.93 mg/L (avg. 105.70 mg/L), respectively. The spatial analysis of Cl^{-} (Fig. 5b) shows that 72.54% of the district groundwater sample falls within the acceptable limit (< 200 mg/L) and 27.45% within the permissible limit (> 200 mg/L) during the pre-monsoon season, while 92.15 and 7.84% of the district groundwater sample falls within the acceptable and permissible limit during the post-monsoon season. Nitrate concentration varied from 5.09 to 103.42 mg/L (avg. 38.06 mg/L) in the pre-monsoon season and from 1.44 to 73.43 mg/L (avg. 22.92 mg/L) in the post-monsoon season. The spatial analysis of NO_3^{-} (Fig. 3c) displays that 60.78% of the district groundwater sample falls within the acceptable limit (< 45 mg/L) and 39.21% within the permissible limit (> 45 mg/L) during the pre-monsoon season, while 74.50 and 25.49% of the district groundwater sample falls within the acceptable and permissible limit recommended by BIS (2012) and WHO (2004) standard during the post-monsoon season. The chief sources of chloride and nitrate are atmospheric precipitation, application of fertilizers, animals waste and discharges of municipal or domestic sewage (Appelo and Postma 1996; Singh et al. 2013; Tiwari et al. 2016). Sulphate concentrations ranged from 21.83 to 157.76 mg/L (avg. 68.03 mg/L) in the pre-monsoon season and from 10.42 to 125.69 mg/L (avg. 44.57 mg/L) in the post-monsoon season. The spatial analysis of sulphate (Fig. 5d) shows that entire groundwater sample falls within the acceptable limit (< 200 mg/L) recommended by the BIS (2012) and WHO (2004) standard during the pre- and post-monsoon season. Fluoride concentrations varied from 0.34 to 1.89 and 0.24 to 1.64 mg/L with an average value of 1.08 and 0.84 mg/L in the pre- and post-monsoon season, respectively. The spatial analysis of F^{-} (Fig. 5e) in the groundwater sample indicates that 56.90, 19.58 and 23.52% of the groundwater sample, respectively, falls within the acceptable

(< 1.0 mg/L) permissible (1.0–1.5 mg/L) and exceeding permissible limit (> 1.5 mg/L) during the pre-monsoon season, while 64.70, 26.20, 9.1% of the groundwater sample, respectively, falls within the acceptable, permissible and exceeding permissible limit during the post-monsoon season. It is an essential element for maintaining normal development of teeth and bones. Fluoride in groundwater may be derived from the weathering of fluoride-bearing minerals like muscovite, biotite, fluorite and fluoroapatite occurred as accessories minerals in the granites and granitic gneisses, besides industrial and agricultural sources (Appelo and Postma 1996; Singh et al. 2011).

Ternary diagrams and Durov diagram

Ternary diagrams for anions and cations are plotted for the pre- and post-monsoon seasons, respectively (Fig. 6a, b). Most of the groundwater samples shows no dominant type in the cation ternary diagram, while the HCO_3^- type in the anion ternary diagram during the both seasons, respectively. However, the cation ternary diagram shows that few groundwater samples are dominated by sodium and calcium during both seasons, respectively. Consequently, two types of prominent hydrochemical facies are observed in the study groundwater sample. Ca–HCO_3 and Na–HCO_3 types of the groundwater were found during both seasons, respectively. The hydrochemical facies does not affect much due to the effluence of monsoon season in the study area.

The major cation and anion concentrations of the samples collected from the groundwaters in the study area were plotted on the Durov diagram (Fig. 7). Durov diagram (1948) helps the interpretation of the evolutionary trends and provides more information on the hydrochemical processes occurring in groundwater system and can indicate mixing of different water types, ion exchange and reverse ion exchange process (Aly et al. 2015). The diagram is a composite plot consisting of two ternary diagrams where the cations (Na^++K^+, Ca^{2+}, Mg^{2+}) of interest are plotted against the anions (Cl^-, HCO_3^-, SO_4^{2-}) of interest; sides form a binary plot of total cation versus total anion concentrations; expanded version includes total dissolved solids (mg/L) and pH data added to the sides of the binary plot to allow further comparisons. Durov diagram was used to evaluate the hydrogeochemical process in the groundwater of the study area and is shown in Fig. 7. The cation triangle displays that most of the groundwater samples are showing no dominant type during both seasons, respectively. The majority of the water samples are falling in the field 5 which indicates mixing process of two or more different facies during both seasons, respectively, while some samples are falling in filed 6 that indicates reverse ion exchange process. On the anion triangle, most of the groundwater samples are showing HCO_3^- type indicates that the groundwaters fall in the region of carbonate weathering during both seasons, respectively. In general, weathering of rocks and ion exchange process are mainly controlling the groundwater chemistry of the study area.

