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ORIGINAL ARTICLE

Assessment of groundwater quality and its controlling processes in Bemetara District of Chhattisgarh State, India

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Abstract

Groundwater withdrawal at very fast rate poses threat on existing groundwater resources in different parts of the world. This reduction in groundwater levels significantly disturbed the natural aquifer flow rate and thereby different hydrogeochemical processes, which may further impair the groundwater quality. The groundwater quality in rural area of Chhattisgarh State is degraded, and the problem of saline water poses health risk to people. In this research investigation, suitability of groundwater of Bemetara District, Chhattisgarh, India, has been evaluated for drinking purpose through water quality index (WQI) method and principal component analysis (PCA). Total 116 groundwater samples were collected during the pre-monsoon (June 2019) and post-monsoon season (December 2019) and analyzed for physicochemical parameters. Total dissolved solids ranged from 250 to 10,440 mg/L and 289 to 3583 mg/L during pre-monsoon and post-monsoon, respectively, and 55% of the total samples exceeded acceptable BIS limit in pre-monsoon, while about 66% samples exceeded in post-monsoon season. SO_4^{2-} concentrations varied from 3 to 5734 mg/L during pre-monsoon and 4.5 to 2002 mg/L during post-monsoon, respectively. Total 28% samples in pre-monsoon and 18% samples in post-monsoon season exceeded the maximum permissible BIS limit (400 mg/L) of SO_4^{2-} ion in the study area. On the basis of WQI, the quality of groundwater varies from “Excellent water” to “Good water” category. The groundwater of northeastern part of the district is not suitable for drinking, and therefore, it is recommended to treat this groundwater before human consumption with special reference to SO_4^{2-} contamination. PCA inferred that four components are sufficient to explain the variance in chemistry of groundwater that is mainly governed by dissolution of gypsum mineral, other rock–water interaction and anthropogenic activities. Further, water quality was improved in the direction of groundwater flow in the study area, establishing a direct relationship between groundwater flow and water quality of the Bemetara District. This study provides very useful database to design sustainable groundwater management plan for the district.

Keywords Groundwater quality · Water quality index · Principal component analysis · Groundwater flow

Introduction

Untreated waste discharge leads to degradation of the surface water quality, and therefore, water supply for different sectors like agricultural, industrial and domestic needs has been fulfilled by groundwater resources. But the rate of usage of groundwater has resulted into declining groundwater levels, which is very critical to available resources, and this decline level reaches up to 80 m in zone of depression (Chen et al. 2005). This reduction in groundwater levels may significantly altered the groundwater flow conditions (Wang et al. 2008; Zhang et al. 1997, 2000; Fan 1998; Xia et al. 2004). Therefore, different studies have been taken to investigate the aquifer flow conditions in respect to the

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sustainable utilization of groundwater resources (USGS 1999; CGWB Report 2019). This decline in groundwater level leads to change in the aquifer hydrogeochemical processes (CGWB Report 2019).

Groundwater quality depends on important process like atmospheric precipitation, runoff and inland surface water. Moreover, the groundwater quality is degraded due to disposal of industrial waste and mining activities (Rodell et al. 2009; Chopra and Gopal 2014; Malyan et al. 2019). Further, groundwater quality in a region is influenced by physical and chemical parameters that are strongly affected by natural processes such as water chemistry in the recharged area, water intermixing, groundwater recharge, aquifer discharge and recharge, and water flow path (Singh et al. 2017; Azhdarpoor et al. 2019; Soleimani et al. 2018). The spatial distribution and zoning of NO_3^- and F^- concentration and their health risk assessment in drinking groundwater of Shiraz metropolitan area in the southwest of Iran and Behbahan City were studied by application of Monte Carlo simulation, sensitivity analysis and geographic information system (Badeenezhad et al. 2019, 2021).

The most convenient method to describe the quality of drinking water resources is the Water Quality Index (WQI). The first attempt to develop a WQI was made in 1948, when scientific community found a correlation between pollution load and certain group of organisms (fish, plant and benthic community) (Alves et al. 2014). Later, Horton developed WQI technique in 1965 (Horton 1965). After that, National Sanitation Foundation (NSF) of United States developed WQI in 1970 which is widely used (Brown et al. 1970). Therefore, WQI is not new tool, but has been extensively used across the world to determine the water quality (Abbasi and Abbasi 2012).

Different water quality indices have been developed and used for the evaluation of water quality for drinking purposes (Horton 1965; McDuffie and Haney 1973; Nemerow and Sumitomo 1970; Brown et al. 1970; Landwehr 1976; Parti et al. 1971; Dinius 1972; Dee et al. 1973). A number of studies have been carried out by different workers for assessing the quality of different water resources of India using WQI, viz. Sajitha et al. (2016), Reza and Gurdeep (2010), Ishaku et al. (2011), Kumar et al. (2014), Saxena et al. (2017), Acharya et al. (2018) and Vijayachandran et al. (2018).

Principal component analysis (PCA) is a useful tool to investigate the chemical relationship between different water quality parameter and thereby predicting the dominating parameters (Sharma and Jain 2006). PCA is a multivariate statistical technique that has been widely used to reduce the dimensionality of large data (Vega et al. 1998; Duan et al. 2016; Zhang et al. 2016). The goal of PCA is to describe the majority of the data sets in a few principal components (PCs), and these PCs are the linear combination of observed data with maximum variations with minimum loss of the actual information (Baghanam et al. 2020). PCA has been applied to explain water quality variable in several studies (Vermonden et al. 2009; Daou et al. 2016; Zhang et al. 2016; Abdelaziz et al. 2020; Chai et al. 2021). Huang et al. (2007) used PCA to explain the storm water quality data for pattern recognition and identification of pollution sources from different urban surface-type catchments.

Sharma and Jain (2006) evaluated groundwater quality of Jodhpur District, Rajasthan (India), using multivariate technique and concluded that F^-, NO_3^-, pH and K^+ have significant influence on the quality of the aquifer. Marin Celestino et al. (2019) used PCA to investigate hydrogeochemical processes in a wastewater-irrigated region (central Mexico) and reported that groundwater chemistry was dominated by three processes: salinization, mineralization and groundwater contamination.

Chai et al. (2021) investigated the source assessment of pollution in the Fen River for different seasons. Giakwad et al. (2020) evaluated the groundwater quality of western coast of Maharashtra, India, with the use of PCA technique. Abdelaziz et al. (2020) studied groundwater quality index based on PCA in Wadi El Natrun, Egypt, and used PCA to reduce the complexity of the data and identified the group of parameters (Na^+, SO_4^{2-}, Cl^-, strontium, Ca^{2+} and molybdenum) that control the groundwater quality.

The groundwater quality in rural area of the Chhattisgarh State is degraded, and the problem of saline water (EC ~ 2000–4500 µS/cm) poses a threat to the people. There is a serious problem of saline water in 113 villages of district Bemetara of Chhattisgarh State, and 1200 to 2600 mg/L of TDS was observed in the groundwater of problematic villages of district Bemetara, which may cause health problem, viz. digestion, high blood pressure, heart attack and kidney problems (CGWB Report 2015). In some parts, the value of SO_4^{2-} is observed up to 800 ppm which causes gastrointestinal disorders among the inhabitants of the area (Mukherjee and Gupta 2010). According to the groundwater quality assessment by Central Ground Water Board, a central agency of government of India, the SO_4^{2-} concentration found up to 763 ppm in Bemetara village of Bemetara District in 2014–2015 (CGWB Report 2015). For the alternate sources, the residents of these villages are using contaminated water from ponds, rivers and drains in the area. In a study of health risk evaluation of uranium in groundwater of Bemetara District, uranium levels in water samples range from 1.15 to 83.5 µg/L and 0.68 to 96.08 µg/L during premonsoon and post-monsoon, respectively, with few samples exceeding the safe limit of 30 µg/L prescribed by WHO (2011), and there is no harmful effect by radiological risk, but chemical risk can affect human health (Sahu et al. 2020). Dahariya et al. (2020) studied the contamination, sources and environmental hazard of groundwater in Bemetara District of Chhattisgarh, India, and reported WQI (406 ± 82) values which clearly demarcate groundwater unsuitability for drinking purposes.

In view of the above scenario of degraded groundwater quality in the district Bemetara of Chhattisgarh State, the aim of the present investigation is (1) to monitor the quality of groundwater for drinking purpose using WQI; (2) to monitor spatial and seasonal variation of important water quality parameters using the application of GIS software; and (3) to identify several factors responsible for degradation of quality of groundwater using principal component analysis.

Study area

Bemetara District is newly formed district of Chhattisgarh State, India, and covering area of 2854.81 km^2 (Fig. 1). It lies in between 21° 22′ and 22° 03′ North latitude and 81° 07′ and 81° 55′ East longitude. Bemetara District has huge quantity of mineral deposits, namely sandstone, limestone (low grade), dolomite and quartzite. Dolomite and limestone mineral were found high in whole district. The study area has a dry and wet tropical climate. The temperature varies from 10 to 48 °C, where the maximum temperature is reached in the month of May and June and minimum temperature fall in January. Bemetara District has flat topography, and totally six rivers flow in the direction of slope of district (north to east), namely Shivnath, Kharun, Surahi, Haff, Sakari and Phonk rivers. Bemetara District geologically comes under Meso- to Neoproterozoic rock sequence of Chhattisgarh supergroup. This Chhattisgarh

