Case Study

Hydrochemical monitoring of groundwater quality for drinking and irrigation use in Rapti Basin

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Abstract
In the present study, groundwater of Siddhartha Nagar district was investigated to ascertain its quality for drinking and irrigation purposes based on Groundwater Quality Index (GWQI) and irrigation indices. Inverse Distance-Weighted (IDW) application was also used to prepare the spatial distribution maps of each groundwater quality parameter. It is observed that Total Dissolved Solid (TDS) in 41.6% of samples and Total Hardness (TH) concentrations in 75% (BIS)/100% (WHO) of samples were much higher than the permissible limit. GWQI values reveal that none of the samples has an excellent quality of water and 16.7% samples having good water quality. Similarly, 33.3%, 41.7% and 8.3% of samples has a fair, poor and very poor water quality respectively. Results from the Piper plot showed that Ca–HCO_3 is the dominant hydrochemical facies. All samples were found in the rock dominance zone in Gibbs plots. Based on residual sodium carbonate (RSC) and soluble sodium percentage (SSP), 8.33% and 33.33% of the samples were found to be in the poor category and according to Kelly's ratio (KR) 8.33% of the samples were found in unsuitable category. Permeability Index (PI) indicates that 50% of the groundwater samples were found in Class I (suitable) and 50% in Class II (marginally suitable) category for irrigation purpose.

Keywords Siddhartha Nagar · Groundwater Quality Index · Inverse distance-weighted (IDW) · Irrigation indices

1 Introduction

In recent years, many hydro-geologist researchers are concerned with different water sector field in urban and rural regions [1, 3]. One of them is groundwater pollution, has increased due to natural and anthropogenic contaminant loading from emerging agricultural practices and is directly related to land use [2–4]. Water quality appraisal is essential for domestic and irrigation usage [5]. Since, distinct uses require distinct criteria as well as standard procedures for examining the water quality [6, 7]. Physical and chemical parameters are the functional feature for groundwater quality assessment, which are particularly affected by natural processes such as geological formations and anthropogenic activities [3, 4]. However, frequent use of poor quality water gives rise to various waterborne diseases [7]. So, there has been increased awareness in public about the safe drinking water in view of its health effect. The occurrence of pollution in groundwater dependent on external physical factors such as, pit-latrines [8], animal waste [9], organic manure [10], sewerage [11], and fertilizers [12]. In addition, intrinsic factors also affect water quality such as the physical composition of the vadose zone substances, accumulation of chemicals, weathering, dissolution, precipitation, ion exchange, and various biological processes usually occurring below the surface.

In India, the rural population prefers the groundwater for drinking and irrigation purpose [13]. Impact of

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groundwater contamination is more prominent particularly in rural areas of developing countries of the world like India [14]. Many studies has been conducted using various analytical approaches for inferring meaningful groundwater quality status in different parts of India [2–4, 6, 12–18]. For instance, Sharma et al. [4] evaluated the groundwater quality and suitability in the Bathinda district of Punjab state, India, and concluded that leaching of salts in vadose zone, the contribution of soluble fertilizers and livestock excrement, are responsible for shallow aquifer water quality deterioration. A study by Thakur et al. [6] in Kullu Valley, Himachal Pradesh, India, assesses water quality and stress on water resources based on ex-ante and hydrochemical approaches shows that water contamination problems are due to lack of sewage treatment facilities. Ravikumar [13] assessed the quality of water of the Markandaya river basin, Belgaum district, India using different water quality indices, trilinear and logarithmic plot in which reported that chemical analysis results like bicarbonates, hardness, potassium, and alkalinity might be high due to anthropogenic and natural influences. In a recent study by Madhav et al. [14] applied conventional hydrogeochemical technique and quality indices to find out the water quality status in rural areas of Sant Ravidas Nagar district of Uttar Pradesh, India for drinking and irrigation purpose. A study was conducted by Kumar et al. [15] in Patiala and Muktsar districts of Punjab, India, identified that excessive use of chemical fertilizers is responsible for the rise of various cations and anions in groundwater. Wagh et al. [16] evaluated the groundwater quality using hydrochemical characterization and water quality index modeling, in the Kadava River Basin, Maharashtra, India. Rao et al. [17] evaluated groundwater quality using entropy water quality index, ionic spatial distribution, binary plot, and principal component analysis in the rural part of Wanaparthy district, India. Furthermore, Raju and Singh [18] studied the quality of groundwater using conventional methods in the adjacent watercourse of Gomti-Ganga in the Lucknow district of Uttar Pradesh, India and reported that silicate and carbonate weathering, as well as cation and anion exchange processes, control the ionic concentrations in groundwater.

Hence it has been concluded from the literature review that hydrochemical analysis of groundwater quality in rural area is an essential requirement. But so far no thorough investigation has been done on groundwater quality assessment in Siddharthnagar district. Most of the people uses shallow aquifer water for their daily activity in selected study area, which is more prone to contamination. Siddhartha nagar is an agriculture dominant district, thus extensive use of pesticides, chemical fertilizer and improper sanitation facilities allow contamination of the shallow aquifer much easily rather than deep groundwater by vertical flow in downward direction [8, 19]. Hence a thorough groundwater quality assessment is required in the selected study area.

The purpose of this study was to determine the quality of groundwater towards drinking and irrigation in Siddharthnagar district. To achieve this objective, various indicators such as Ground Water Quality Index (GWQI), Residual Sodium Carbonate (RSC), Permeability Index (PI), Kelly's Ratio (KR), Magnesium Hazard (MH), Sodium Percent (Na %), Sodium Adsorption Ratio (SAR) and Soluble Sodium Percentage (SSP) were calculated. In addition, statistical analysis, Piper trilinear plot, Wilcox diagrams, Doneen's classification, and Gibb's plot have also been studied to describe chemical controls.

2 Study area

2.1 Sampling location and climate

Siddharthnagar district is situated in the Uttar Pradesh state of India, lies between 27° N to 27° 28′ N latitudes and 82° 45′ E to 83° 10′ E longitudes in toposheets no. 63I/3, 63I/4, 63 M/3, 63 M/4 and 63 J/1 shown in Fig. 1. District falls under semi-arid region and its geographical area is 2895 km^2. This climate is considered to be monsoon influenced humid subtropical climate (Cwa), according to the Köppen–Geiger [20] climate classification. The average temperature is 24.6 °C and varies during the year by 15.3 °C and average rainfall is 1372 mm in a year [21]. Sampling locations are chosen in such a manner which gives appropriate information about groundwater quality. A total of 12 groundwater samples were collected from shallow aquifer from different locations are presented in Table 1.

2.2 Geology and hydrogeology

Rapti basin is a part of Indo-Gangetic plain in terai region of Uttar Pradesh, India. Rapti River is the principle stream of the basin originates from Nepal at an elevation of about 3048 m in Dregaunra range [22].

