Research Article

Hydrogeochemical modeling based approach for evaluation of groundwater suitability for irrigational use in Korba district, Chhattisgarh, Central India

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Abstract

Systematic assessment of groundwater suitability for irrigation purpose was evaluated in Korba district, Chhattisgarh, Central India. As a part of the assessment, groundwater physico-chemical data of 56 locations were considered. Ascertaining the groundwater suitability and its characteristics, various quality indices and hydrogeochemical studies were performed. Quality results showed that groundwater of the study area was mostly alkaline in nature, where a total of 17% groundwater samples were found hard to very hard, 9% were slight to moderate hazard, and 4% were high saline type. Chemical indices, namely Sodium percentage (Na%), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Permeability Index (PI), Kelly's ratio (KR) and Magnesium adsorption ratio (MAR) were evaluated. According to the computed indices, majority of the samples were found to be suitable for irrigation. Based on USSL plot, around 54% of samples fell in C_1-S_1 and C_2-S_1 fields, indicating low to medium salinity with a low alkali hazard. Hence, groundwater fell under C_1-S_1 and C_2-S_1 fields can be used to irrigate all kind of soils with marginal increase of risk level for exchangeable Na^+ content. Results of hydrogeochemical model suggested that groundwater of the study area were mainly influenced by rock-water interaction phenomena. Groundwater hydrogeochemical facies was characterized through Piper plot and Chadha's diagram, which showed Ca–Mg–HCO_3 type groundwater as the dominating facies within the study region.

Keywords Groundwater · Irrigation groundwater suitability · Hydrogeochemistry · Rock-water interaction · Korba

1 Introduction

Globally, groundwater is a major source of water that is used for agriculture, domestic, and drinking purposes. Often its quality is ignored, especially for irrigation use. However, where groundwater source and irrigation system are essential to agricultural practices, quality is important in terms of leaching fractions, irrigation management, and also for water treatment in order to achieve maximum crop productivity [1]. Extensive application of insecticides, pesticides and synthetic fertilizers for agricultural production in recent years have raised serious concerns regarding degradation of groundwater quality [2]. While a rapidly growing population and increasing industrial activities are contributing to anthropogenic pollution in both surface and sub-surface water,fluoride, arsenic, highly dissolved solids, and iron concentration in groundwater are causing geogenic pollution [3]. Agriculture is a major sector in India and contributes approximately 14% of the Gross Domestic Product (GDP) [4]. This underlines the need for good quality of irrigation groundwater.

The quality of irrigation water is defined in terms of TDS, major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), and anions (HCO_3^- and CO_3^{2-}); an excess concentration of these in groundwater will lead to sodicity, salinity, and permeability problems in the soil, thereby hampering plant growth and crop yield [4].

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Deterioration in the physical properties of soil in the long run hinges on the quantum of total dissolved salts, sodium carbonate, and sodium bicarbonate concentrations in irrigated water [5]. Globally, the most widespread problems associated with poor water quality are increased salinity, reduced infiltration rate, and specific ions (Na^+, Cl^-) toxicity [6]. However, these problems vary depending on the type of crop grown, climate, soil type, drainage, irrigation method, etc. Good quality water is very essential to sustain crop production and to prevent damage to sensitive crops from salts, pesticides, and trace metals [7]. Moreover, low sodium irrigation water is very essential to sustain soil structure stability [8]. Therefore, it is important to evaluate the main variables while classifying irrigation water quality.

A hydrogeochemical study gives a clearer understanding of plausible changes in water quality as development takes place. The geochemistry of groundwater can demonstrate its suitability for irrigation usage [9]. Water is an excellent solvent, so it is essential to know the geochemistry of dissolved constituents and methods of reporting data. Chemometric techniques such as correlation analysis, graphical analysis, and factor analysis play a major role in the elaborate study of groundwater geochemistry and the interdependence of ions.