Estimation of GIS-based WQI

Water quality index is one of the most effective tools to communicate information on the quality of any water body. The WQI was computed to assess the quality of groundwater of Bokaro district for the pre-and post-monsoon seasons. The computed WQI values of groundwater samples ranged from 54.73 to 228.02 (avg. 125.51) in the pre-monsoon season and

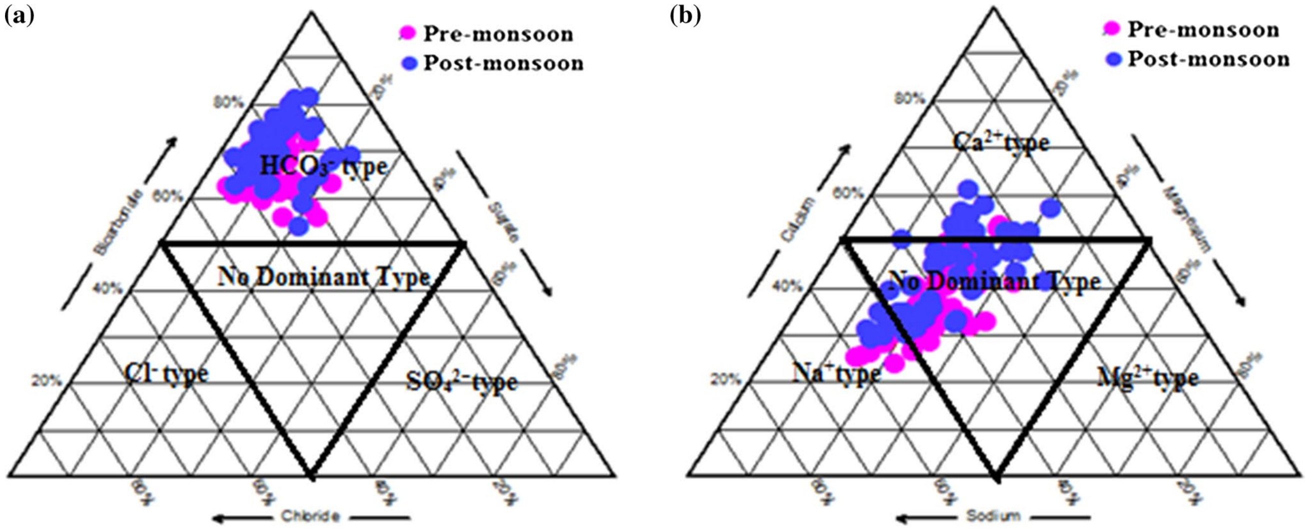

Fig. 6 Ternary anion (**a**)–cation (**b**) diagram of the groundwater samples

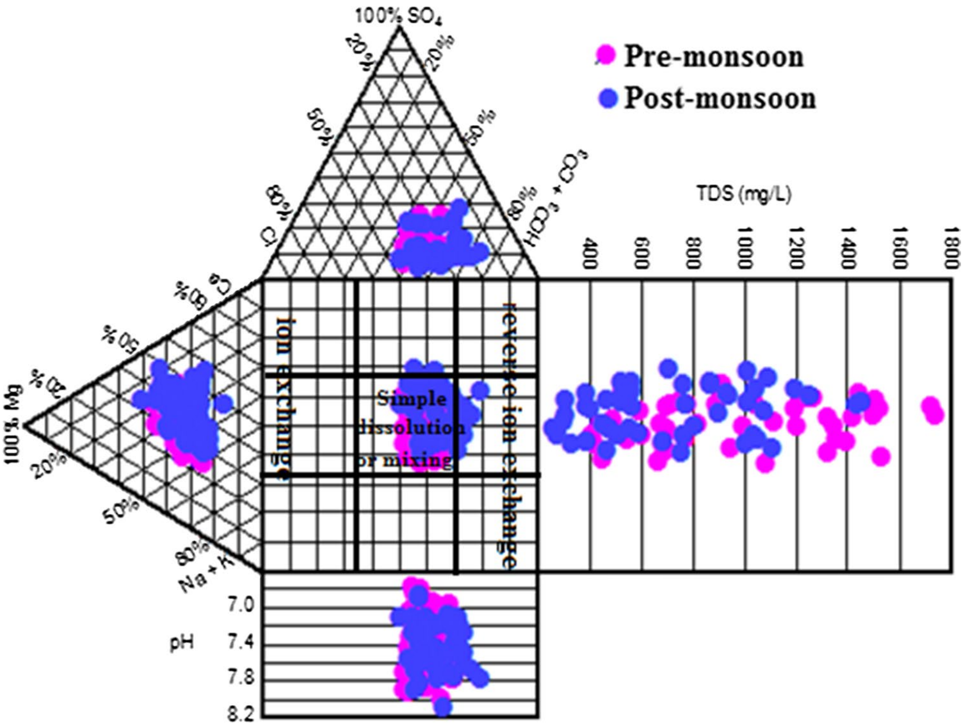

Fig. 7 Durov diagram for Bokaro district groundwater samples

from 38.85 to 185.61 (avg. 95.11) in the post-monsoon season, respectively. The highest WQI value was calculated for the samples collected from the Siwandih, Hazari and Bhawanipur sampling locations (Table 4). The higher WQI values in the groundwater of the Bokaro district were found in the pre-monsoon season as compared to the post-monsoon season as shown in Fig. 8. The higher values of WQI in the study area were observed due to the higher concentrations of TDS, F^-, Cl^-, NO_3^- and SO_4^{2-} in the groundwater samples during both the seasons, respectively. The WQI values in the groundwater samples may be attributed due to the natural and anthropogenic activities of the study area. However, lower values of WQI in the post-monsoon season of the study area indicate a dilution affect. Among all of the groundwater samples, the percentage (%) of WQI categories was good (43. 13%), poor (50.98%) and very poor (5.89%) in the pre-monsoon season (Table 5 and Fig. 8a). However, in the post-monsoon season the percentage (%) of WQI categories is excellent (11.77%), good (43. 13%) and poor (45.10%) of the groundwater samples (Table 5 and Fig. 8b). These results indicate the groundwater is moderately polluted and not suitable for direct drinking uses.