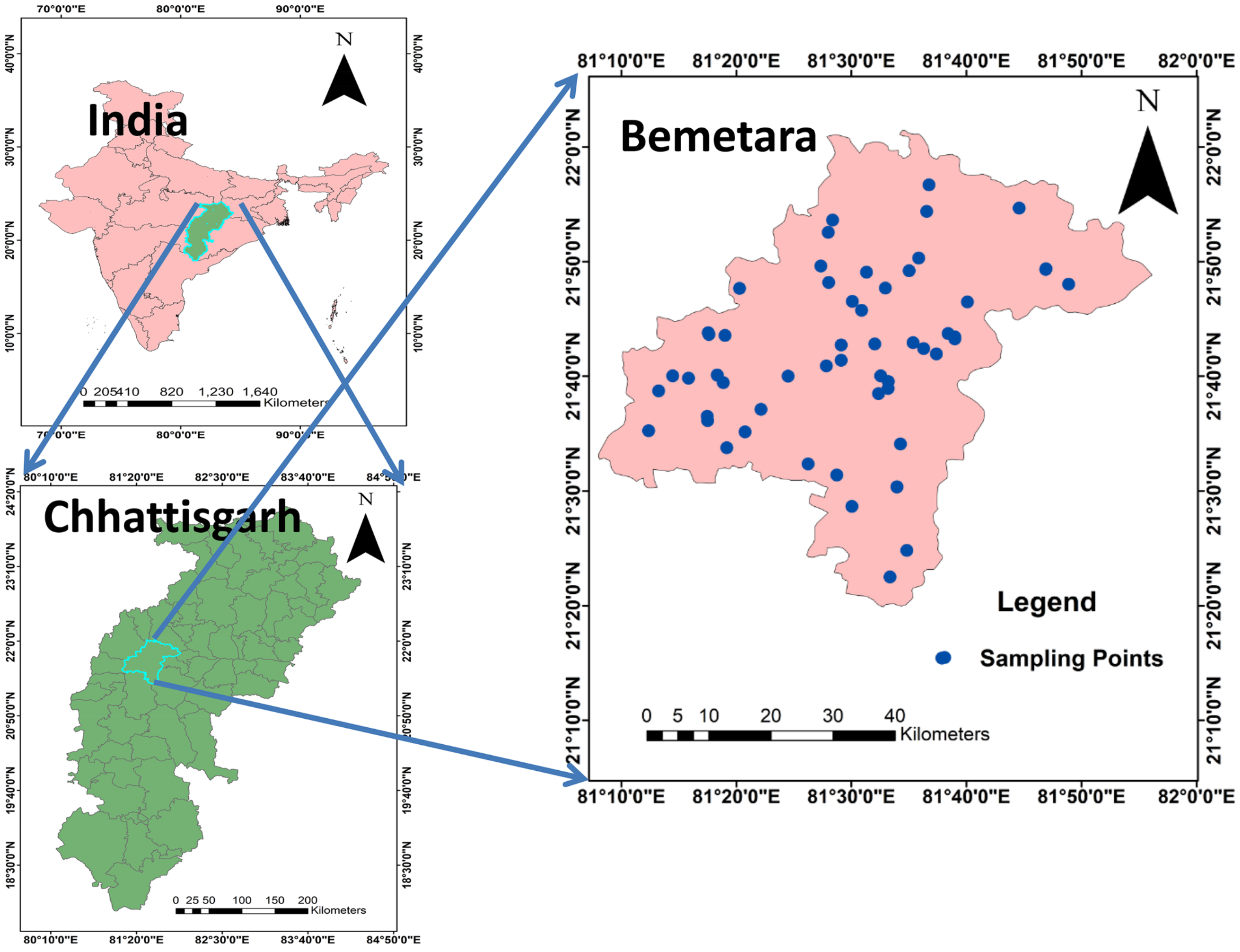

Fig. 1 Map showing the location of sampling sites in the study area

supergroup is divided further into different groups; our study area falls under Raipur group which comprises four types of geological formation (Maniyari formation, Hirri formation, Tarenga formation and Chandi formation). The reddish brown and purple non-calcareous shale containing gypsum form the characteristics of Maniyari formation, under most of the district area occurred (District Survey Report Bemetara Chhattisgarh 2016).

Hydrogeology of the study area

The hydrogeological formation of study area mainly consists of arenaceous–argillaceous–calcareous rocks and is enriched by limestone/dolomite and calcareous shale. The groundwater in these formations occurs under water table, semi-confined and confined conditions. The weathered, cavernous and fractured part of the formation constitutes the aquifer in the area and has great potential in regards to groundwater yield and thereby development groundwater in the district. Geology and hydrogeology of the study area shown in Figs. 2 and 3, respectively. The gypsum karsts occurring in the Maniyari formation of this province are more productive. Though gypsum is more soluble than calcite, their alternative assemblage with thinly laminated shale provides special condition that favors dissolution of gypsum laminae causing roof collapses to create larger openings. However, all the formations in the district are productive (CGWB Report 2015).

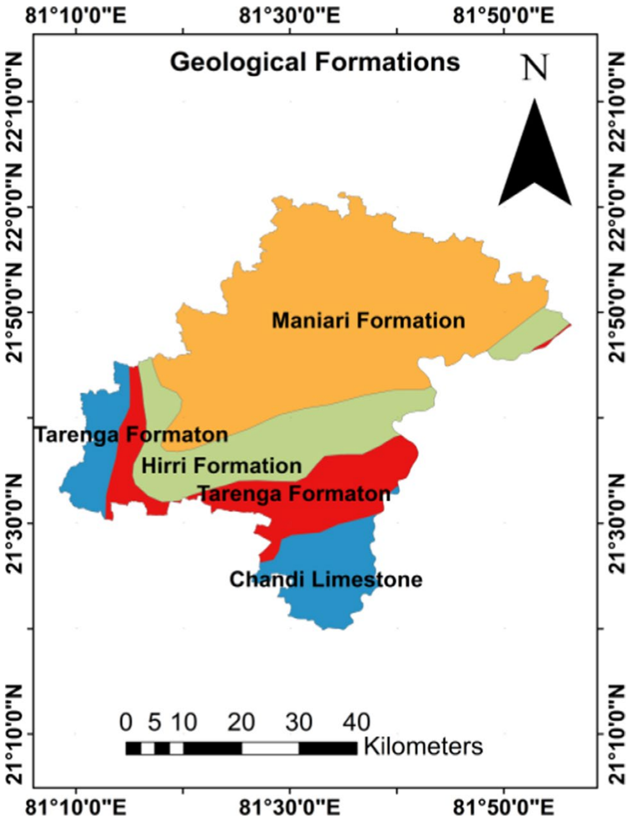

Fig. 2 Geology map of the study area

Material and methods

Water sampling and analytical techniques

In total, 116 samples were collected from groundwater sources of 51 locations of the district Bemetara, viz. open wells, dug wells, borewells and handpumps, during pre-monsoon (June 2019) and post-monsoon (Dec. 2019), which are extensively being used for drinking water purpose and analyzed for physicochemical parameters using standard methods (APHA 2005). Groundwater samples were taken from one open well from each of 51 locations, but borewell samples were also collected from seven locations along with open well. Before collecting samples, handpumps/borewells were pumped for 5 min to get represented water sample and the sampling bottle was rinsed with the same water. In situ parameters were analyzed on site like pH and electrical conductivity using Hach, USA make HQ40d portable handheld multimeter. Other parameters like major cation and anion were analyzed using Metrohm ion chromatograph. The ionic balance error (IBE) test was performed (Eq. 1) (Freeze and Cherry 1979) and was below 5% for all samples, which support the data accuracy and reliability of the analysis. Total alkalinity and HCO_3^- were determined by autotitrator of SI analytical instrument, a Xylem brand.

$$\text{IBE }(\%) = \frac{\sum \text{cation} - \sum \text{anion}}{\sum \text{cation} + \sum \text{anion}} \times 100 \tag{1}$$

Water quality index (WQI)

WQI is an important method that is used for the evaluation of quality of water for drinking purposes (Subba Rao 1997; Avvannavar and Shrihari 2008; Mishra and Patel 2001; Badeenezhad et al. 2020). BIS (2012) and WHO (2011) set standard limit to different water quality parameters for drinking purposes, and some of these are incorporated into calculation of WQI. Here, we took ten parameters (Table 1) for calculating WQI and each parameter is assigned a weight (w_i) depending upon the importance of overall quality of water.

The assigned weight ranges from 1 to 5, where 5 is the highest and 1 is the lowest weight (Srinivasamoorthy et al. 2008; Vasanthavigar et al. 2010). In the next step, the relative weight (W_i) is calculated by Eq. 2 as follows:

Fig. 3 Hydrogeology map of the study area

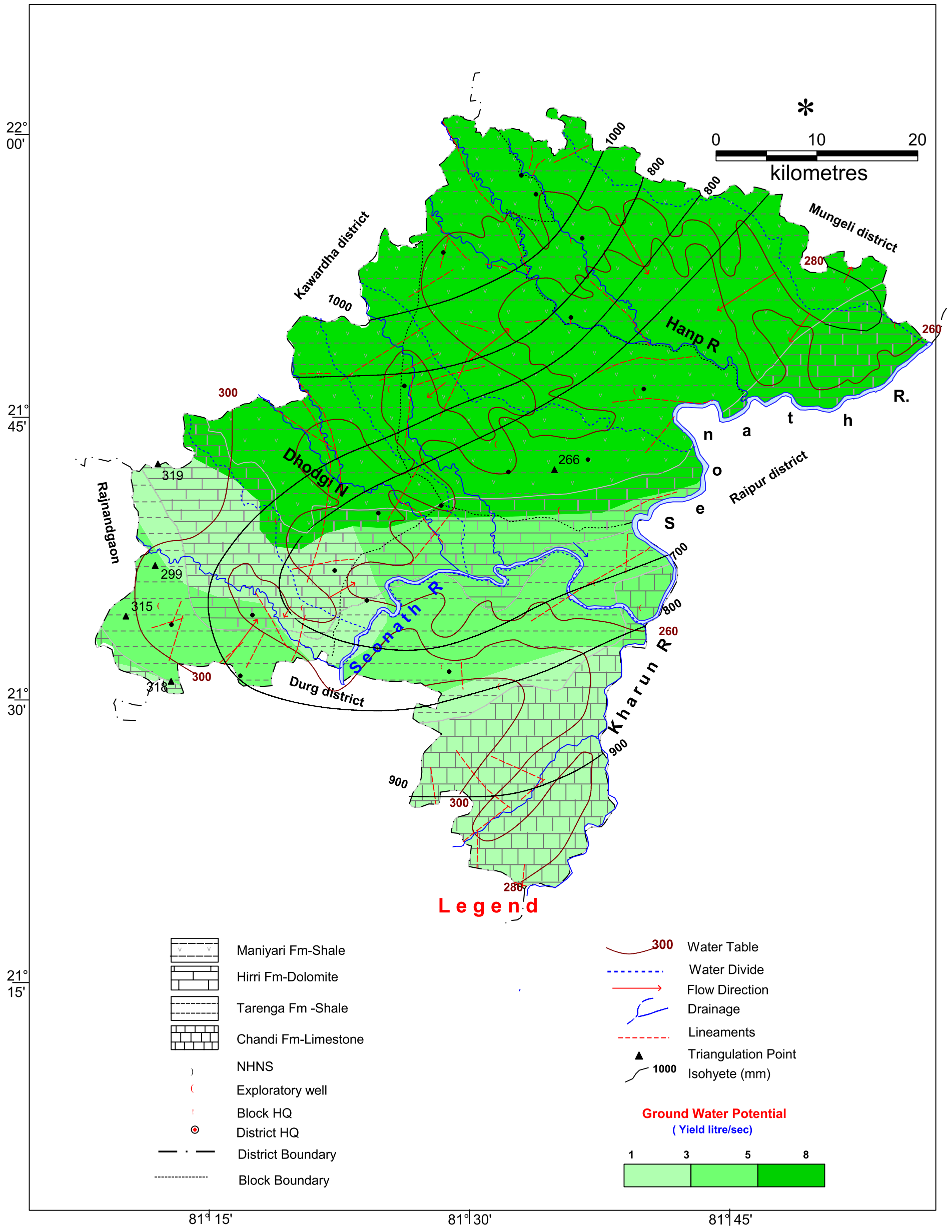

Table 1 Relative weight of chemical parameters

Chemical parameters (mg/L)	Indian Standard (BIS 10500, 2012)	Weight (w_i)	Relative weight $W_i = w_i/\sum_{i=1}^{n} w_i$
Total dissolved solids	500	5	0.131
HCO_3^-	244	1	0.026
Cl^-	250	5	0.131
SO_4^{2-}	200	5	0.131
NO_3^-	45	5	0.131
F^-	1.0	5	0.131
Ca^{2+}	75	3	0.079
Mg^{2+}	30	3	0.079
Na^+	200	4	0.105
K^+	10	2	0.053

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

where W_i is the relative weight, w_i is the assigned weight of each parameter and n is the total number of parameters.

Chemical parameters and their calculated relative weight (W_i) are given in Table 1.

The next quality rating value (q_i) is calculated by Eq. 3:

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

where q_i is the quality rating, C_i is the concentration of parameter in water sample (ppm) and S_i is the BIS value for each parameter in ppm.

And finally WQI is calculated by Eqs. (4) to (5):

$$\mathrm{SI}_i = W_i \times q_i \tag{4}$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SI}_i \tag{5}$$

where SI_i = subindex of ith parameter; q_i = rating based on the concentration of ith parameter; n = number of parameters.

Five WQI classes and water types can be categorized accordingly as given in Table 2.

Data processing

An univariate and multivariate normal distribution are required for the best outcomes of the statistical multivariate methods like PCA (Zhou et al. 2007; Oppong and Agebedra 2016; Marin et al. 2018). Shapiro–Wilk's (Shapiro and Wilk 1965) and Royston's tests (Royston 1983) were used to verify the univariate and multivariate normality conditions, respectively. The Spearman's rank correlation was used in this multivariate analysis because water quality data were non-normal distribution, and this correlation method is best suitable for reducing deviation of variables (Marin Celestino et al. 2019). Based on Royston's test, the dataset has a non-normal distribution. To achieve a normal-like distribution, the original set of variables was transformed using a logarithmic transformation (natural logarithm). To approach the best conditions of the multivariate analysis, feature scaling on the database was done using standardization (or Z-score normalization). Standardization minimizes the variance in variables and protects dissimilarity metrics such as the Euclidean distance from being severely influenced (Davis and Sampson 1986). Each variable was normalized to its Z score, which was determined using Eq. (6):

$$Z_i = \frac{X_i - \text{mean}}{S} \tag{6}$$

where Z_i is the standardized Z score, X_i is each variable's value, and mean and S are each variable's mean value and standard deviation, respectively. The Kolmogorov–Smirnov (K–S) test was used to assess how well the transformed variables were adjusted to the normal log distribution (Rizvi et al 2015; Muangthong and Shrestha 2015; Marin Celestino et al. 2019; Castillo et al. 2021). The precision and acceptability of the data for PCA were assessed by using the Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity tests. KMO is a metric for determining the sampling's adequacy by identifying the proportion of shared variation that might be linked by unknown factors (Marin Celestino et al. 2019; Castillo et al. 2021). The KMO and Bartlett's sphericity test results are described in the results and discussion section.

Table 2 Classification of WQI for drinking purpose in the study area

WQI classes	Type of water
< 50	Excellent water (EW)
50–100	Good water (GW)
100.1–200	Poor water (PW)
200.1–300	Very poor water (VW)
> 300	Unsuitable for drinking purpose (UW)

Principal component analysis (PCA)

In PCA, the standardized and normalized data as discussed in earlier section are used. Factors are produced through an eigenvalue analysis of the correlation matrix. These factors are vector which shows interorthogonality within a multidimensional space defined by a number of variables in the analysis (Sharma and Jain 2006). Unlike the original variable, the factors are uncorrelated with each other. They are described by means of their correlation with (or "loading" on) the original variables and ranked in order of the amount of the total variance they explain. A loading close to one indicates a strong relationship between factor and the variable, whereas a zero loading indicates no relationship (Davis and Sampson 1986; Sharma and Jain 2006). Among the whole factors, first few factors explain the bulk of total variance and the remaining factors are not used in the analysis. These retained factors were then rotated using Varimax method. Varimax rotation tried to attain a simple structure, whereby factor loading is close to one or zero. This helps in the interpretation of the factors that either does or does not include a particular variable. Principal component and factor analysis are applied on the groundwater of the district Bemetara, and the whole analysis has been carried out using software RStudio Vs 1.4.1106.

Results and discussion

Hydro-chemical characteristics of groundwater of the study area

In total, 116 samples were collected from the study area during the year 2019–2020 from the abstraction sources in collaboration of Water Resources Department (WRD), Govt. of Chhattisgarh, Raipur. The minimum, maximum and average values of all the chemical parameters for both the seasons are given in Table 3.

Table 3 Hydro-chemical characteristics of groundwater of the study area (pre- and post-monsoon 2019)

S. No	Parameters	Minimum	Maximum	Average
1	pH	6.2 (6.14)	7.72 (7.22)	7.06 (6.7)
2	EC (µS/cm)	390 (452)	16,312 (5598)	1808 (1569)
3	TDS (mg/L)	250 (289)	10,440 (3583)	1157 (1004)
4	Alkalinity (mg/L)	83 (52)	280 (415)	183 (210)
5	Hardness (mg/L)	119 (116)	3267 (2124)	657 (604)
6	Na^+ (mg/L)	7 (8)	2694 (201)	103 (66)
7	K^+ (mg/L)	0.67 (0.15)	53 (201)	11.4 (22.3)
8	Ca^{2+} (mg/L)	26 (26)	569 (648)	167 (162)
9	Mg^{2+} (mg/L)	11 (12)	488 (259)	58 (49)
10	HCO_3^-(mg/L)	101 (62)	341 (506)	223 (256)
11	Cl^- (mg/L)	10 (12)	1080 (652)	92 (109)
12	SO_4^{2-} (mg/L)	3 (4.5)	5734 (2002)	469 (283)
13	NO_3^- (mg/L)	0 (0)	194 (569)	26 (53)
14	F^- (mg/L)	0.06 (0)	2.4 (1.04)	0.45 (0.42)

*Values in the parentheses represent post-monsoon values of different parameters

The pH of all collected samples is alkaline in nature and varies from 6.2 to 7.7 and 6.1 to 7.1 during pre-monsoon season (PRS) and post-monsoon season (PMS), respectively. Almost all samples are found within BIS (2012) and WHO (1996) standard limits of 6.5–8.5.

In Bemetara District, total dissolved solid (TDS) in groundwater ranges from 250 to 10,440 mg/L and 289 to 3583 mg/L during PRS and PMS, respectively. About 55% samples exceeded the acceptable limit (ALT) but lies below the prescribed maximum permissible limit (MPL) of 2000 mg/L in PRS and about 66% samples were found above ALT but within 2000 mg/L in PMS. The maximum value of TDS 10440 mg/L was observed in the groundwater of the village Kunra of the block Nawagarh. The spatial distribution map of TDS for PRS and PMS is shown in Fig. 4.

CO_3^-, HCO_3^- and hydroxides are mainly responsible for alkalinity in water system. The alkalinity value varied from 83 to 280 mg/L and 52 to 415 mg/L during PRS and PMS, respectively. About 50% samples exceeded ALT but under the prescribed MPL of 600 mg/L in PRS, and about 59% samples were found above ALT but are under 600 mg/L in PMS. None of the sample crossed the prescribed limit of 600 mg/L during PRS and PMS, respectively (Fig. 5).