The Quaternary geology of the Indo-Gangetic plain was classified on the basis of sediments into Older Alluvium and Newer Alluvium [23]. It was reclassified by Pathak et al. [24] as Upper Siwalik (Upper Pliocene to Lower Pleistocene), Older Alluvium (Middle to Upper Pleistocene), and Newer Alluvium (Upper Pleistocene to Recent) in order of superposition. The Older Alluvium consists of oxidized, brown to yellow and khaki colored sediments, whereas the Newer Alluvium consists of unoxidised, grey and khaki sediments [22]. Moreover, the Older Alluvium, termed as Varanasi Older Alluvium (VAO) [25] consists of multiple fill polycyclic sequence of sand, silt, and clay [22,

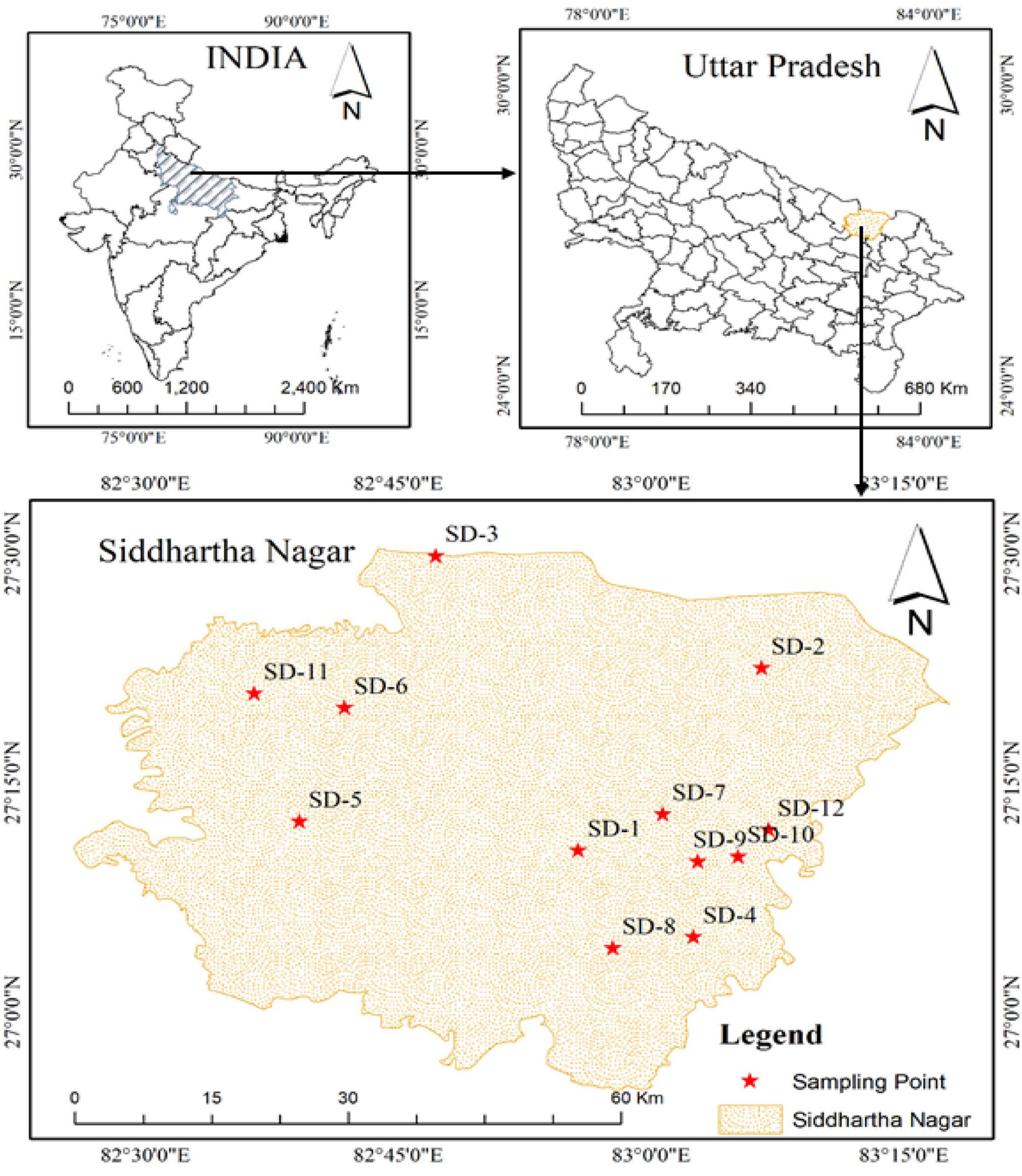

Fig. 1 Sampling location in Siddhartha Nagar district

26]. Furthermore, the study conducted by Singh et al. [26] illustrated that in the present study area, the presence of clay and calcrete nodules (kankar) and oxidized brown yellowish stains reflect the character of VAO.

Central Ground Water Board (CGWB) constructed an exploratory well in Siddhartha Nagar district up to 310 m bgl [27]. In the study area, both confined and unconfined aquifer systems are prevalent [22, 28]. The pre-monsoon depth to water level ranges from 2.5 to 6.33 m bgl, whereas

Table 1 Details of sampling location with latitude and longitude

S. no.	Sample ID	Block name	Latitude	Longitude
1	SD-1	Bansi	27.1752° N	82.9315° E
2	SD-2	Bardpur	27.3753° N	83.1099° E
3	SD-3	Barhani	27.4975° N	82.7872° E
4	SD-4	Bhanwapur	27.0818° N	83.0423° E
5	SD-5	Dumariyaganj	27.2078° N	82.6526° E
6	SD-6	Itwa	27.3316° N	82.6971° E
7	SD-7	Jogiya	27.2491° N	83.0120° E
8	SD-8	Khesraha	27.0696° N	82.9623° E
9	SD-9	Mithawal	27.1642° N	83.0463° E
10	SD-10	Naugarh	27.2990° N	83.0927° E
11	SD-11	Shoharatgarh	27.4473° N	82.6082° E
12	SD-12	Uska bazar	27.1986° N	83.1166° E

in post-monsoon depth to water level varies from 1.47 m to 5.68 m bgl. Sediment from ground level varies from 15 to 20 m, comprises fine to medium grained sand with thin clay at top. The first aquifer zone, observed at depth of 2.74 to 12.19 m is an unconfined aquifer. The second aquifer is confined between 16.45 and 35.02 m. It is confined by 2.74 m and 1.8 m thick clay zones at the top and bottom respectively. At places the thickness of these confining clay zones, both upper and lower, are varying from 1.5 to 3.65 m. The third aquifer lies below 38.40 m and a clay layer of 6 m thickness is observed at 61 m [26].

3 Material and methodology

3.1 Experimental procedure

The assessment of groundwater quality has been done by selecting 13 hydrochemical parameters. Groundwater samples were collected from 12 shallow boreholes (Fig. 1). All samples were collected according to the standard procedure in 1 L clean polyethylene bottles and noted the location of sample collection (Table 1) during summers of 2016. Hydrogen Ion Concentration (pH), and Electrical Conductivity (EC) were measured at the sampling site using PC/300 portable hand-held waterproof digital meter. Total dissolved solids (TDS) were measured using CB18845 Generic hand-held TDS-3 digital meter. Total Hardness (TH) was determined by Ethylene Diamene Tetra Acetic Acid (EDTA) titrimetric method using Black-T indicator. Samples were filtered using cellulose filters (0.45 μm) for determining the cations and anions using Ion chromatography (Metrohmn 792B-IC), which showed an accuracy of ± 2%. Cations were measured using Metrosep C2/100 column such as Sodium (Na^+, mg L^{-1}), Potassium (K^+, mg L^{-1}), Calcium (Ca^{2+}, mg L^{-1}), Magnesium (Mg^{2+}, mg L^{-1}), while Metrosep A Supp 4/250 was used to measure the anions such as Fluorine (F^-, mg L^{-1}), Chlorine (Cl^-, mg L^{-1}), Sulphate (SO_4^{2-}, mg L^{-1}), Nitrate (NO_3^-, mg L^{-1}), Carbonate (HCO_3^-, mg L^{-1}). To check the veracity of the chemical analysis, charge-balance error were estimated which was observed to be within the acceptable range (± 5%) [29].