The residents at Korba district depends on groundwater resources for drinking, domestic, industrial and agricultural purpose [10]. Though the study area is known for extensive coal mining activities, still agricultural practices are an important economic activity. This study aims to assess the quality and suitability of groundwater for irrigation in the study area. Therefore, this study is undertaken as an initial attempt to illustrate the level and nature of groundwater pollution as it is also associated with mining activities. Till date no such systematic analysis regarding irrigation suitability has been carried out in the entire Korba district, Central India as per the knowledge of authors.

This study focuses on assessing the quality of groundwater for its suitability for irrigation in Korba district, using a multiparametric hydrochemical approach. The sub-objectives of this study are: (1) to understand the hydrogeochemical characteristics of groundwater based on absolute amount of ions; (2) to ascertain the principle variables (indices) based on interactions among ions, for the classification of irrigation water suitability; and (3) to identify the dominant hydrogeochemical processes controlling groundwater geochemistry.

The remaining part of the paper is organized as follows. In Sect. 2, the detail description of the study area is discussed. Section 3 includes the data collection of groundwater physico-chemical parameters, computation of groundwater quality indices and the groundwater hydrogeochemical analysis. Section 4 includes the result of the current research work along with discussions. Finally in Sect. 5 the overall research work is conluded with suggestive future works.

2 Study area

The Korba district is the industrial hub of Chhattisgarh state and situated between 22°01′50″ and 23°01′20″ N latitude and between 82°07′20″ and 83°07′50″E longitude (Fig. 1). The total geographical area of the study area is 7145.44 sq.km and comprises blocks, namely, Podi upraroa, Korba, Kartala, Katghora and Pali. The study area is blessed with abundant minerals like coal, bauxite, fire clay, building stone, and limestone. Some of the major coal mines such as Gevra (one of the biggest coal mines of Asia), Kusmunda and Dipka, all located in Korba Coalfields (KCF) reported that the Korba district is categorized into three major geological groups viz., Chotanagpur Gneissic Complex (CGC), Chhattisgarh Supergroup (CSG) and Gondwana Supergroup [11]. However, CGC and gondwanas encompass over 90% of the study region. Talchir, Karaharbhari, Barakar and Kamthi Formations belong to Gondwana Supergroup. The huge tract between Korba and Hasdeo-Anand Coalfield is occupied by Talchir group. Karaharbhari Formation comprises of sub greywacke and pebbly sandstone is marked as a narrow linear patch in the extreme north eastern portion, while the Barakar Formation comprising of feldspathic and ferruginous type of sandstone extends over the major portion of the Korba-Gondwana basin. The Kamthi Formation comprising of coarse type ferruginous sandstone with shale and coal seams forms prominent ridges in the eastern part of the Korba district. Geology map of the study area is shown in Fig. 2. Around 54% (3882.79 sq. km) of the total area is covered by forests, 2595.86 sq.km (36% approx.) is covered by agricultural lands while rest 666.79 sq.km is covered by Waste/barren land, mining area, water body and built-up area [12]. Kharif is the primary cropping season in the study area and Paddy is the main crop followed by wheat, maize and jawar. Pulses, oilseeds, sugarcane, etc. are also grown in the region. Paddy is sown in nearly 83% of the net sown area. The principal soils of the district include ultisols, inceptisols and alfisols.

3 Methodology

3.1 Physico-chemical dataset

The pre-monsoon (May) groundwater physico-chemical data for 56 locations were collected from the Central Ground Water Year Book, 2016–2017 to analyze their