The presence of bivalent ions mainly Ca^{2+} and Mg^{2+} with their compounds cause hardness in water. Total hardness value ranges from 119 to 3267 mg/L and 116 to 2124 mg/L during PRS and PMS, respectively. About 50% samples cross the ALT of 200 mg/L but lie below the MPL of 600 mg/L, and 38% samples exceeded the prescribed MPL 600 mg/L during PRS. During the PMS, about 67% samples are within the prescribed MPL and 28% samples cross the prescribed MPL. The spatial distribution maps of hardness are shown in Fig. 6 for both the seasons. It is observed from the spatial distribution maps of both the season that the northeastern part of the study area is highly contaminated and the value

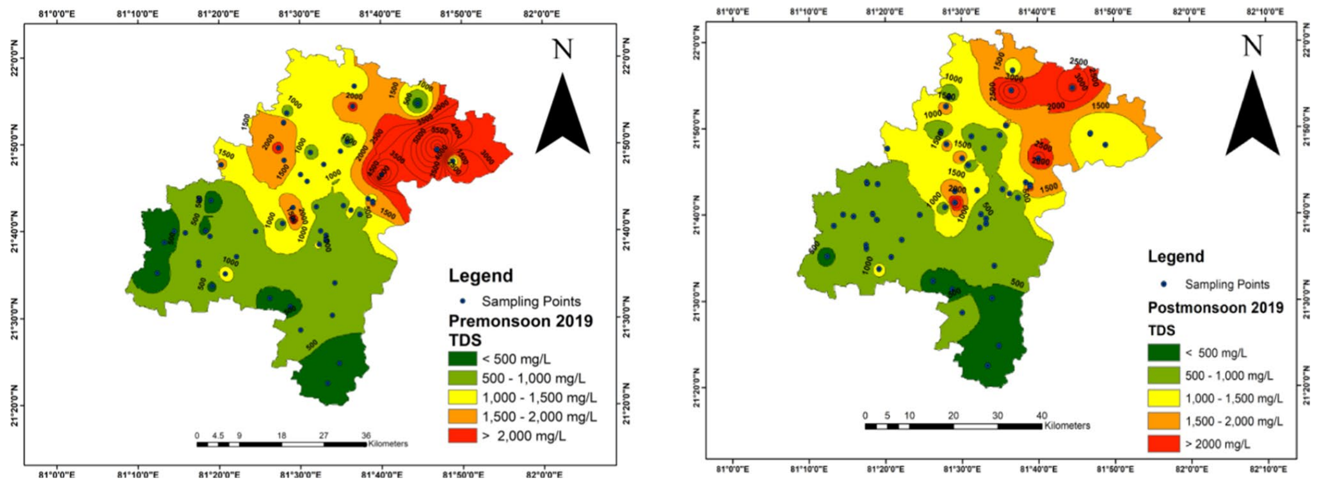

Fig. 4 Spatial distribution of TDS in the groundwater of the study area (pre- and post-monsoon 2019)

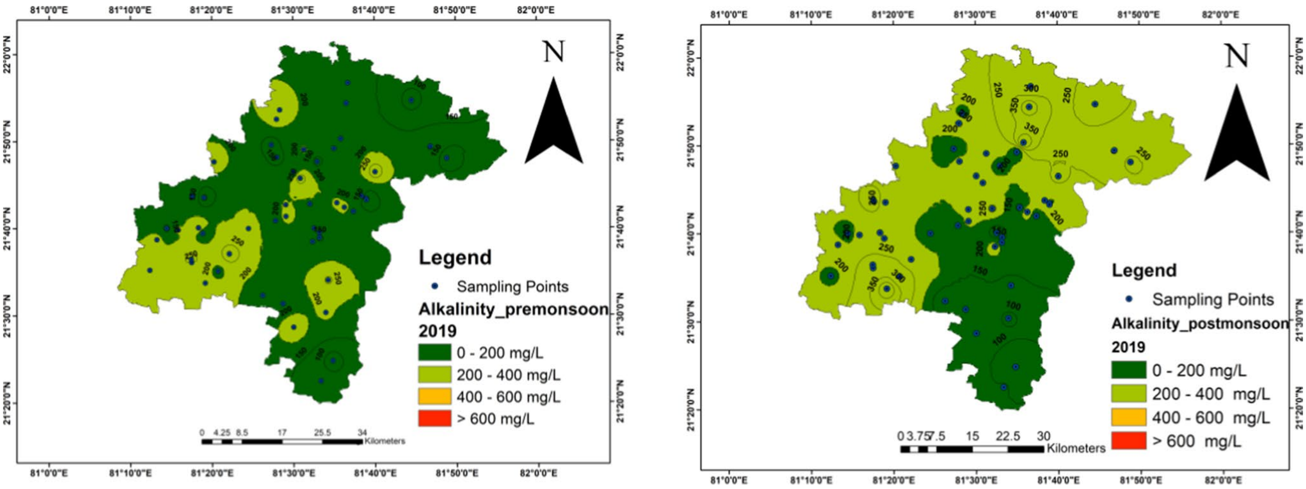

Fig. 5 Spatial distribution of alkalinity in the groundwater of the study area (pre- and post-monsoon 2019)

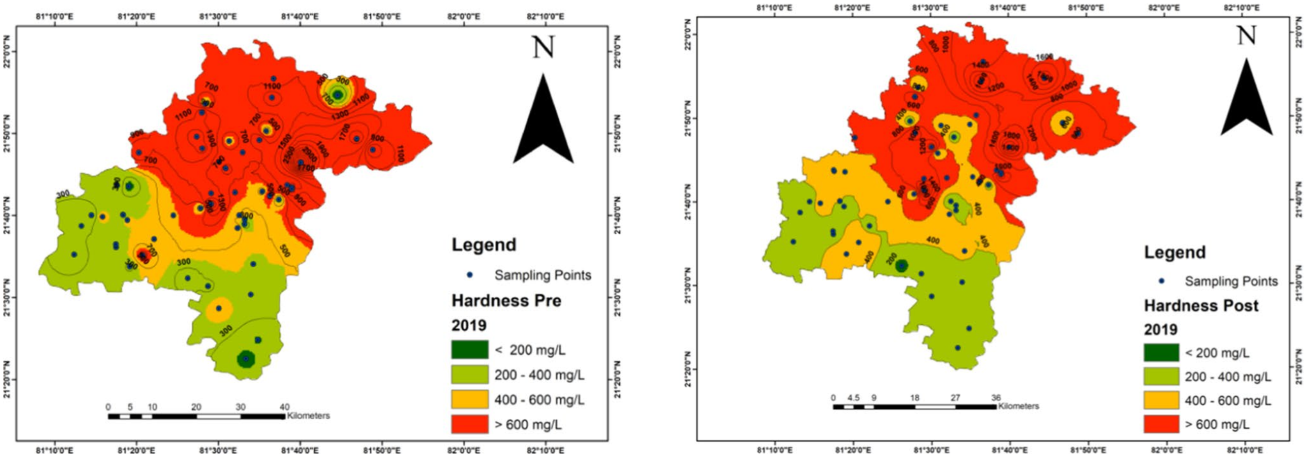

Fig. 6 Spatial distribution of hardness in the groundwater of the study area (pre- and post-monsoon 2019)

of hardness crossed 3000 ppm and the maximum value of hardness 3267 mg/L was observed in the groundwater of the village Bitkuli of the block Bemetara.

In groundwater of the study area, the values of Ca^{2+} range from 26 to 569 mg/L and 26 to 648 mg/L during PRS and PMS, respectively. About 24% samples crossed the prescribed MPL of 200 mg/L during the PRS and 17% samples crossed the prescribed MPL during the PMS. The less number (7%) of samples crosses the MPL in the PMS because of the dilution effect as compared to PRS. The value of Mg^{2+} varies from 11 to 488 mg/L during PRS and 12 to 259 mg/L during PMS. Only 12% samples exceed prescribed MPL 100 mg/L during PRS and 7% exceed above 100 mg/L during PMS.

The value of Cl^{-} ranges from 10 to 1080 mg/L and 12 to 652 mg/L during PRS and PMS, respectively. More than 90% samples lie within the prescribed ALT of 250 mg/L during both the seasons. NO_3^{-} content in the study area ranges from 0 to 194 mg/L and 0 to 569 mg/L during PRS and PMS, respectively. About 93% of the samples of the study area fall within MPL of 45 mg/L and 7% of samples even crossed the MPL during PRS and about 67% of the samples of the study area fall within the prescribed MPL of 45 mg/L and 33% of samples even crossed the prescribed MPL during PMS. F^{-} in the groundwater of Bemetara District ranges from 0.06 to 2.4 mg/L and 0 to 1.04 mg/L during PRS and PMS, respectively. Almost all samples lie under the prescribed ALT of 1.0 mg/L during both the seasons.

SO_4^{2-} is generally found as soluble salts of Ca^{2+}, Mg $^{2+}$ and Na $^{+}$ in the groundwater. During the PRS, the concentration of SO_4^{2-} ranges from 3 to 5734 mg/L and 4.5 to 2002 mg/L during PMS. BIS sets 200 mg/L as the ALT and 400 mg/L as MPL for SO_4^{2-} in drinking water. In Bemetara District about, 55% of the samples are below the prescribed

ALT of 200 mg/L and 28% samples exceeded the value of MPL of 400 mg/L during the PRS, while 67% samples lie below the ALT and 19% sample exceeded prescribed MPL of 400 mg/L during PMS. The spatial distribution of SO_4^{2-} in the study area is shown in Fig. 7 for PRS and PMS. The northeastern area of the study area is highly contaminated as shown in the spatial distribution maps for both the seasons, and the maximum value of SO_4^{2-} 5735 mg/L was observed in the groundwater of the village Kunra of the block Nawagarh.

Depthwise variation of groundwater quality of the study area

Depthwise distribution of groundwater samples has been arranged in three categories, i.e., shallow aquifer (0–20 m), medium aquifer (21–40 m) and deep aquifer (> 40 m). In PRS, about 31% samples from the shallow aquifer (SA), no sample from medium and 2% sample from deep aquifer lie under the ALT of TDS, i.e., 500 mg/L (BIS 2012), while about 49% samples from the SA, 2% samples each from medium and deep aquifer exceeded limit of TDS, i.e., 2000 ppm (BIS 2012), and only 14% samples from SA exceeded the MPL of TDS. In case of PMS, about 26% samples from the SA, no sample from the medium and deep aquifer fall within the ALT, while about 64% samples from SA, 2% samples from deep aquifer exceeded the ALT but under the MPL of TDS and 9% samples from SA exceeded the MPL of TDS (Table 4).

During PRS, about 48% samples from the SA, 2% samples from medium and no sample from deep aquifer fall within ALT of alkalinity, i.e., 200 mg/L (BIS 2012), while about 46% samples from the SA, 0% samples from medium aquifer and 3% samples from deep aquifer lie under the limit of MPL of alkalinity, i.e., 600 mg/L (BIS 2012) and no samples from SA, medium aquifer and deep aquifer exceeded the MPL of alkalinity. In case of PMS, about 41% samples from the SA, no sample each from medium and deep aquifer fall within the ALT, while only 57% samples from SA and 2% samples from deep aquifer lie above ALT but under the MPL of alkalinity and none of samples from SA, medium aquifer and deep aquifer exceeded the MPL of alkalinity (Table 5).