3.2 Analytical approaches (correlation and spatial)

Correlation Matrix Analysis (CMA) is a bivariate method was used to explain the relationship between two chemical parameters in this study. Correlation analysis statistically indicates how closely the two variables associated. It can vary from − 1 (absolute negative relationship) to + 1 (true positive relationship) [18]. The terms "significant/strong", "moderate" and "insignificant/poor" are used to indicates the values as > 0.75, 0.75–0.50 and 0.50–0.30, respectively [18, 30].

In the present study, the spatial analysis tool of ArcGIS software (version 10.4.1) was used to interpolate the hydrochemical data by Inverse distance-weighted (IDW) method [31].The shape file of Siddhartha Nagar district was extracted and digitized from the Survey of India toposheets using ArcGIS software. The sampling sites (Latitude and Longitude) were correctly positioned with the help of Global Positioning System (GPS, Garmin Montana 650) and imported in GIS platform.

4 Result and discussion

4.1 General hydrochemical characterization of groundwater

The complete hydrochemical data of groundwater is presented in Table 3 and comparison of hydrochemical data of groundwater with Bureau of Indian Standards (BIS) [32] and World Health Organization (WHO) [33] standards is presented in Table 2 with minimum (Min.), maximum (Max.), mean and standard deviation (SD) values.

The pH of groundwater samples has been found to be in the range 7.5–8.2 with an average value of 7.8, which is under the limit with respect to BIS [32] and WHO [33] in all samples shown in Table 2. The spatial distribution of pH variation is shown in (Fig. 2a). It was found that in north-western part, east-northern part and south-eastern part shows slightly alkaline water.

The Na^+ concentration varied from 11 to 150 mg L^{-1} with a mean of 53 mg L^{-1}. There is no prescribed limit of Na^+ concentration in groundwater for drinking purpose as per BIS [32] as well as with respect to WHO [33].The spatial distribution map of sodium (Fig. 2b), reveals that

Table 2 Comparison of physiochemical data of groundwater with BIS and WHO standards

Parameters	Min.	Max.	Mean	SD	BIS	WHO
pH	7.5	8.2	7.8	0.2	6.5–8.5	7.0–9.2
Na^{+}	11	150	53	39.6	–**	–**
Ca^{2+}	32	124	59.3	23.5	75	75
Mg^{2+}	15	46	31.6	10.5	30	30
K^{+}	1.1	3.6	2.5	0.8	–**	10
NO_3^-	0.1	40	4.2	11.5	45	50
Cl^-	7.1	106	34.2	32.4	250	250
F^-	0.3	1.2	0.8	0.3	1	1.5
HCO_3^-	268.4	549.1	406.2	88.7	–**	300
SO_4^{2-}	1.6	33	11.8	11.4	200	200
TDS	276.3	744.3	474.6	141.3	500	500
TH	150	450	278.3	87.6	200	100

–**Represents no prescribe limits

maximum concentration observed in the southeastern part of the study area.

The concentration of Ca^{2+} in groundwater of Siddhartha Nagar district was found to be in the range of 32–124 mg L^{-1} with a mean value of 59.3 mg L^{-1}. It was observed that Barhani sampling point has a high concentration of Ca^{2+} with respect to BIS [32] and WHO [33] limits respectively. The spatial distribution map reveals that the Ca^{2+} concentrations increase in northeastern and northwestern part of study area shown in Fig. 2c.

The concentration of Mg^{2+} was found to be in the range of 15–46 mg L^{-1} with a mean value of 31.6 mg L^{-1}. It is also found that 50% of samples show above the prescribed limit with respect to BIS [32] and WHO [33]. It is noticed from the spatial distribution map (Fig. 2d), that the concentration of Mg^{2+} is high in southwestern part of study area.

Groundwater in Siddharth Nagar area is likely to have significant NO_3^- levels under natural and anthropogenic condition. The concentration of NO_3^- was found between 0.08 and 40 mg L^{-1}. NO_3^- values were within the prescribed limit of BIS [32] and WHO [33] in all samples. Spatial distribution map of NO_3^- is shown in Fig. 2e.

Cl^- was the third most abundant anion found in the study area, with concentration between 7.1 and 106 mg L^{-1}. The spatial distribution map of the Cl^- (Fig. 2f) shows that there was a high concentration in the northeastern and northwestern along with some southeastern part of the area. The main reason for the high concentration of Cl^- in the urban part of Siddharthnagar district was might be due leaching from sewerage.

The concentration of fluoride have been found to be between 0.3 and 1.2 mg L^{-1}. There is a high fluoride anomaly in the west southern and east northern part of the study area, which is shown in Fig. 2g. According to BIS [32], 2 samples have been found to be above the permissible limit, while according to WHO [33] standards, all of samples are found to be under the prescribed limit.

The concentration of Total Hardness (TH) was found to be between 150 and 450 mg L^{-1} (Table 2). The TH is marginally high due to Ca^{2+} and Mg^{2+}, because they are dominant cations in the present study area. Hard water is not suitable for drinking purpose but hardness of drinking water, particularly high levels of magnesium helps in reducing risk for cardiovascular disease [34]. Spatial distribution map of total hardness is shown in Fig. 2h.

The concentration of HCO_3^- anion varied in the range of 268.4 – 549.1 mg L^{-1} with a mean of 406.2 mg L^{-1} in the study area. The result reveals that 83% of samples are not within the limit with respect to WHO [33] guidelines which is 300 mg L^{-1} (Table 2). Looking at the spatial distribution map of HCO_3^- (Fig. 2i) it has been found that some part of the northwest region is above the permissible limit. It's also seen that southeastern part is slightly higher concentration.

The concentration of SO_4^{2-} was found to be between 1.6 and 33 mg L^{-1}, with a mean value of 11.8 mg L^{-1}. All samples have been found to be within the range with respect to the BIS [32] and WHO [33] standards, respectively. Spatial distribution map of SO_4^{2-} concentration is shown in Fig. 2j.