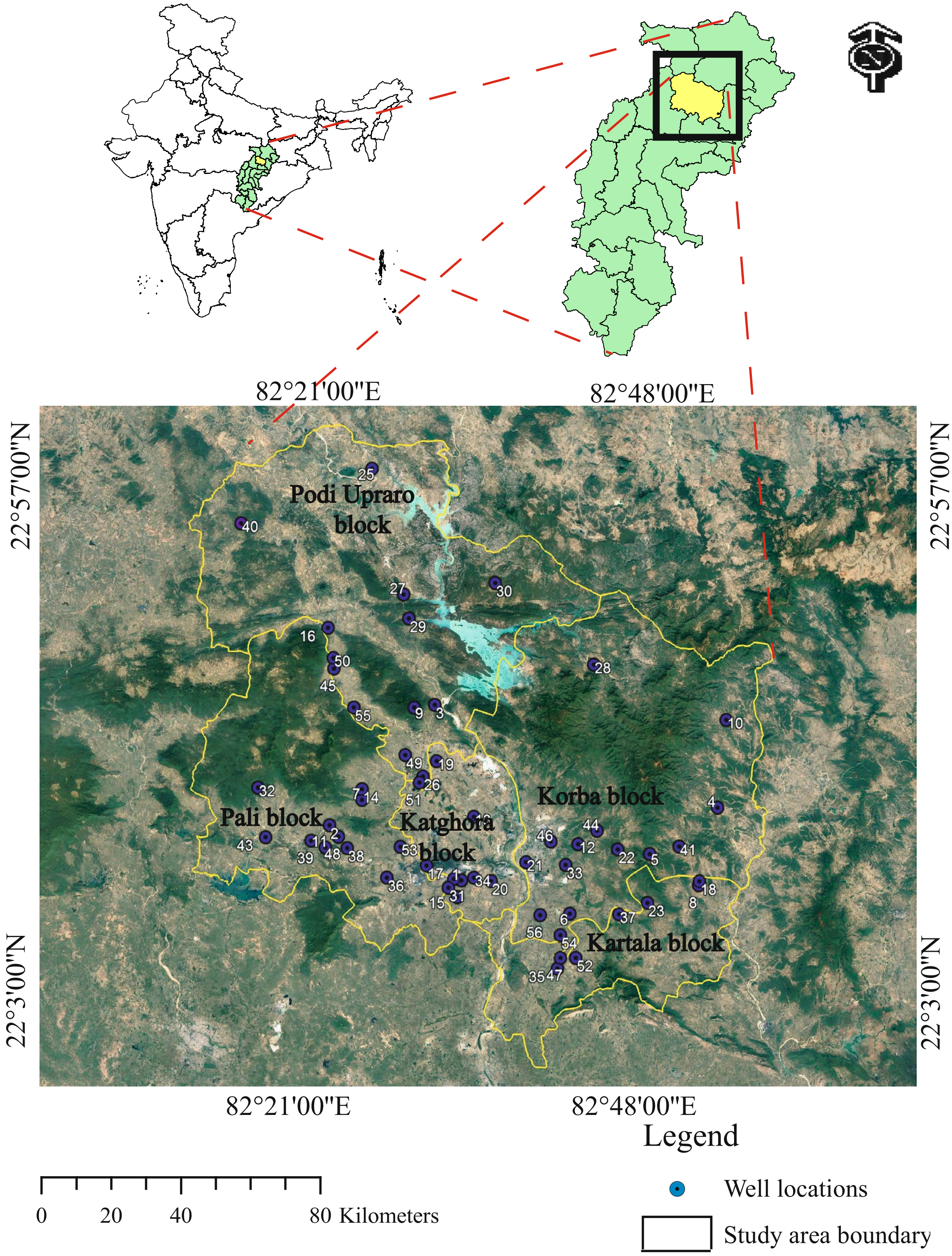

Fig. 1 Location map of the study area

suitability for irrigation purposes. Seventeen physicochemical parameters were selected namely, pH, EC (Electrical Conductivity), TDS (Total dissolved solids), TA (Total alkalinity), TH (Total hardness), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Fe^{2+}, HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^-, F^-, SiO_2 and PO_4^{3-}. All the parameters were expressed in mg/L except pH (unitless) and EC (µS/cm). Various chemical/quality indices were computed by considering the concentrations of groundwater major