In PRS, about 12% samples from the SA, 0% samples each from medium and deep aquifer fall within the ALT of hardness, i.e., 200 mg/L (BIS 2012), while about 48% samples from the SA, 0% samples from medium aquifer and 2% samples from deep aquifer lie below the MPL of hardness, i.e., 600 mg/L (BIS 2012), and only 38% samples from SA exceeded the MPL of hardness. In case of PMS, about 5% samples from the SA, no sample from the medium and deep aquifer fall within the ALT, while about 66% samples from SA, 2% samples from deep aquifer crossed the ALT but are under MPL of hardness and 27% samples from SA exceeded the MPL of hardness (Table 6).

In PRS, about 53% samples from the SA, 0% samples from medium and 2% samples from deep aquifer fall within the ALT of SO_4^{2-}, i.e., 200 mg/L (BIS 2012), while about 17% samples from the SA, 0% samples from each medium aquifer and deep aquifer lie under MPL of SO_4^{2-}, i.e., 400 mg/L (BIS 2012), and 26% samples from SA, 2% samples from medium aquifer and 0% samples from deep aquifer exceeded the MPL of $SO_4^{2-.}$ In PMS, about 66% samples from the SA, no sample from the medium and 2% samples from deep aquifer fall within the ALT, while only 14% samples from SA lie in between ALT and MPL of SO_4^{2-} and 19% samples from SA exceeded the MPL of SO_4^{2-} (Table 7).

From the above discussion, it may be concluded that almost all collected groundwater samples belong to shallow aquifer and the significant amount of collected contaminated with higher SO_4^{2-} contamination. Further, water quality at different depths at the same site of few locations has been

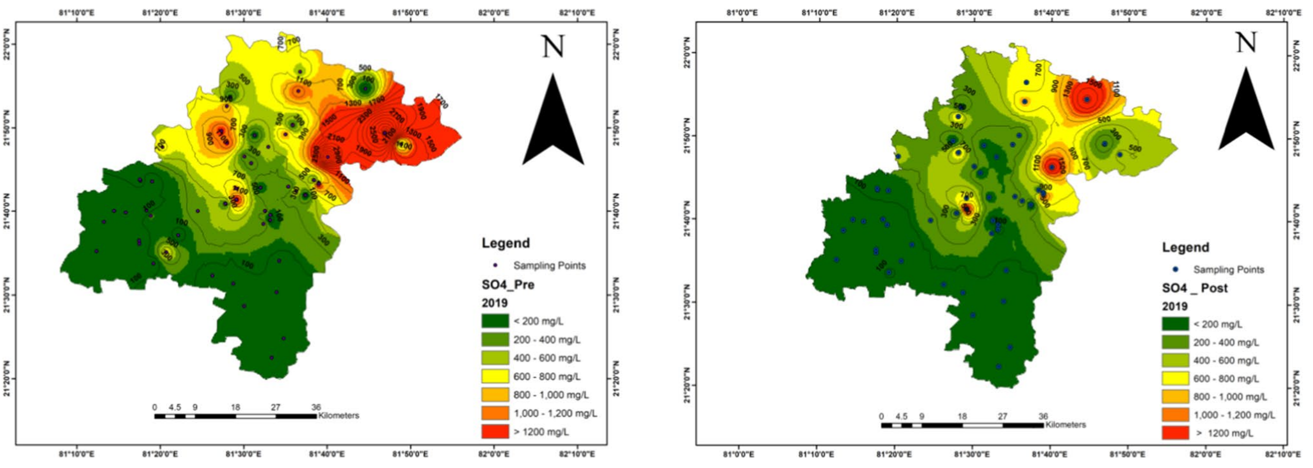

Fig. 7 Spatial distribution of SO_4^{2-} in the groundwater of the study area (pre- and post-monsoon 2019)

Table 4 TDS distribution in groundwater of the study area

S. No	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1	0–500	0–20	1,4,8,24,28,37,38,40,43,44,46,47,51,55,56,57	1,2,4,15,17,24,28,29,34,36,37,38,40, 42,57	27.58	25.86
		20–40	54	–	1.72	0
		> 40	2	–	1.72	0
2	501–2000	0–20	3,6,7,11,13,14,15,19,20,21,22,23,26,27,29,30,32,33,34,35,36,39,41,42,45,48,50,52,53	3,6,7,9,10,11,13,14,16,18,19,20,21,22,23,26,27,30,32,33,35,39,41,43,44,45,46,47,48,50,51,52,53,54,55,56,58	48.97	63.8
		20–40	10,58	–	3.44	0
		> 40	49	49	1.72	1.72
3	> 2000	0–20	5,9,12,16,17,18,25,31	5,8,12,25,31	13.79	8.62
		20–40	–	–	0	0
		> 40	–	–	0	0
Total number of samples			58	58	100	100

Table 5 Alkalinity distribution in groundwater of the study area

S. No	Alkalinity, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1	0–200	0–20	1,4,5,8,11,12,13,14,15,16,17,20,22,24,26,28,29,32,34,37,38,40,42,45,50, 51,56	1,2,3,4,15,17,19,22,23,24,28,29,32,33, 34,35,36,37,38,39,40,43,56, 57	44.83	41.37
		20–40	10,54,58	–	5.17	–
		> 40	–	–	–	–
2	201–600	0–20	3,6,7,9,18,19,21,23,25,27,30,31,33,35,36,39,41,43,44,46,47,48,52,53,55, 57	5,6,7,8,9,10,11,12,13,14,16,17,18,20,21,25,27,30,31,41,42,44,45,46,47,48,50, 51,52,53,54,55,58	46.56	56.90
		20–40	–	–	–	–
		> 40	2, 49	49	3.44	1.72
3	> 600					
		0–20	–	–	–	–
		20–40	–	–	–	–
		> 40	–	–	–	–
Total number of samples			58	58	100	100

studied and it was observed that higher concentrations of different water quality parameters were generally observed at higher depths below the ground, which is due to more residence time of groundwater in the deeper aquifer (Fig. 8).

Water quality index

Hydro-chemical data of groundwater of Bemetara District were processed for determination of WQI and thereby quality check for drinking purposes. To assess water quality, sampling station was selected as to cover all Bemetara District areas and all sampling points shown in Fig. 1. Ten parameters, i.e., HCO_3^-, TDS, SO_4^{2-}, Cl^-, NO_3^-, Ca^{2+}, Mg^{2+}, F^-, Na^+ and K^+, were taken into account to calculate WQI for each station and for both the season. Finally, single numeric value represents the type of water according to WQI classes given in Table 2. WQI has been computed for 58 groundwater samples for PRS and PMS

Table 6 Hardness distribution in groundwater of the study area

S. No	Hardness range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1	0–200	0–20	4,8,29,37,38,51,56	4,28,40	12.06	5.17
		20–40	–	–	0	0
		> 40	–	–	0	0
2	201–600	0–20	1,2,3,5,14,19,23,24,32,33,34, 35,36,38, 39,40,41,42,43,44, 46,47,48,50,53,54, 55,57	1,2,3,9,10,15,17,19, 21,22,23,24,27,29, 32,33,34,35,36,37, 38,39,41,42,43,44, 45,46,47,48,50,51, 53,54,55,56,57,58	48.28	65.52
		21–40	–	–	0	0
		> 40	49	49	1.72	1.72
3	> 600	0–20	6,7,9,10,11,12,13, 15,16,17,18,20,21, 22,25,26,27,28,30, 31,52,58	5,6,7,8,11,12,13,14,16,18,20,25, 26,30, 31,52	37.93	27.58
		20–40	–	–	0	0
		> 40	–	–	0	0
Total number of samples			58	58	100	100

Table 7 SO_4^{2-} distribution in groundwater of the study area

S. No	SO_4^{2-} range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1	0–200	0–20	1,2,3,4,8,19,23,24, 26,28,34,35,36,37, 38,39,40,41,43,44, 46,47,48,50,51,53, 54,55,56,57,58	1,2,3,4,6,7,15,19, 20,21,24,26,28,29, 32,34,35,36,37,38, 39,40,41,42,43,44, 45,46,47,48,50,51, 53,54,55,56,57,58	53.45	65.52
		20–40	–	–	0	0
		> 40	49	49	1.72	1.72
2	201–400	0–20	5,6,14,20,21,27,29,32,33,42	7,9,10,14,22,23,27,33	17.24	13.79
		20–40		–	0	0
		> 40	–	–	0	0
3	> 400	0–20	7,9,11,12,13,15,16,17,18,22,25,30 ,31, 45,52	5,8,11,12,13,16,18,25,30,31,52	25.87	18.96
		20–40	10	–	1.72	0
		> 40	–	–	0	0
Total number of samples			58	58	100	100

(Table 8). The values of WQI range from 26.24 to 1001.59 for PRS and 25.64 to 538.63 for PMS.

It has been observed from Table 7 that 32.27% samples fall under "Good water" category and 27.58% samples found to be "Excellent water" for PRS. Cumulative "Excellent water" and "Good water" category represents about 60% of the samples in PRS. In case of PMS, 46.55% samples fall under "Good category" and 15.52% samples represent "Excellent water." About 62% samples represent combination of two categories, i.e., "Excellent water" and "Good water." All five WQI categories distribution in percentage for PRS and PMS has been provided in Supplementary material as Fig. S1.