Total dissolved solids (TDS) are frequently used as water quality parameter. Total dissolved solids are the approximate total amount of mineral constituents such as Ca^{2+}, Cl^-, K^+, Mg^{2+}, Na^+, NO_3^-, HCO_3^-, and CO_3^- ions [29]. The concentration of TDS varies from 276.3 to 744.3 mg L^{-1}, with a mean value of 474.6 mg L^{-1} (Table 2). Excluding sample SD-3, SD-8, and SD-9 (Table 3), all the samples show less TDS concentration (< 500 mg L^{-1}) which is below the limit with respect to BIS [32] and WHO [33]. TDS < 1000 mg L^{-1}, indicates fresh quality of water

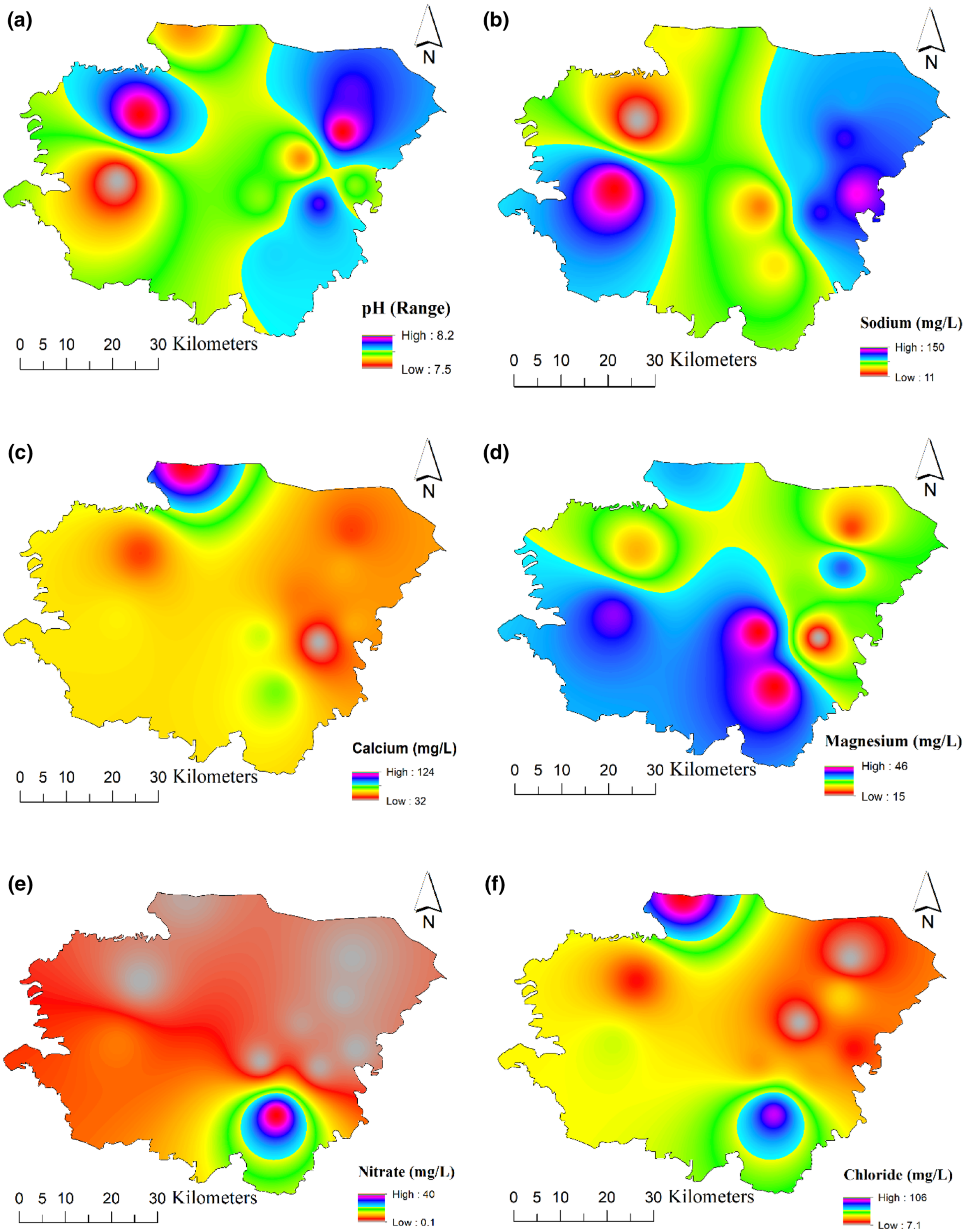

Fig. 2 Spatial distribution maps of different hydrochemical parameter **a** pH **b** sodium **c** magnesium **d** calcium **e** nitrate **f** chloride **g** fluoride **h** total hardness **i** bicarbonate **j** sulfate **k** total dissolved solids **l** potassium

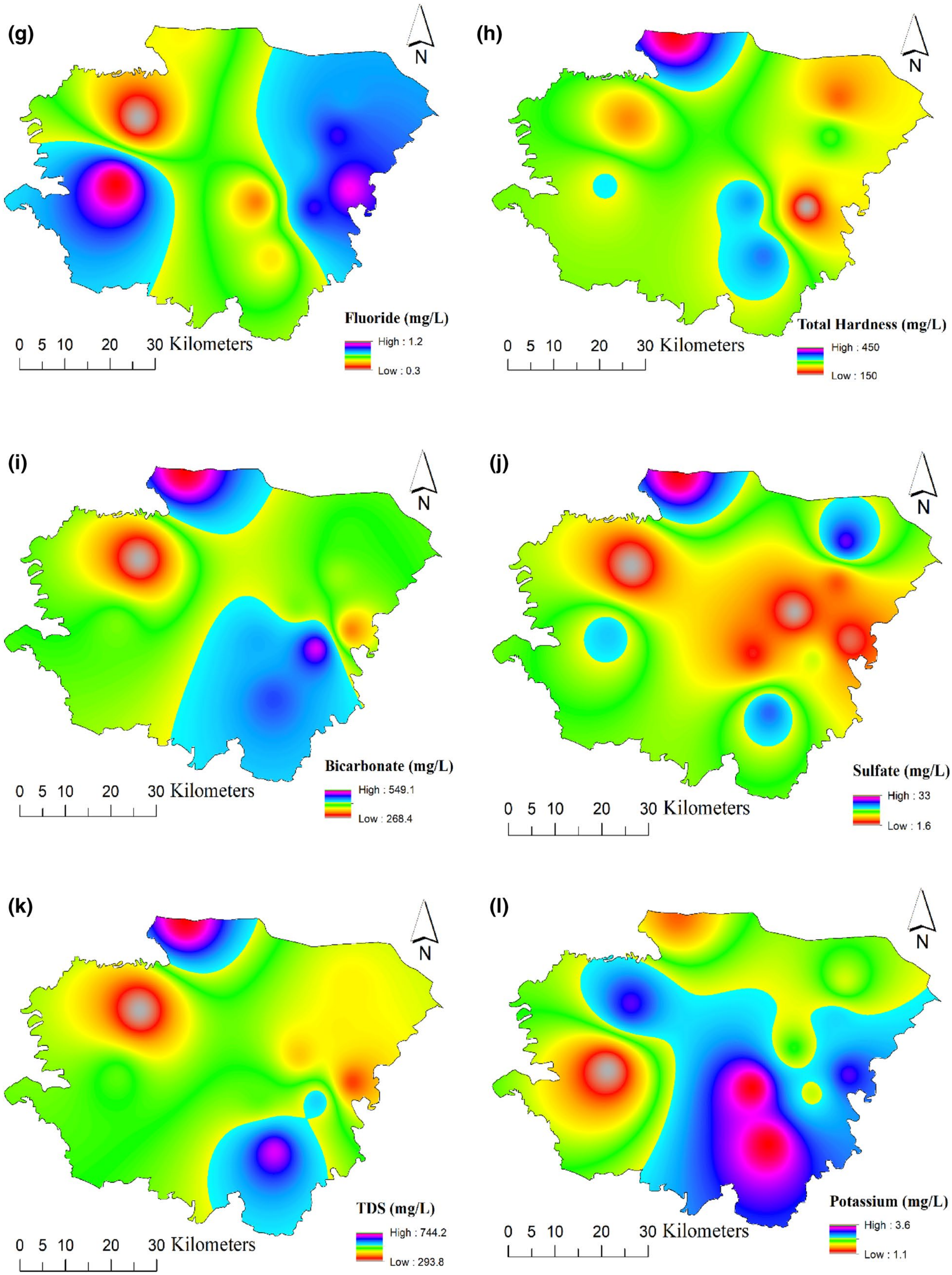

Fig. 2 (continued)