Conclusion

The spatial and temporal analysis of physicochemical parameters of the groundwater of Bokaro district was assessed to determine its suitability for drinking purpose. pH values of the groundwater were slightly acidic to slightly alkaline nature during both the seasons. Concentrations of TDS, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^- and F^- exceeded permissible limits of drinking water standards prescribed by the WHO (2004) and BIS (2012) in the study area during both seasons. The other parameters (Cl^-, SO_4^{2-}, and Na^+) were within the limits during both seasons, respectively. The higher concentration of TDS in the study area may be due to the presence of higher concentration of Ca^{2+}, Mg^{2+} HCO_3^-, F^- and NO_3^-. The lower concentrations of TDS, TH, Ca^{2+}, Mg^{2+} HCO_3^-· F^- and NO_3^- of the groundwater samples during the post-monsoon season as compared to the pre-monsoon season indicate that monsoon plays a significant role for decreasing the concentrations of these parameters. The hydrochemical analysis of studied groundwater samples revealed that most of the groundwater samples belong to HCO_3^- type of anions facies and some samples Ca^{2+} and Na^+ type, and remaining samples are no dominant type of cation facies. The GIS-based WQI results showed that 50.98% and 45.10% of the groundwater samples were found as a poor category in the pre- and post-monsoon seasons and not suitable for drinking use. The results of present study revealed that the chemistry of groundwater of the study area was controlled by the rock weathering, ion exchange processes and anthropogenic activities. Proper water resources management plans are requiring in the study for managing the groundwater resources problems.