Water quality of groundwater of district Bemetara is found to be good for some part of the district, but the rest of the area is not fit for drinking purposes. To find out the degraded water quality zones in the study area, spatial distribution map has been created using Arc GIS Software Vs 10.4 with the use of IDW technique (Fig. 9). It was evident from Fig. 9 that water quality is good in the southwestern part of the study area, while water quality is poor to unsuitable for drinking in the northeastern side of Bemetara District

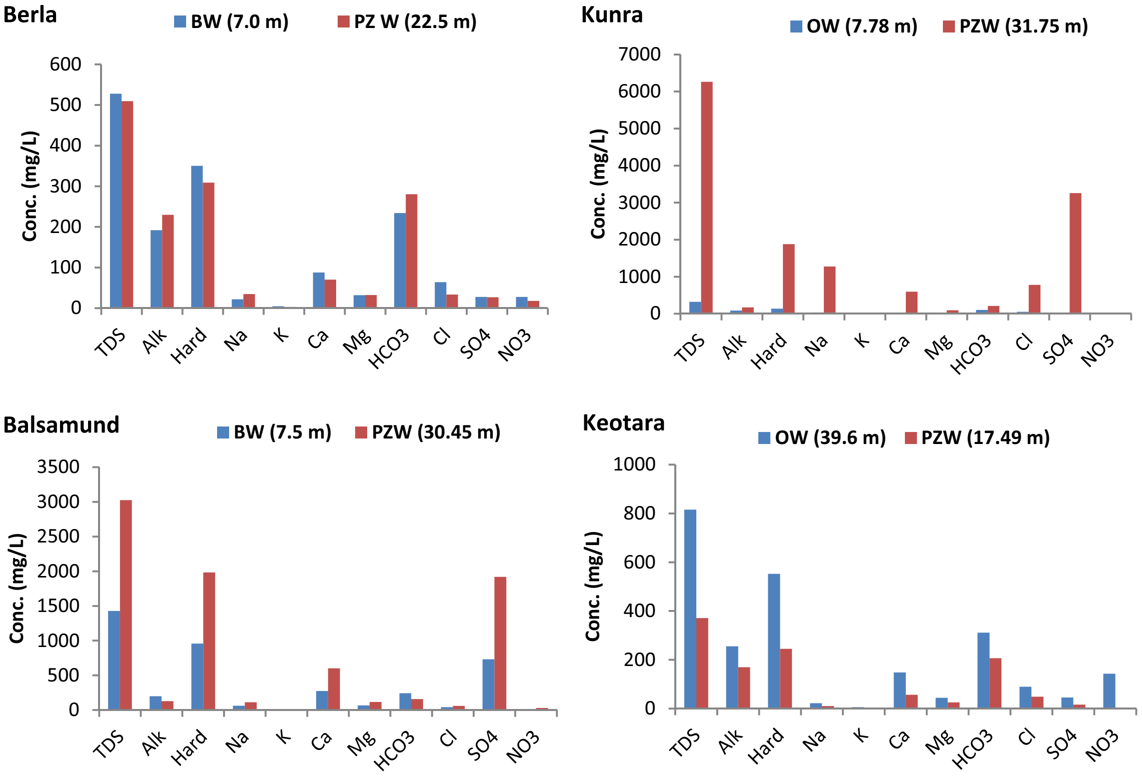

Fig. 8 Water quality at different depths

that needs treatment before direct consumption in case of pre-monsoon season and almost the same pattern was found for post-monsoon season. It may be inferred that quality of groundwater is not suitable for drinking in the northeastern zone of Bemetara District for both the seasons.

Correlation among the chemical parameters

Correlation among the physicochemical parameters for both the seasons has been evaluated using correlation matrix and given in Table 9. The correlation values were grouped into three classes as very strong correlation (r greater than 0.75), moderate correlation ($r=0.50$–0.75) and low correlation ($r=0.30$–0.50). From the obtained correlation results, a very strong positive correlation is obtained between Ca^{2+} and SO_4^{2-} (0.98), Na^+ and Cl^- (0.87), Na^+ and F^- (0.86) during the PRS, while Ca^{2+} and SO_4^{2-} (0.94) for the PMS. A moderate positive correlation was found between $Mg^{2+}$and Ca^{2+} (0.67), $Mg^{2+}$and SO_4^{2-} (0.70), $Mg^{2+}$and F^-(0.52), Ca^{2+} and F^- (0.62) during the PRS and Mg^{2+} with SO_4^{2-} (0.71), Mg^{2+} with NO_3^- (0.68), $Mg^{2+}$with Cl^- (0.64), Mg^{2+} with HCO_3^- (0.54) and Na^+ with Ca^{2+}(0.59), Na^+ with NO_3^- (0.68), Na^+ with Cl^-(0.66), Na^+ with SO_4^{2-} (0.65), Na^+ with HCO_3^- (0.54) during the PMS. From the above discussion, it may be concluded that there may be common source of Ca^{2+}, Mg^{2+} and SO_4^{2-} in the groundwater, i.e., dissolution of dolomite or gypsum mineral. Further, SO_4^{2-}plotted against the Ca^{2+}, Mg^{2+}, Na^+ and K^+ (Fig. 10) and the best relationship was observed between Ca^{2+} and SO_4^{2-} (maximum r^2), further supporting the fact that the source of SO_4^{2-} in the groundwater of the study area may be $CaSO_4$, i.e., gypsum, which is present in Maniyari shale formation of the region.

Principle component analysis

PCA is a multivariate method that reduces the dimensions of a dataset that contain different variables which are interrelated to each other. PCA was used to study the origin of major salts in the groundwater of Bemetara. Before applying PCA, two tests were performed to analyze the statistical interrelation among the parameters. The KMO test value was 0.5, and Bartlett's sphericity value was 0.00 that confirmed the data are appropriate and suitable for PCA (Zhang et al. 2020). Eigenvalues and cumulative contribution of all principal components for both the seasons are given in Table 10, and varimax rotated component loadings are given in Table 11. Different components incorporated in the explication of sources for both the seasons are presented in Table 12.

In pre-monsoon season, only four principal components (PCs) were taken into account with eigenvalue more than

Table 8 WQI of groundwater of study area (pre- and post-monsoon 2019)

S. No	Sample code	Location	Source	Pre-monsoon		Post-monsoon	
				WQI	Type of water	WQI	Type of water
1	BMT-1	Berla	BW	40.91	EW	53.11	GW
2	BMT-1(Pz)	Berla	PzW	44.29	EW	46.31	EW
3	BMT-2	Bijabhat	BW	81.08	GW	104.9	PW
4	BMT-3	Balsamund	OW	30.04	EW	25.64	EW
5	BMT-3(Pz)	Balsamund	PzW	340.9	UW	358.9	UW
6	BMT-4	Pindri	OW	223.0	VW	237.2	VW
7	BMT-5	Bemetara	OW	141.3	PW	118.6	PW
8	BMT-6	Sambalpur	OW	36.54	EW	313.7	UW
9	BMT-7	Kunra	OW	301.1	UW	208.0	VW
10	BMT-7(Pz)	Kunra	PzW	1001.6	UW	207.9	VW
11	BMT-8	Murra	OW	117.4	PW	135.6	PW
12	BMT-9	Nawagarh	OW	218.9	VPW	538.6	UW
13	BMT-10	Jhal	OW	129.0	PW	152.8	PW
14	BMT-11	Andhiyarkhor	OW	77.01	GW	177.4	PW
15	BMT-12	Jhal	OW	111.0	PW	54.18	GW
16	BMT-13	Sagona	OW	214.8	VW	179.4	PW
17	BMT-14	Kanhera	OW	227.0	VW	46.32	EW
18	BMT-15	Chilphi	OW	252.4	VW	229.31	VW
19	BMT-16	Dadhi	OW	63.07	GW	58.01	GW
20	BMT-17	Bahera	OW	122.6	PW	203.7	VW
21	BMT-18	Baiji	OW	162.7	PW	73.53	GW
22	BMT-19	Jhalam	OW	165.6	PW	71.29	GW
23	BMT-20	Baba Mohtara	OW	67.3	GW	121.8	PW
24	BMT-21	Kusmi	OW	34.01	EW	35.71	EW
25	BMT-22	Bitkuli	OW	573.6	UW	305.8	UW
26	BMT-23	Khilora	OW	101.6	PW	115.3	PW
27	BMT-24	Jeori	OW	135.6	PW	119.0	PW
28	BMT-25	Amora	OW	33.20	EW	63.74	GW
29	BMT-26	Farri	OW	88.58	GW	66.54	GW
30	BMT-27	Bhurki	OW	193.3	PW	181.4	PW
31	BMT-28	Dunra	OW	258.2	VW	407.3	UW
32	BMT-29	Ninwa	OW	84.42	GW	61.44	GW
33	BMT-30	Deorbija	OW	96.99	GW	79.25	GW
34	BMT-31	Rampur (Bhand)	OW	68.10	GW	58.52	GW
35	BMT-32	Deori	OW	53.50	GW	75.60	GW
36	BMT-33	Anandgaon	OW	66.21	GW	61.67	GW
37	BMT-34	Pirda	OW	40.33	EW	76.14	GW
38	BMT-35	Ufra	OW	26.24	EW	37.32	EW
39	BMT-36	Sankra	OW	81.69	GW	73.07	GW
40	BMT-37	Sondh	OW	36.29	EW	34.25	EW
41	BMT-38	Kodwa	BW	64.46	GW	59.44	GW
42	BMT-39	Saja	OW	70.47	GW	46.80	EW
43	BMT-40	Jata	OW	51.70	GW	82.09	GW
44	BMT-41	Saja	OW	43.02	EW	54.74	GW
45	BMT-42	RakhiJoba	OW	131.7	PW	85.08	GW
46	BMT-43	Deokar	HP	41.43	EW	98.76	GW
47	BMT-44	Mohgaon	OW	38.19	EW	48.44	EW
48	BMT-45	MouhaBhata	OW	68.51	GW	56.25	GW
49	BMT-46	Beltara	HP	58.65	GW	86.08	GW

Table 8 (continued)

S. No	Sample code	Location	Source	Pre-monsoon		Post-monsoon	
				WQI	Type of water	WQI	Type of water
50	BMT-47	Beltara	OW	59.18	GW	93.79	GW
51	BMT-48	Thelka	OW	40.69	EW	63.75	GW
52	BMT-49	Thankamariya	OW	166.1	PW	125.6	PW
53	BMT-50	Keotara	OW	92.95	PW	103.5	PW
54	BMT-50(Pz)	Keotara	OW	30.99	EW	99.59	GW
55	BMT-51	Bortara	OW	44.42	EW	66.84	GW
56	BMT-52	Sawartala	OW	40.29	EW	66.53	GW
57	BMT-53	Parpodi	OW	42.77	GW	40.57	EW
58	BMT-54(Pz)	Khandesra	OW	97.21	GW	76.95	GW