Table 3 Laboratory and field observation of hydrochemical data of groundwater

Sample	pH	Na^+	Ca^{2+}	Mg^{2+}	K^+	NO_3^-	Cl^-	F^-	HCO_3^-	SO_4^{2-}	TDS	TH
SD-1	7.7	33	68	44	3.6	0.2	28	0.4	451.5	4.9	501.8	350
SD-2	7.9	76	48	19	2.0	0.2	7.1	0.9	390.5	27	438.1	200
SD-3	7.6	78	124	34	1.5	0.5	106	0.6	549.1	33	744.3	450
SD-4	8.2	24	32	24	2.1	0.1	7.1	0.6	268.4	1.8	276.3	180
SD-5	7.5	48	64	39	1.1	7.4	43	1.2	403	21	503.8	320
SD-6	8.0	11	48	22	3.1	0.1	18	0.3	268.4	1.6	293.8	210
SD-7	7.6	46	52	29	2.2	0.9	7.1	0.8	402.7	1.7	416	250
SD-8	7.8	89	72	44	3.6	40	92	0.5	475.9	24	685.8	360
SD-9	7.9	150	36	15	2.4	0.4	28	1.0	512.5	13	566.8	150
SD-10	8.0	35	56	36	2.6	0.1	35	1.0	378.3	6.3	436.8	290
SD-11	7.7	32	56	46	2.4	0.3	21	0.8	451.5	3.8	475.8	330
SD-12	7.7	14	56	27	3.1	0.1	18	1.1	323.4	3.4	356.2	250
Number and percentage of samples exceeding permissible limit with respect to BIS (32) and WHO (33) guidelines												
BIS percentage	0 (0)	NA	1 (8.3%)	6 (50%)	NA	0 (0)	0 (0)	2 (16.6%)	NA	0 (0)	5 (41.6%)	9 (75%)
WHO percentage	0 (0)	NA	1 (8.3%)	6 (50%)	0 (0)	0 (0)	0 (0)	0 (0)	10 (83.3%)	0 (0)	5 (41.6%)	12 (100%)

Units of all the parameters expressed in mg L^{-1}, except pH and electrical conductivity expressed in µmhos/cm; NA not applicable

Table 4 Overall groundwater quality classification criteria based on GWQI

S. no.	Range	Category	Percentage	Rank	Sample no.
1	0–25	Excellent	0	I	–
2	26–50	Good	16.7	II	SD-1, SD-6
3	51–75	Fair	33.3	III	SD-3, SD-4, SD-8, SD-11
4	76–100	Poor	41.7	IV	SD-2, SD-7, SD-9, SD-10, SD-12
5	101–150	Very poor	8.3	V	SD-5
6	> 150	Unfit for drinking	0	VI	–

presence in the selected sites of the study area. Spatial distribution of TDS concentration is shown in Fig. 2k.

The concentration of K^+ was found to be between 1.1 and 3.6 mg L^{-1}, with a mean value of 2.5 mg L^{-1}. All samples have been found to be within the range with respect to WHO [33] standards. Spatial distribution map of K^+ concentration is shown in Fig. 2l.

4.2 Groundwater Quality Index analysis

Groundwater Quality Index (GWQI) is the most widely used approach for complete groundwater quality assessment. The method of calculating GWQI is described in detail by Raju and Singh [18]. Six categories were categorized to classify the groundwater quality on the basis of their respective index range i.e. excellent (0–25), good (26–50), fair (51–75), poor (76–100), very poor (101–150) and unfit for drinking (> 150). The data observed from laboratory analysis has been used to calculate GWQI using Horton's method [35] shown in Eq. 1.

Table 5 Index value of individual samples assessment in study area

Sample	GWQI	Status	Sample	GWQI	Status
SD-1	46.34	Good	SD-7	77.09	Poor
SD-2	82.15	Poor	SD-8	58.04	Fair
SD-3	56.87	Fair	SD-9	91.52	Poor
SD-4	57.57	Fair	SD-10	94.64	Poor
SD-5	108.83	Very poor	SD-11	75.39	Fair
SD-6	30.61	Good	SD-12	100.03	Poor

$$\mathrm{GWQI} = \sum \mathrm{qnWn} / \sum \mathrm{Wn} \tag{1}$$

where qn = Quality rating of nth water quality parameter and Wn = Unit weight of nth water quality parameter.

4.3 Drinking water quality

Groundwater quality classification details based on index range is presented in Table 4. None of the samples were found in excellent and unfit water quality category. Only 16.7% of samples show good water quality drinking purpose (Rank II). Similarly 33.3% (Rank III), 41.7% (Rank IV) and 8.3% (Rank V) of the samples fall in fair, poor and very poor category, respectively. Based on Table 5, the index value of each sample illustrates that SD-1 and SD-6 have good water quality, while SD-3, SD-4, SD-8, SD-11 and SD-2, SD-7, SD-9, SD-10, SD-12 samples are found to be fair and poor water quality category respectively. Only sample SD-5 having the value of 108.3 has very poor water quality in the study area.

4.4 Gibbs and piper plot depictions

Gibbs plot [36] is widely used to understand the mechanism governing the groundwater chemistry with respect to cations and anions. The plot is classified into three zones as precipitation dominance, vaporization dominance, and rock dominance. TDS values were plotted against cation ratio $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ and anion ratio $(Cl^-)/(Cl^- + HCO_3^-)$, which is shown in Fig. 3a, b. All groundwater samples have been found in the rock dominance zone, which suggests that the rock-water interaction is the main controlling mechanism of groundwater chemistry.

In order to understand the hydrochemical facies, major ion chemical data have been plotted on the piper trilinear diagram [37]. The diagram consist of two triangle and one rhombus shape field in center. The overall hydrochemical characteristics of water samples are represented in the central rhombus shape field shown in Fig. 4. Based on the plot, $Ca–HCO_3$ is the major hydrochemical facies followed by $Na–HCO_3$ water type. The diagram represents that alkaline earths $(Ca^{2+} + Mg^{2+})$ exceeds alkalies $(Na^+ + K^+)$ and weak acid (HCO_3^-) exceeds strong acids $(Cl^- + SO_4^{2-})$. Overall, Ca^{2+} type and HCO_3^- type are dominating cation and anion followed by Mg^{2+} and Na^+ type, and Cl^- and SO_4^{2-}, respectively.