Table 4 Water quality index values for the groundwater during pre-and post-monsoon season of the Bokaro district

S. no.	Location	WQI values Pre-monsoon	Description	WQI values Pre-monsoon	Description
Gw1	Badhadih	118.02	Poor water	71.36	Good water
Gw2	Jharna	79.81	Good water	63.11	Good water
Gw3	Chinigariya	109.34	Poor water	74.27	Good water
Gw4	Bermo	85.23	Good water	65.78	Good water
Gw5	Bijulia	133.69	Poor water	74.98	Good water
Gw6	Parbatpur	179.50	Poor water	112.00	Poor water
Gw7	Kudwadih	185.74	Poor water	124.05	Poor water
Gw8	Dantu	90.28	Good water	53.29	Good water
Gw9	Kashi Jharia	102.34	Poor water	82.15	Good water
Gw10	Dantu	167.79	Poor water	127.54	Poor water
Gw11	Jainamore	110.37	Poor water	89.05	Good water
Gw12	Dhandaber	80.25	Good water	56.79	Good water
Gw13	Siwandih	214.86	Very poor water	183.02	Poor water
Gw14	Gudkutarh	186.34	Poor water	163.61	Poor water
Gw15	Santhaldih	59.39	Good water	41.47	Excellent water
Gw16	Pupunki	69.94	Good water	45.89	Excellent water
Gw17	Telgaria more	196.16	Poor water	136.86	Poor water
Gw18	Hazari	204.61	Very poor water	155.42	Poor water
Gw19	Kalyanpur (Baru)	129.31	Poor water	103.42	Poor water
Gw20	Mamkudar	91.38	Good water	62.85	Good water
Gw21	Laghla	172.48	Poor water	129.21	Poor water
Gw22	Bhawanipur	228.16	Very poor water	185.61	Poor water
Gw23	Chadankiyari	174.21	Poor water	145.21	Poor water
Gw24	Khasmahal	58.40	Good water	42.57	Excellent water
Gw25	Sitanalah	178.13	Poor water	138.05	Poor water
Gw26	Pidrajora	159.16	Poor water	125.16	Poor water
Gw27	Tulbul	148.57	Poor water	102.20	Poor water
Gw28	Peterwar	169.67	Poor water	138.25	Poor water
Gw29	Pindrajora	196.06	Poor water	160.58	Poor water
Gw30	Gomia	119.89	Poor water	87.99	Good water
Gw31	Jainamore	98.25	Good water	79.49	Good water
Gw32	Nerki	77.84	Good water	55.57	Good water
Gw33	Balidih	147.64	Poor water	120.19	Poor water
Gw34	Telgaria more	168.72	Poor water	135.68	Poor water
Gw35	Pichri	61.23	Good water	42.37	Excellent water
Gw36	Chapri	128.92	Poor water	103.69	Poor water
Gw37	Baladih	123.81	Poor water	104.58	Poor water
Gw38	Phusro	93.27	Good water	79.48	Good water
Gw39	Khadudih	73.52	Good water	51.12	Good water
Gw40	Bodro	85.61	Good water	63.82	Good water
Gw41	Lalpania	97.64	Good water	75.34	Good water
Gw42	Khutari	54.73	Good water	38.85	Excellent water
Gw43	Nawadih	95.77	Good water	68.35	Good water
Gw44	Siwandih	158.34	Poor water	119.97	Poor water
Gw45	Laghla	69.66	Good water	47.07	Excellent water
Gw46	Peterwar	87.09	Good water	69.47	Good water
Gw47	Bazar Sammittee	88.18	Good water	73.33	Good water
Gw48	Sitanalah	183.54	Poor water	139.51	Poor water
Gw49	Badhnadih	102.51	Poor water	78.49	Good water
Gw50	Parbatpur	90.68	Good water	70.83	Good water
Gw51	Laheria tanr	83.56	Good water	57.52	Good water