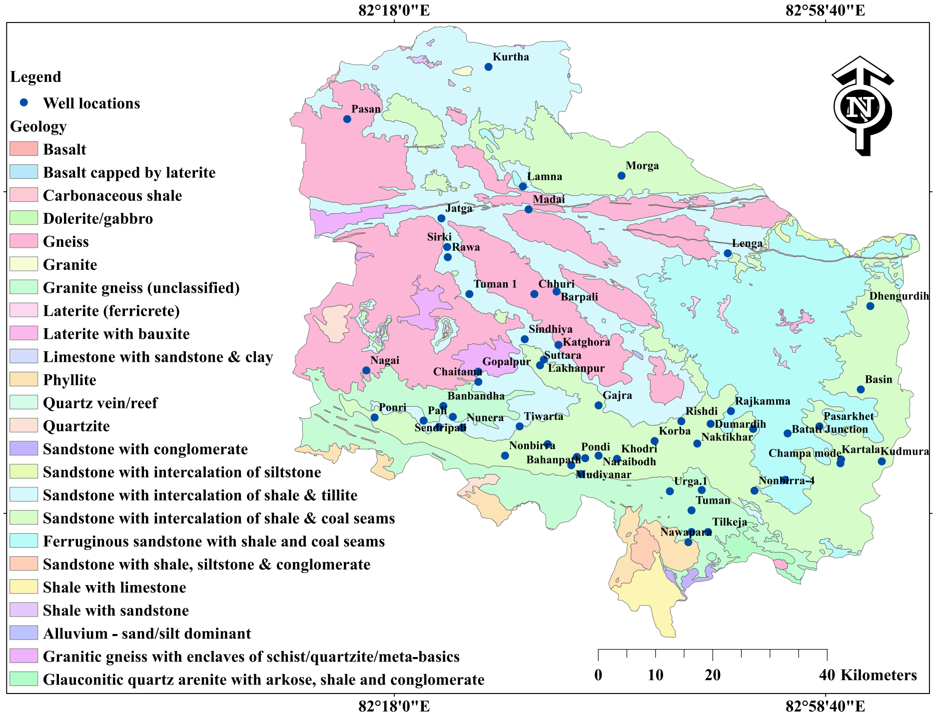

Fig. 2 Geology map of the study area

cations and anions and by using the standard formulae. Various irrigation water quality indices including Sodium percentage (Na%), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Permeability index (PI), Kelly's ratio (KR), and Magnesium adsorption ratio (MAR) were determined. All indices were determined by converting the respective ions from mg/L to meq/L.

3.2 Evaluation of irrigation quality indices

3.2.1 Na%

Sodium percentage was used to assess sodium hazard in groundwater with respect to water quality for irrigation usage. Doneen [13] and Wilcox [14] define sodium soluble percentage as:

$$Na(\%) = \frac{[Na^+] + [K^+]}{[Na^+] + [K^+] + [Ca^{2+}] + [Mg^{2+}]} * 100 \tag{1}$$

Water with less than 20% Na was classified as excellent water for irrigation purpose, as suggested by [14].

3.2.2 SAR

SAR is one of the most important indices to assess sodium/alkalinity in groundwater associated with the presence of high Na^+ and low Ca^{2+} and Mg^{2+} concentrations. Hence, higher Na^+ content signifies higher sodic or alkali hazard in groundwater and conversely, predominance of cations (Ca^{2+} and Mg^{2+}) in groundwater means lesser alkali hazard. Richards [5] defines SAR as:

$$SAR = \frac{[Na^+]}{\sqrt{\frac{1}{2}\left([Ca^{2+}] + [Mg^{2+}]\right)}} \tag{2}$$

Water with a SAR value of < 10 was categorized as excellent water for irrigation use, as proposed by [5]. Lower the ionic strength of the solution, higher is the the sodium hazard for a given SAR.