4.5 Correlation linkage depictions

The relationship of hydrochemical parameters has been described using the Spearman rank coefficient correlation matrix presented in Table 6. It shows a significant link between EC and TDS (1:1), which reflects that EC is a function of TDS in groundwater [18]. Likewise, EC and TDS have strong correlation with major cations such as Ca^{2+}, Na^+, K^+ and major anions such as HCO_3^-, SO_4^{2-}, and Cl^-, which indicates that TDS is derived from these ions [3]. Na^+ shows a +ve association with Cl^- (0.37), which is might be due to remnant saline water trapped in the sediments [3]. Na^+ also shows the moderate positive association (0.72) with HCO_3^-, which confirms the presence of $Na–HCO_3$ water type in some parts of the

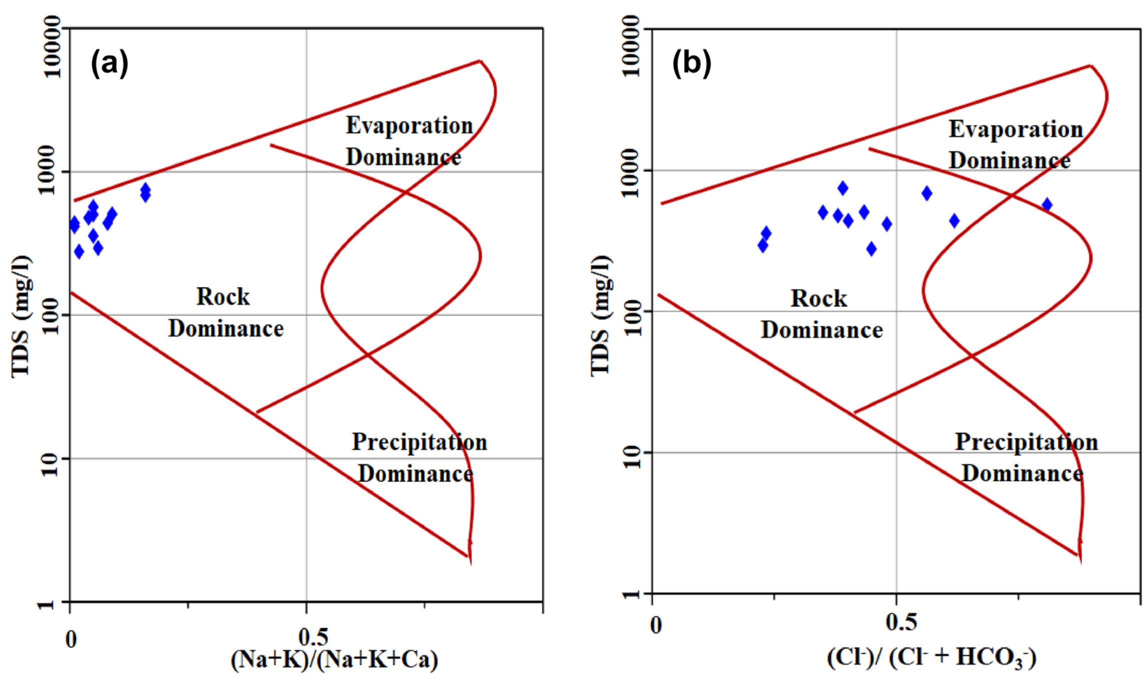

Fig. 3 Gibbs plots **a** TDS versus (Na + K)/(Na + K + Ca) **b** TDS versus Cl (Cl + HCO_3)

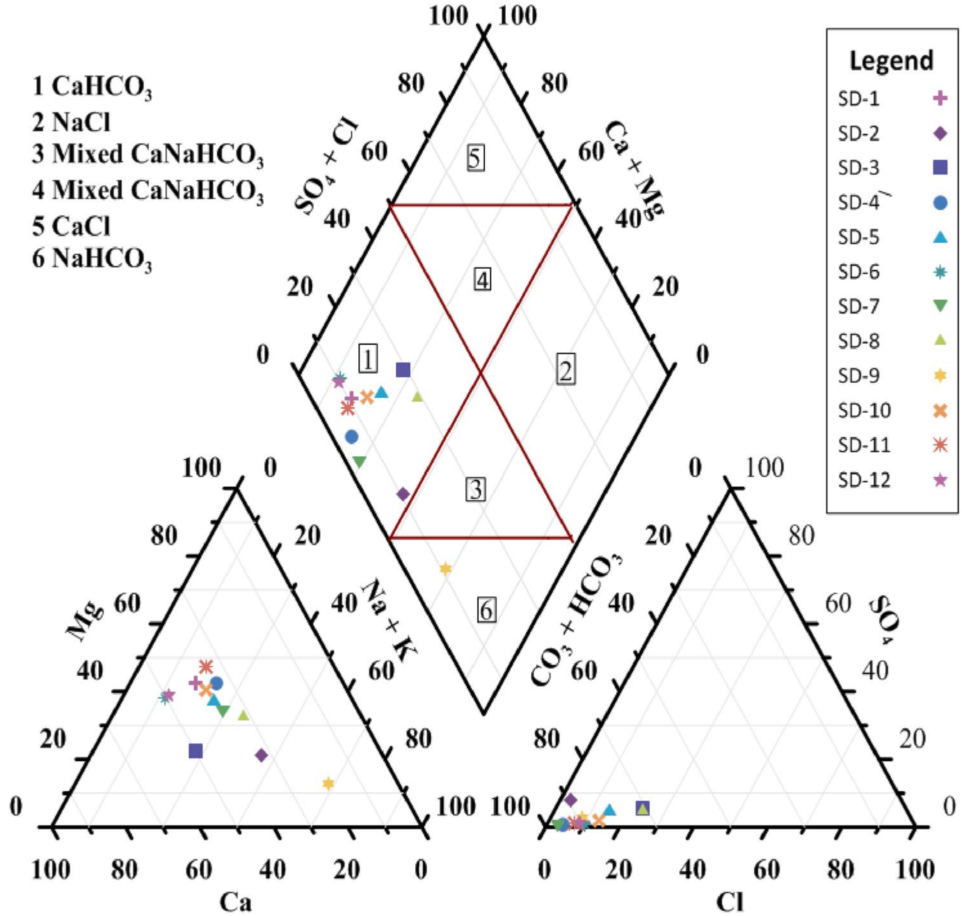

Fig. 4 Piper's trilinear plot for major ion data of groundwater, Siddhartha Nagar district

Table 6 Correlation coefficient matrix of groundwater samples of study area

	pH	Na^+	Ca^{2+}	Mg^{2+}	K^+	NO_3^-	Cl^-	F^-	HCO_3^-	SO_4^{2-}	TDS	EC	TH
pH	1												
Na^+	–0.06	1											
Ca^{2+}	–0.58	0.09	1										
Mg^{2+}	–0.48	–0.27	**0.47**	1									
K^+	0.25	–0.17	–0.18	0.19	1								
NO_3^-	–0.09	0.29	0.19	**0.41**	**0.35**	1							
Cl^-	–0.35	**0.37**	**0.84**	**0.44**	–0.04	**0.58**	1						
F^-	–0.31	0.21	–0.20	–0.10	–0.45	–0.15	–0.19	1					
HCO_3^-	–0.54	**0.72**	**0.60**	**0.34**	–0.13	0.26	**0.65**	0.09	1				
SO_4^{2-}	–0.32	**0.59**	**0.62**	0.06	–0.41	**0.38**	**0.71**	0.10	**0.60**	1			
TDS	–0.50	**0.66**	**0.74**	**0.40**	–0.10	**0.49**	**0.87**	0.00	**0.93**	**0.76**	1		
EC	–0.50	**0.66**	**0.74**	**0.40**	–0.10	**0.49**	**0.87**	0.00	**0.93**	**0.76**	**1.00**	1	
TH	–0.62	–0.08	**0.90**	**0.81**	–0.03	**0.33**	**0.78**	–0.18	**0.57**	**0.45**	**0.69**	**0.69**	1