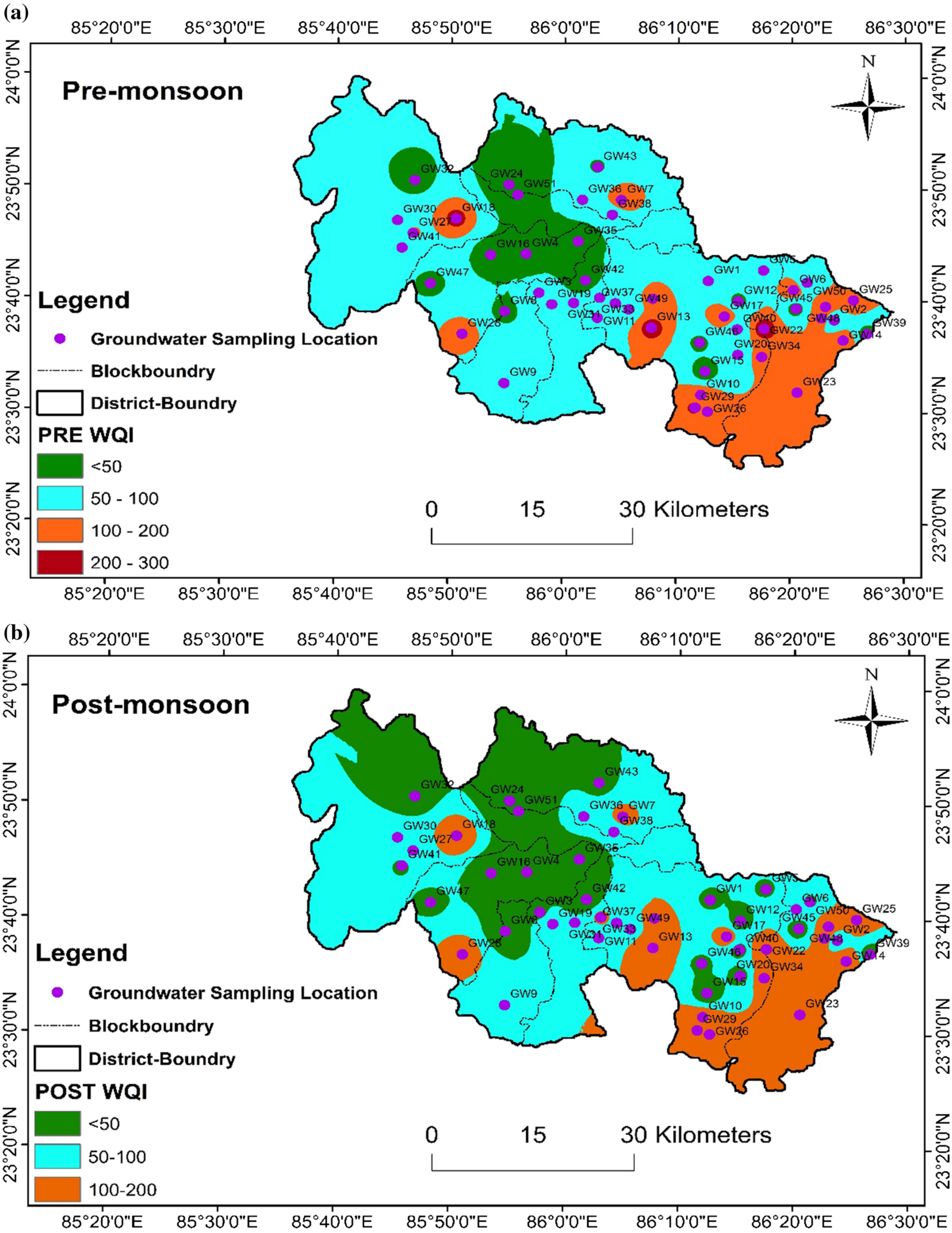

Fig. 8 Spatial distribution of WQI values in the groundwater of the Bokaro district

Table 5 Classification of water based on WQI in percentage

WQI range	Type of water	% of samples in the pre-monsoon	% of samples in the post-monsoon
< 50	Excellent water		11.77% (6)
50–100	Goodwater	43.13% (22)	43.13% (22)
100–200	Poor water	50.98% (26)	45.10% (23)
200–300	Very poor water	5.89% (3)	–
> 300	Water unsuitable for drinking purpose	–	–

Acknowledgements Authors thank the Head of Department of the Department of Environmental Science and Engineering, Indian Institute of Technology (Indian School of mines), Dhanbad, India, for providing research laboratory for analytical work and permission to publish this research article. We are grateful to the Editors and anonymous reviewers for their valuable suggestions.

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