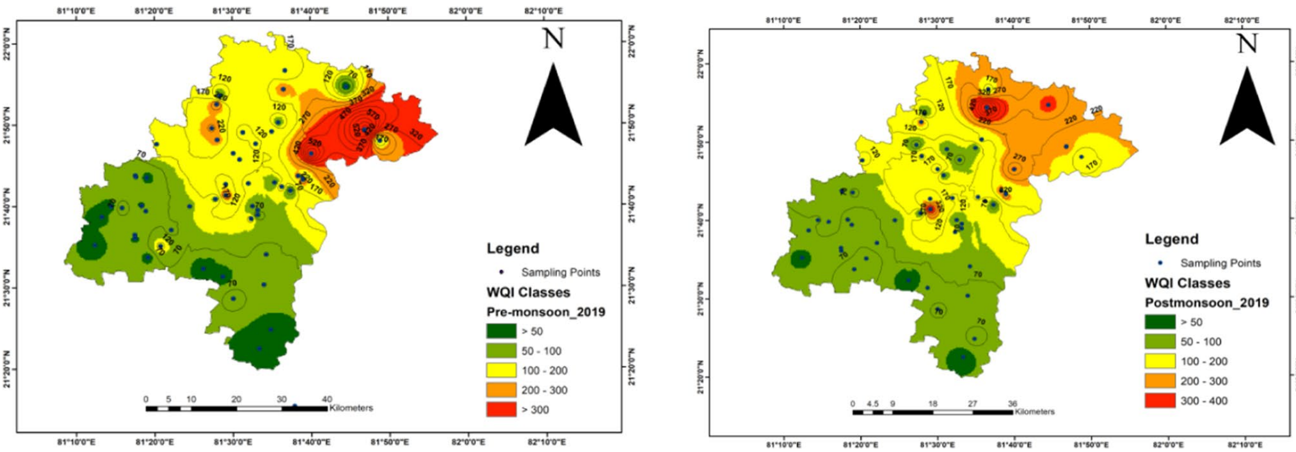

Fig. 9 Spatial distribution of WQI classes for pre- and post-monsoon season (2019) in the study area

1 or near to 1, accounting for 87.09% of total variance, and individual percentage of the variation in the data was 50.49%, 17.80%, 10.72% and 8.08%, respectively (Table 10). The first principal component (PC1) was mainly characterized by SO_4^{2-}, EC, Mg^{2+}, Ca^{2+}, Cl^- and F^- in groundwater that may be attributed to dissolution of gypsum mineral and weathering of Cl^- bearing rocks (Sharma and Kumar 2020; Mullaney et al. 2009). In addition, the F^- may be due to rock–water interactions in the aquifer, and therefore, this factor (F1) may be considered to represent the local geogenic process. Also, PC1 shows 50.49% of the total variation in the data. The second principal component (PC2) accounts17.80% of the total variation in the dataset and had loading on NO_3^-, HCO_3^- and alkalinity. NO_3^- in groundwater is mainly contributed from extensive usage of chemical fertilizers (Zhang et al. 2020), and therefore, this factor (F2) was considered to represent the anthropogenic source. The third principal component (PC3) characterized by K^+, Mg^{2+}, Cl^- and NO_3^- accounts for 10.72% of the total variation in the data. K^+, Mg^{2+} and Cl^- were resulted from the interaction of groundwater and rock materials. The NO_3^- in groundwater was associated with chemical fertilizers application in farming and could consider this factor (F3) mixed type source, i.e., geogenic and anthropogenic. The fourth principal component (PC4) had been loaded with pH, Na^+ and NO_3^-which accounts for 8.08% of the total variation in the dataset. Na^+ may be observed in livestock and domestic waste (Zhang et al. 2020) and could enter subsurface system where there are inappropriate management activities of waste. Therefore, this factor (F4) was called as nonpoint source of pollution mainly from agriculture.

In the post-monsoon season, four PCs can explain 87.61% of total variation with individual contributions of 54.30%, 16.43%, 11.13% and 5.76%, respectively (Table 10). EC, hardness, Na^+, Ca^{2+}, Mg^{2+} and SO_4^{2-} had high loading in PC1. These ions are related to natural geogenic processes as same explained in factor (F1) in pre-monsoon season. In PC2 loading element were pH, HCO_3^-, SO_4^{2-} and NO_3^-, accounting for16.43% of the total variance. NO_3^- and SO_4^{2-} could be resulted from different agricultural activities

Table 9 Correlation matrix between physicochemical parameters

	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	F^-
Pre-monsoon season										
TDS	1									
Na^+	**0.897**	1								
K^+	0.319	0.255	1							
Ca^{2+}	**0.769**	0.445	0.265	1						
Mg^{2+}	**0.668**	0.357	0.206	**0.670**	1					
HCO_3^-	− 0.044	− 0.139	0.198	− 0.033	0.261	1				
Cl^-	**0.792**	**0.876**	0.460	0.425	0.285	− 0.064	1			
SO_4^{2-}	**0.985**	**0.850**	0.234	**0.804**	**0.704**	− 0.109	**0.690**	1		
NO_3^-	0.045	− 0.057	**0.616**	0.170	0.089	0.285	0.259	− 0.054	1	
F^-	**0.868**	**0.821**	0.231	**0.620**	**0.528**	− 0.131	**0.756**	**0.848**	0.015	1
Post-monsoon season										
TDS	1									
Na^+	**0.853**	1								
K^+	0.169	0.164	1							
Ca^{2+}	**0.901**	**0.594**	− 0.035	1						
Mg^{2+}	**0.890**	**0.859**	0.107	**0.678**	1					
HCO_3^-	0.488	**0.544**	0.208	0.326	**0.543**	1				
Cl^-	**0.573**	**0.669**	0.247	0.373	**0.641**	0.360	1			
SO_4^{2-}	**0.907**	**0.651**	− 0.007	**0.943**	**0.714**	0.263	0.232	1		
NO_3^-	**0.543**	**0.686**	0.404	0.239	**0.681**	0.325	**0.709**	0.232	1	
F^-	0.381	0.238	− 0.166	0.429	0.356	0.337	− 0.070	0.463	− 0.098	1

Bold values are indicate strong correlationcoefficient between chemical parameters at level of significance 5%

(Zhang et al. 2020) and consider similar as to source (F4) in the pre-monsoon season, i.e., nonpoint source of pollution. HCO_3^-, Cl^-, NO_3^- and F^- were loading elements that contribute 11.13% of the total variance. NO_3^- related to anthropogenic source, whereas F^- and Cl^- are mainly attributed to geogenic source. Therefore, this factor (F3) is considered as mixed type source as explained in the pre-monsoon season, i.e., geogenic and anthropogenic. The fourth principal component (PC4) was mainly characterized by Na^+ and Cl^-, explaining 5.76% of the total variance. As explained earlier in the pre-monsoon data, this factor (F1) can be regarded as local geogenic processes and salinity.

Variation of water quality along groundwater flow

The investigation of aquifer water flow conditions is very crucial for sustainable water resource management of any region. The movement of groundwater flow interacts with aquifer rock material and carries chemical species in dissolved form (Rakhmatullaev et al. 2010, 2012; Huneau et al. 2011).

Groundwater level observations from the mean sea level (MSL) were taken from the all selected sampling points in the study area for both the seasons. For the identification of the direction of water flow, spatial contour maps of water levels have been prepared for both the seasons (Fig. 11). Groundwater moves from northeast direction to northwest direction and from northeast to southeast direction during both the seasons of the study area. Further, River Kharun and River Sheonath are flowing along the southeastern boundary, further supporting the direction of groundwater flow direction (Fig. 3). However, from the spatial distribution map of SO_4^{2-} (Fig. 7), it is evident that the concentration increases from northwest to northeast and southwest to northeast part of the study area. Therefore, it may be inferred from the above discussion that the SO_4^{2-} decreases with the direction of flow of groundwater (i.e., NE to NW). Also, among all four blocks of the district (Nawagarh, Bemetara, Berla and Saja), two blocks, i.e., Nawagarh and Bemetara, have high SO_4^{2-} contamination in the study area. High concentration in these blocks may be attributed to existing Maniyari shell formation comprising reddish brown and purple non-calcareous shale with gypsum interbands.

Water quality improves from northeast to northwest part of the district during both the seasons (Fig. 9). As we compared the trend of groundwater flow and water quality (WQI), it was observed that water quality was improved along the flow of groundwater. Therefore, a direct relationship was found