Significant correlation
Moderate correlation
Insignificant correlation

present study area. The moderate association (0.59) between Na^+ and SO_4^{2-} indicates infiltration of SO_4^{2-} in the shallow aquifer through anthropogenic activity [18]. Similarly Ca^{2+} positively linked with HCO_3^- (0.60), SO_4^{2-} (0.60), and strongly with TH (0.90). It also noticed that pH has –ve correlation with all other parameters

Table 7 Values of irrigation indices for assessing irrigation water quality

Sample	SAR	RSC	SSP	KR	MH	%Na	PI	EC
SD-1	0.63	2.56	47.30	0.20	38.39	50.10	49.43	772
SD-2	1.85	0.69	142.57	0.83	79.30	144.76	80.20	674
SD-3	1.23	-0.59	60.92	0.38	80.28	61.58	51.59	1145
SD-4	0.65	1.76	68.26	0.29	30.25	71.68	68.02	425
SD-5	0.95	1.32	70.56	0.32	53.08	71.46	54.71	775
SD-6	0.26	1.52	22.24	0.11	14.82	25.63	55.43	452
SD-7	1.02	2.00	81.34	0.40	50.65	83.56	65.40	640
SD-8	1.66	0.33	115.03	0.53	94.09	117.68	60.16	1055
SD-9	4.19	0.08	370.10	2.14	153.47	373.58	98.43	872
SD-10	0.73	1.88	58.87	0.26	40.36	61.31	55.21	672
SD-11	0.64	3.21	54.91	0.21	38.84	57.17	51.62	732
SD-12	0.31	1.89	24.60	0.12	18.02	27.51	52.12	548

Table 8 Classification of groundwater based on RSC

Range of RSC	Category	Sample falling in different categories	
		No. of samples	% of sample
< 1.5	Excellent	9	75
1.5–3.0	Good	2	16.67
3.0–6.0	Poor	1	8.33
> 6.0	Unsuitable	Nil	–

Table 9 Classification of groundwater based on SSP

Range of SSP	Category	Sample falling in different categories	
		No. of samples	% of sample
< 20	Excellent	NIL	–
20–40	Good	2	16.67
40–80	Fair	6	50.00
> 80	Poor	4	33.33

in study area. The slight positive association (0.19) between NO_3- and Ca^{2+} shows the presence of excessive use of chemical fertilizer since $Ca(NO_3)_2$ is mainly used as a component in fertilizer [38]. In addition, positive association (0.35) between NO_3- and K^+ reflects poor sanitary conditions and disproportionate usage of NO_3- containing fertilizers for high crop yields [47].

4.6 Irrigation water quality

Groundwater is a main source for agricultural irrigation in Siddhartha Nagar District. In order to assess the quality of groundwater in relation to irrigation purpose, it is necessary to evaluate the composition and concentration of dissolved components [1, 4, 13, 15]. Thus it is very important to calculate the water quality indices for irrigation perseverance. Groundwater quality for irrigation purpose is explained on the basis of RSC, PI, KR, MH, Na %, SAR, SSP, and EC values presented in Table 7. All the selected indices were described earlier in detail by Kumar et al. [15], Wilcox [39], Eaton [40], Szabolcs and Darab [43], Kelly [44], Richards [46], and Doneen [48].

4.6.1 Residual sodium carbonate (RSC)

Generally RSC is calculated to describe influence of bicarbonate and carbonate on the quality of water [40]. It was estimated using CO_3^-, HCO_3^-, Ca^{2+} and Mg^{2+} ions where all the concentrations are expressed in meq L^{-1}shown in Eq. 2.

$$RSC = [(CO_3 + HCO_3^-) - [(Ca^{2+} + Mg^{2+})] \quad (2)$$

According to RSC classification range, 75% of the samples fall under excellent category. Similarly 16.17% and 8.33% of the samples fall under good and poor category respectively. None of the samples are fall under unsuitable category as presented in Table 8.

4.6.2 Soluble sodium percentage (SSP)

SSP was determined by using the measured concentration of Na^+, K^+, Ca^{2+}, and Mg^{2+}, where all the concentration are expressed in meq L^{-1} shown in Eq. 3.

$$SSP = \left[\frac{Na}{(Ca + Na + Mg)}\right] \times 100 \quad (3)$$

SSP values ranges from 22.24 to 370.10 shown in Table 7. As per Wilcox [39] classification 16.67% samples found to fall under good category, 50% samples fall under fair category and 33.33% samples fall under poor category as presented in Table 9.

4.6.3 Magnesium hazard

In general, Ca^{2+} and Mg^{2+} maintain a state of equilibrium in most waters [41]. In addition, high concentrations of Ca^{2+} and Mg^{2+} in groundwater can degrade soil quality, which adversely effects the crop yield [42]. Moreover, Mg^{2+} has more severe effects on crop yield than Ca^{2+}. Hence, Magnesium hazard (MH) ratio is very useful to evaluate the suitability of water for irrigation [43]. MH ratio above 50% is considered to be unsuitable for irrigation. It is calculated using Eq. 4.

$$\mathrm{MH} = \left[\frac{\mathrm{Mg}}{\mathrm{Ca} + \mathrm{Mg}}\right] \times 100 \tag{4}$$

MH ratio ranges from 21.51 to 45.09% which is less than 50% in all the samples (Table 7) shows good quality of water for irrigation.

4.6.4 Kelly's ratio

It is calculated by using Eq. 5 stated by Kelly [44], where concentrations are expressed in meq L^{-1}. Water can be categorized into three categories based on Kelly's ratio (KR). Kelly' ratio of groundwater in the study area ranges from 0.11 to 2.14 with an average of 0.48 (Table 7). According to the KR range, it has been found that 91.67% and 8.33% of the samples were suitable and unsuitable for irrigation, respectively (Table 10).

$$KR = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}} \tag{5}$$

4.6.5 Electrical conductivity (EC) versus %Na or Wilcox diagram

Wilcox [39] proposed a diagram between EC against % Na for examining the suitability of groundwater quality for irrigation presented in Fig. 5. Originally the diagram is parted into five different classes namely excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable, and unsuitable. It is found that 50% of the samples fall in excellent to good zone and 41.66% of the samples fall in good to permissible zone. Whereas 8.33% of the samples fall in permissible to doubtful zone. None of the sample found to fall in doubtful to unsuitable and unsuitable zone shown in Fig. 5.