3.2.3 RSC

The RSC was used to evaluate alkalinity hazards associated with high HCO_3^- and CO_3^{2-} ions in comparison to Ca^{2+} and Mg^{2+} ions in groundwater. Eaton [15] define RSC as:

$$RSC(meq/L) = \left([HCO_3^-] + [CO_3^{2-}]\right) + \left([Ca^{2+}] + [Mg^{2+}]\right) \tag{3}$$

In accordance with the computed indices, RSC values were classified into three subclasses: < 1.25 meq/L in groundwater was considered safe/suitable for irrigation whereas values between 1.25 meq/L and 2.5 meq/L denote marginal safety, and > 2.5 meq/L denotes non-suitability for irrigation use (Table 2).

3.2.4 PI

Doneen [13] proposed the classification of irrigation water based on permeability index. PI values were evaluated considering Ca^{2+}, Mg^{2+}, Na^{+}, and HCO_3^- ions, as shown in Eq. 4:

$$PI(\%) = \frac{\left(\left[Na^+\right] + \left[\sqrt{HCO_3^-}\right]\right)}{\left(\left[Ca^{2+}\right] + \left[Mg^{2+}\right] + [Na^+]\right)} * 100 \quad (4)$$

Accordingly, PI was classified into three subclasses: Class I (PI > 75%), Class II (PI between 25 and 75%), and Class III (PI < 25%). Class I and II categories represent water good for irrigation while Class III is considered unsuitable for irrigation.

3.2.5 KR

Kelly's ratio is also an important criterion for evaluating suitability of groundwater quality for irrigation purpose. Kelly [16] defines Kelly's ratio as (Eq. 5):

$$KR = \frac{\left[Na^+\right]}{\left[Ca^{2+}\right] + \left[Mg^{2+}\right]} \quad (5)$$

Accordingly, KR < 1 indicates good quality water and of > 1 indicates water unsuitable for irrigation.

3.2.6 MAR

MAR was used to assess Mg^{2+} hazards in water. Paliwal [17] and Rao et al. [18] define MAR as (Eq. 6):

$$MAR(\%) = \frac{\left[Mg^{2+}\right]}{\left[Ca^{2+}\right] + \left[Mg^{2+}\right]} * 100 \quad (6)$$

If MAR in groundwater exceeds 50%, the water quality was considered unfit for irrigation and if it was less than 50%, it was good for irrigation.

3.3 Hydrogeochemical analysis

To understand groundwater geochemistry, the following approaches were considered:

3.3.1 Gibbs plot

The plotting of values of specific water quality parameters over Gibbs' diagram [19] provides clarity on which particular factor such as rock-water interaction, evaporation, or precipitation plays a dominant role in controlling the hydrogeochemistry of an area. In the present study Gibbs' diagrams for cations and anions were plotted using the available groundwater chemicals.

3.3.2 Piper and Chadha's plot

The overall characterization of hydrogeochemical data is possible by knowing the composition of water and understanding its hydrogeochemical evolution and the grouping of same composition of major dissolved ions that can be graphically depicted through Piper trilinear diagram and Chadha's plot.

Piper trilinear diagram was proposed by [20] to show major cationic and anionic composition of groundwater samples and to assess the hydrogeochemical evolution of groundwater. The Piper plot comprises of three (two triangular and one central diamond-shaped) fields, each reflecting the respective dominant water types. Two triangular fields were plotted separately, one field represented percentage meq/L values of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and the other showed percentage meq/L values of major anions (HCO_3^-, CO_3^{2-}, Cl^-, and SO_4^{2-}), which were projected on the central diamond-shaped plot to identify overall types or characteristics of groundwater chemistry. The central plot between the two triangles represented the groundwater composition of an area with respect to both cations and anions.