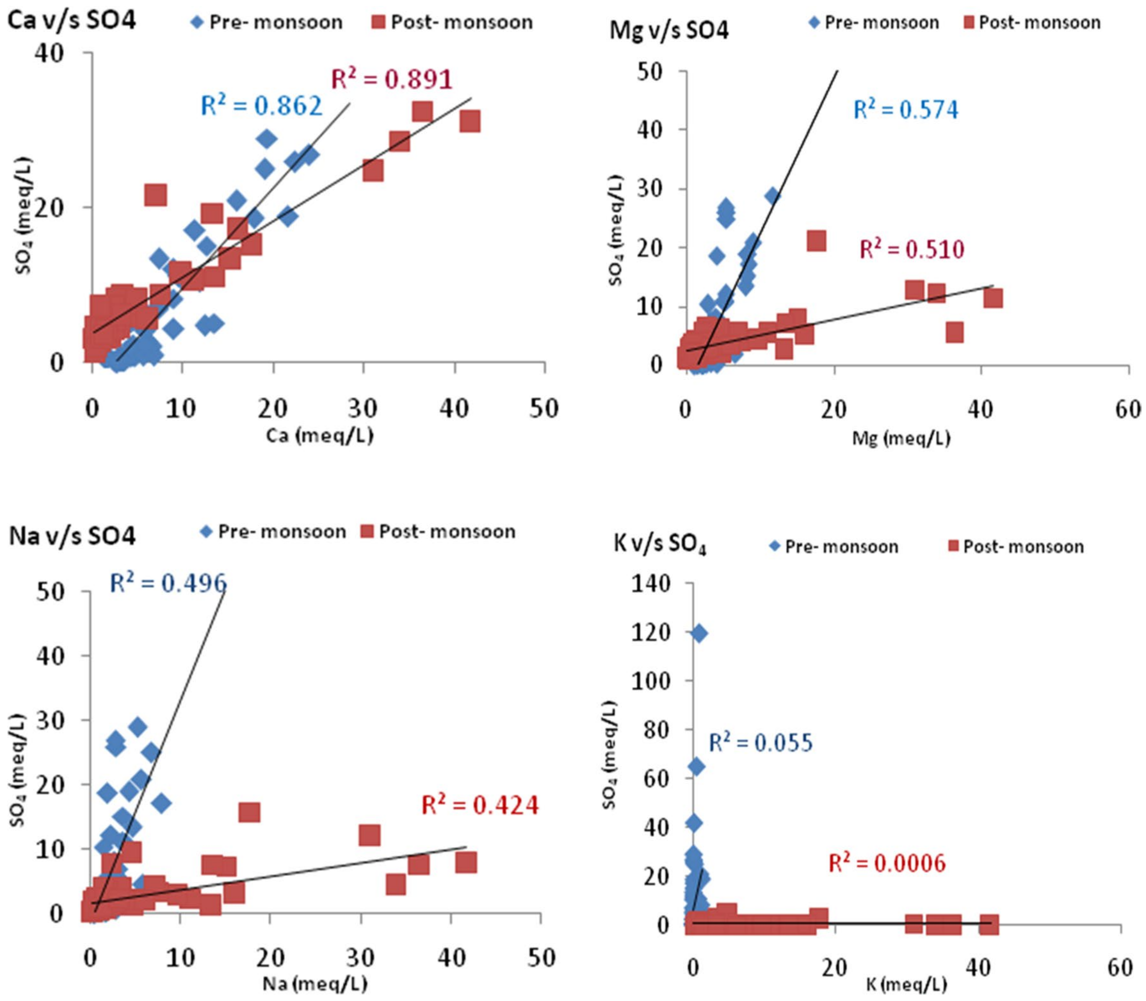

Fig. 10 Plots of SO_4^{2-} against Ca^{2+}, Mg^{2+}, Na^+ and K^+

Table 10 Eigenvalue and cumulative contribution of all PCs for pre- and post-monsoon season

S. No	Pre-monsoon			Post-monsoon		
	Eigenvalue	% of total variance	Cumulative % of variance	Eigenvalue	% of total variance	Cumulative % of variance
1	7.07	50.49	50.49	7.60	54.30	54.3
2	2.49	17.80	68.29	2.30	16.43	70.73
3	1.50	10.72	79.01	1.55	11.13	81.86
4	1.13	8.08	87.09	0.81	5.76	87.61
5	0.94	6.69	93.78	0.94	4.73	92.34
6	0.34	2.44	96.22	0.34	3.36	95.71
7	0.26	1.83	98.05	0.26	2.23	97.94
8	0.18	1.29	99.34	0.18	1.31	99.24
9	0.09	0.66	100.00	0.09	0.72	99.96
10	0.00	0.00	100.00	0.00	0.03	99.99
11	0.00	0.00	100.00	0.00	0.01	100.00
12	0.00	0.00	100.00	0.00	0.00	100.00
13	0.00	0.00	100.00	0.00	0.00	100.00
14	0.00	0.00	100.00	0.00	0.00	100.00

Table 11 Varimax rotated component loading (pre- and post-monsoon)

Variable	Principal component loading							
	Pre-monsoon				Post-monsoon			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
pH	0.007001	– 0.08824	0.124527	**0.561421**	0.02271	– **0.44155**	– 0.23359	0.26074
EC	– **0.37202**	– 0.04103	0.004598	0.076464	**0.355805**	0.084165	0.069085	0.108312
TDS	– 0.37202	– 0.04103	0.004598	0.076464	0.355805	0.084165	0.069085	0.108312
Alk	0.008587	**0.576006**	0.149197	0.298514	0.224614	– **0.30131**	– 0.46683	– 0.11901
Hard	– 0.31871	0.126725	0.288038	– 0.28036	**0.341009**	0.193156	0.024581	0.063351
Na^+	– 0.31655	– 0.15599	– 0.18318	**0.325382**	**0.321737**	– 0.11042	0.102968	– 0.1727
K^+	– 0.14231	0.282524	– **0.50391**	– 0.08476	0.063796	– **0.3754**	0.17346	**0.752238**
Ca^{2+}	– **0.30748**	0.050968	0.180323	– 0.36419	**0.305847**	0.285715	0.003484	0.168289
Mg^{2+}	– **0.27134**	0.199855	**0.371088**	– 0.11782	**0.336912**	– 0.04175	0.06267	– 0.16792
HCO_3^-	0.008587	**0.576006**	0.149197	0.298514	0.224614	– 0.30131	– **0.46683**	– 0.11901
Cl^-	– **0.29408**	– 0.03939	– **0.39846**	0.233771	0.230009	– 0.25228	**0.32915**	– **0.35567**
SO_4^{2-}	– **0.36631**	– 0.08556	0.107504	0.018663	**0.301909**	**0.311342**	0.006571	0.267055
NO_3^-	– 0.04697	**0.376588**	– **0.47535**	– **0.30284**	0.219071	– **0.32101**	**0.372602**	– 0.16129
F^-	– **0.33157**	– 0.10881	– 0.05459	0.100056	0.149729	0.268059	– **0.45561**	– 0.01299

Bold values are indicates the higher contribution of loadings of different physicochemicalparameters in different principal components

Table 12 Different components incorporated in the interpretation of pollution sources (pre- and post-monsoon)

Component	Factors/pollution sources	
	Pre-monsoon	Post-monsoon
1	Geogenic factor (F1) SO_4^{2-}, EC, Mg^{2+}, Ca^{2+}, Cl^- and F^-	Geogenic factor (F1) EC, hardness, Na^+, Mg^{2+}, Ca^{2+} and SO_4^{2-}
2	Anthropogenic factor (F2) NO_3^-, HCO_3^- and alkalinity	Non-point source factor(F2) pH, HCO_3^-, SO_4^{2-} and NO_3^-
3	Mixed type factor (F3) K^+, Mg^{2+}, Cl^- and NO_3^-	Mixed type factor (F3) HCO_3^-, Cl^-, NO_3^- and F^-
4	Nonpoint source factor (F4) pH, Na^+, and NO_3^-	Geogenic factor (F4) Na^+ and Cl^-

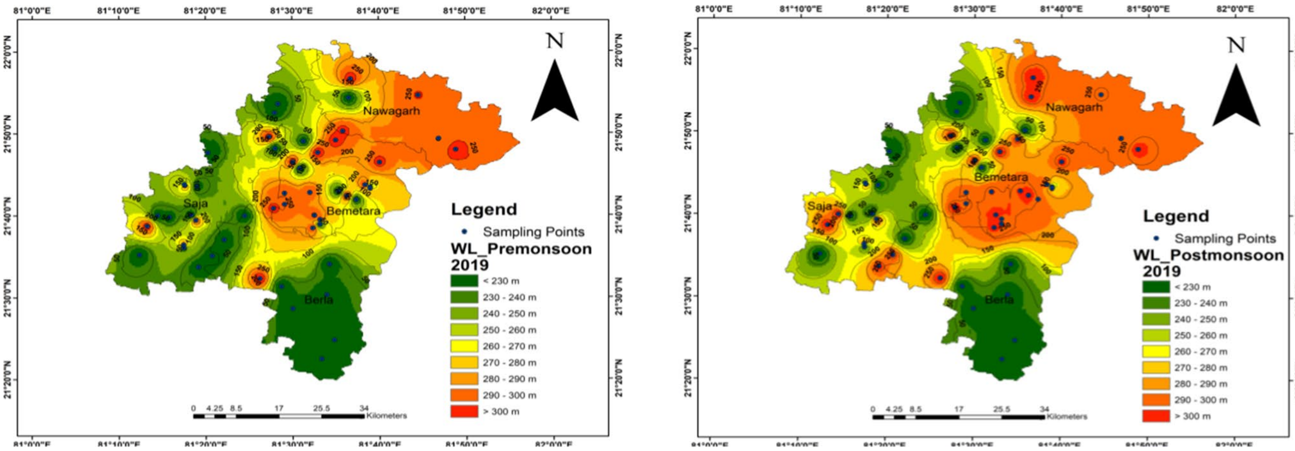

Fig. 11 Groundwater level (msl) in the study area during pre- and post-monsoon (2019)

between groundwater flow and water quality of the Bemetara District.

Conclusion

For any scheme of drinking water supply in an area, it is mandatory to have the status of water quality of the water resources being used for drinking water supply. Therefore, the evaluation of water quality becomes essential for development of water resource strategies for sustainable water use and to provide database for future planning. Spatial distribution maps were prepared to identify degraded water quality zones, possible sources of pollution and specific parameters not conforming to drinking water quality standards. BIS for drinking water have been violated for physicochemical parameters, viz. TDS, total hardness, Ca^{2+}, Mg^{2+}, SO_4^{2-} and NO_3^-. The groundwater quality changes from region to region along the depth of water table, and generally higher concentrations were observed in deeper aquifers. The source of SO_4^{2-} in the groundwater of the study area may be attributed to dissolution of gypsum as evident from relationship between Ca^{2+} and SO_4^{2-} ($r^2 > 0.8$). WQI at different locations has been computed to check the quality of groundwater for drinking purpose and 60% of the samples fall from “Excellent water” to “Good water” category in PRS and about 62% of samples in PMS. About 9% samples were found to be unsuitable for drinking purpose. Spatially, it is revealed that the drinking water sources existing in the northeastern area of the district were found to be contaminated with high SO_4^{2-} concentration which is not fit for direct public consumption. Multivariate analysis gives insight to different possible potential sources contributing to groundwater pollution in the area and inferred that four components are sufficient to explain the variance in groundwater chemistry mainly controlled by dissolution of gypsum mineral, other rock–water interaction and anthropogenic activities. Water quality was improved in the direction of groundwater flow in the study area, establishing a direct relationship between groundwater flow and water quality of the Bemetara District. This study provides very useful database for policymaker and state government to design sustainable groundwater management plan for the district.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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