Table 10 Classification of groundwater based on KR

Range of KR	Category	Sample falling in different categories	
		No. of samples	% of sample
< 1	Suitable	11	91.67
1–2	Marginal	NIL	–
> 2	Unsuitable	1	8.33

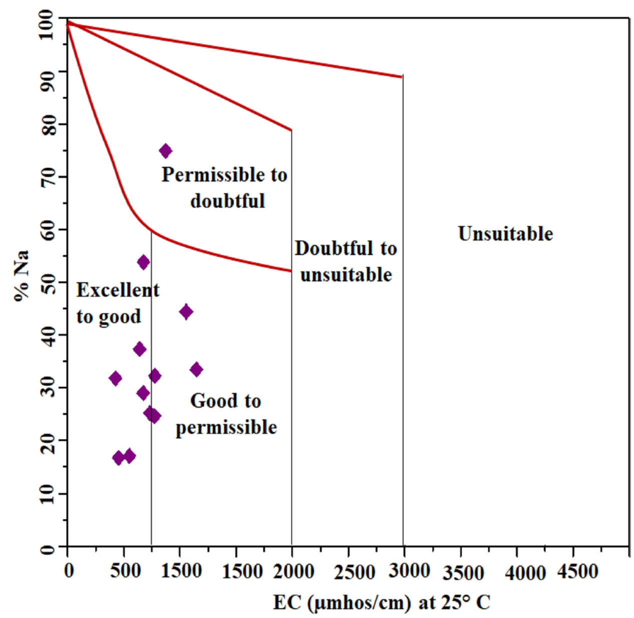

Fig. 5 Wilcox diagram, EC versus % Na

4.6.6 Sodium hazard (SAR) versus EC or USSL diagram

It is recognized that poor drainage conditions in study area causes salinity hazard (C), which forms saline soils. Sodium hazard (S) makes soil dense and water-resistant

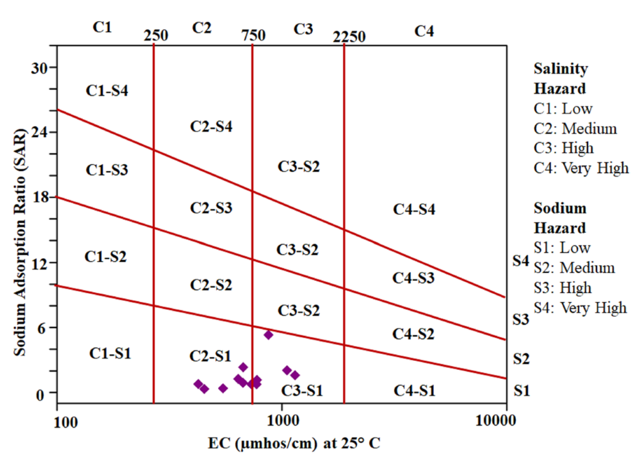

Fig. 6 USSL diagram, EC (salinity hazard) against SAR

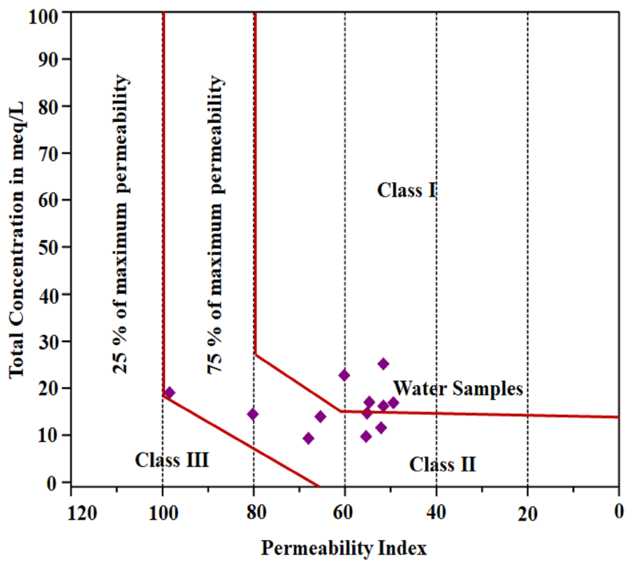

Fig. 7 PI versus total concentration (in meq L^{-1})

due to interchange of Na^+ for Ca^{2+} in soils [45]. United States Salinity Laboratory's diagram [46] classifies the groundwater quality into 16 zones to measure the degree of appropriateness for irrigation presented in Fig. 6, in which the salinity hazard (C) is divided into four classes such as low (< 250), medium (250–750), high (750–2250) and very high (> 2250), respectively. Similarly, the sodium hazard (S) is classified into four classes such as low (< 10), medium (10–18), high (18–26) and very high (> 26) water classes, respectively. It is found that 75% of the samples fall in C2-S1 and 25% in C3-S1 zone respectively presented in Fig. 6. C3-S1 zone samples have high salinity and low sodium hazard, this type of groundwater cannot be used for irrigation without salinity control. Rao [47] have pointed out that salinity alter the growth of plants in different means such as specific ion toxicity, osmotic effects, and nutritional disorders. The continuous use of such groundwater in the long term possibly increase the both salinity and alkalinity hazard in the soil.

4.6.7 Permeability Index

Soil permeability is directly proportional to plant growth, low permeable soil doesn't support plant growth. Doneen [48] classify the groundwater quality with relation to Total concentration of ions (in meq L^{-1}) against permeability index (PI) shown in Fig. 7. The unit of soil permeability in terms of permeability index defined in Eq. 7, where all ions are expressed in meq L^{-1}.

$$PI = \left[\frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na}\right] \times 100 \quad (6)$$

Permeability index has three categories such as class I (100% of maximum permeability), class II (75% of maximum permeability), and class III (25% of maximum permeability). The class I represents suitability, class II represents marginal suitability and class III represents unsuitability for irrigation. PI indicates that 50% of the groundwater samples fall under suitable category (class I) and the reaming 50% samples fall in marginal suitability category (class II) for irrigation.

5 Conclusion

Groundwater is only a major source for drinking and irrigation uses in the present study area. The results of the general hydrochemical analysis suggest that the major cations and anions concentrations are within the BIS and WHO guideline values, except Ca^{2+}, Mg^{2+}, F^-, HCO_3^-, TDS, and TH in some samples. The order of cations is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$, while for the anions it is $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$. In addition, the result shows that Ca^{2+}, Mg^{2+}, and HCO_3^- are the dominant ions in the present study area. High concentration of HCO_3^- in 83.3% of samples represents that temporary hardness is prevalent in the study area. Based on TH, it was found that 75% and 100% of the samples indicate elevated concentration according to BIS and WHO. Considering the GWQI values, it has been concluded that drinking water quality is poor in 41.7% of the samples, while good and very poor water quality was found in 16.7% and 33.3% of the samples. From the Gibbs plot, it is concluded that all the samples were found in the rock dominance zone. Results from the Piper plot showed that Ca–HCO_3 is the dominant hydrochemical facies.

On examination of suitability of waters towards agricultural use, it is found that, based on the RSC classification, 75% of the samples fall in the excellent category, 16.17% of the samples fall in the good category and 8.33% of the samples fall in the poor category. On the basis of PI, 50% of the ground water samples were found to be under a suitable category (class I) and 50% of the samples were found to be in the marginal suitability category (second class) for irrigation. As per SSP investigation, 16.67% of the samples were found to be in good category, 50% of the samples were in the appropriate category and 33.33% of the samples were found to be in the poor category for irrigation. Similarly, according to Wilcox diagram, 8.33% and 25% samples according to SAR versus EC analysis are not up to the mark for irrigation purpose. The current study will help policymakers and competent authorities to take preventive measures on a long-term basis.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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