Chadha's plot [21] is an expanded version of the Piper plot, which was constructed by plotting the difference between alkaline earths (Ca^{2+} and Mg^{2+}) and alkalis (Na^{+} and K^{+}) in meq/L on the abscissa and the difference between weak acids (HCO_3^-, CO_3^{2-}) and strong acids (Cl^- and SO_4^{2-}) on the ordinate.

3.3.3 Chloro alkaline indices (CAI)

Groundwater composition mainly relies on the ion exchange process [22]. Ion exchange between groundwater and its surrounding host rock can be computed by CAI, as suggested by [23]. Evaluation of base-exchange through CAI was computed using the following equation:

$$CAI = \frac{\left[Cl^-\right] - \left(\left[Na^+\right] + \left[K^+\right]\right)}{\left[Cl^-\right]} \quad (7)$$

The negative value of CAI implies the exchange of Na^{+} and K^{+} ions with Ca^{2+} and Mg^{2+} of the surrounding host rock material, indicative of cation–anion exchange reaction [24], while the positive value of CAI represents base-exchange reaction among groundwater and the aquifer materials.

4 Results and discussion

4.1 Groundwater chemistry based on the absolute amount of ions

The various physico-chemical parameters and irrigation indices with their minimum, maximum, mean concentration, standard deviation (SD), skewness and kurtosis are presented in Table 1. The classification of groundwater samples indicated their suitability for irrigation based on the different quality constituents (Table 2).

The pH value of the 56 groundwater samples varied between 7.51 and 8.40 (mean value = 8.06 and SD = 0.21). The pH results suggested the alkaline nature of the groundwater in the study area. All the samples were found to be within permissible limits i.e., 6–8.5 [25, 26] and can be used for irrigation.

Water salinity, measured through EC, was considered as an important measure of irrigation water quality as it affects the productivity of crops. Higher EC concentration in water leads to the formation of saline soil [2]. The higher the EC concentration, the higher is the salt concentration and lesser will be the water available to plants [27]. The groundwater EC value (at 25°C) in the study area ranged from 80 to 1697 µS/cm (mean value = 322.70 µS/cm and SD = 266.81 µS/cm) (Table 1). Based on groundwater EC values, irrigation water was categorized into four subclasses [5] of low salinity: 0–250 µS/cm, moderate salinity: 250–750 µS/cm, high salinity: 750–2250 µS/cm, and very high salinity: > 2250 µS/cm. Result showed that approximately 56% of the wells in the study area had low saline water, 43% moderate saline water, and only 1% (one well) had high saline water (Table 2). As per [28], the EC values showed that majority of the samples (98.21%) were categorized as excellent to good (Table 2). Since EC is also an indicator of total dissolved salts in water, TDS concentration was also investigated to ascertain salinity hazard.

The TDS value of the groundwater samples varied from 56 to 1187.90 mg/L (mean value = 225.89 mg/L and SD = 186.77 mg/L). Based on the classification of TDS as suggested by [29], most of the sampling locations were found suitable for irrigation. A total of 91% of the samples were suitable for irrigation (wells with TDS < 450 mg/L) and 9% showed slight to moderate hazard (TDS between 450 and 2000 mg/L) (Table 2). Therefore, it can be inferred that the groundwater in the study area has low to moderate salinity.

Table 1 Values of various physico-chemical parameters and irrigation water quality indices

Parameters and irrigation indices	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
pH	7.51	8.40	8.06	0.21	−1.14	0.55
EC (µS/cm)	80	1697	322.70	266.81	2.86	11.99
TDS (mg/L)	56	1187.90	225.89	186.77	2.86	11.99
TA (mg/L)	10	220	81.52	54.51	0.68	−0.59
TH (mg/L)	15	700	107.59	103.50	3.73	19.16
Ca^{2+} (mg/L)	4	142	26.54	22.46	2.88	12.06
Mg^{2+} (mg/L)	1.20	82.80	9.90	12.24	4.16	22.71
Na^+ (mg/L)	2.90	69.50	20.99	18.07	1.12	0.42
K^+ (mg/L)	0.80	26.50	6.02	4.74	1.93	6.16
Fe^{2+} (mg/L)	0	8.89	0.95	1.97	2.92	8.36
HCO_3^- (mg/L)	12	268	99.11	66.30	0.67	−0.59
CO_3^{2-} (mg/L)	0	6	0.21	1.12	5.14	25.35
Cl^-(mg/L)	7.10	223.70	36.35	36.78	2.82	11.42
SO_4^{2-}(mg/L)	0.80	104.60	14.78	18.90	2.59	8.99
F^-(mg/L)	0	2.10	0.24	0.44	2.60	6.72
SiO_2(mg/L)	3.30	118.7	33.61	26.80	1.14	1.08
PO_4^{3-}(mg/L)	0	2.41	0.36	0.46	2.13	6.11
Na (%)	13.82	74.69	34.65	12.31	0.78	1.08
SAR	0.17	2.46	0.88	0.61	0.95	0.16
RSC(meq/L)	−10.29	0.81	−0.51	1.53	−5.02	31.14
PI (%)	27.60	129.24	81.50	19.84	−0.27	0.29
KR	0.10	2.77	0.48	0.43	3.20	14.49
MAR (%)	9.90	62.24	35.92	12.11	−0.01	−0.47

Table 2 Classification of samples showing their suitability for irrigation based on different groundwater quality constituents

Parameters and lindices	Range	Category of irrigation water quality	Number of samples	Description
TDS (mg/L)	< 450	Excellent	51	Best for irrigation
	450–2000	Moderate	05	Slight to moderate
	> 2000	Hazard	00	Unsuitable for irrigation
EC(μS/cm)	< 250	Excellent	29	Low salinity hazard
	250–750	Good	26	Moderate salinity hazard
	750–2250	Permissible	01	High salinity hazard
	> 2250	Doubtful	00	Very high salinity hazard
TH(mg/L)	< 75	Soft	29	Suitable
	75–150	Moderately hard	17	Marginally suitable
	150–300	Hard	09	Doubtful
	> 300	Very hard	01	Unsuitable
Na %	0–20	Excellent	06	Best suited for irrigation
	20–40	Good	34	Suitable
	40–60	Permissible	15	Acceptable
	60–80	Doubtful	01	May be used for irrigation
SAR	0–10	Excellent	56	Suitable in all types of soils and for crops, except for crops sensitive to Na^+
	10–18	Good	00	Suitable for coarse textured or organic soil with permeability
	18–26	Fair	00	Harmful for almost all soils
	> 26	Poor	00	Unsuitable for irrigation
RSC (meq/L)	< 1.25	Good	56	Safe for irrigation
	1.25–2.5	Medium	00	Marginally suitable for irrigation
	> 2.5	Bad	00	Unsuitable for irrigation
PI (%)	> 75	Class I	37	Excellent quality for irrigation
	25–75	Class II	19	Good quality for irrigation
	< 25	Class III	00	Unsuitable for irrigation
KR	< 1	Safe	51	Suitable for irrigation
	> 1	Unsafe	05	Unsuitable for irrigation
MAR (%)	< 50	Safe	51	Suitable for irrigation
	> 50	Unsafe	05	Unsuitable for irrigation

Total alkalinity in groundwater signifies the presence of natural salts in the sub-surface water. The permissible limit of TA for irrigation water is below 30 mg/L. The TA in the study region varied from 10 mg/L to 220 mg/L (mean value = 81.52 mg/L and SD = 54.51 mg/L) (Table 1).

Total hardness in an area signifies hard water due to the high concentration of Ca^{2+} and Mg^{2+} ions and sometimes dissolved compounds such as Fe^{2+}. When Ca^{2+} and Mg^{2+} ions react with HCO_3^- or Cl^- or SO_4^{2-} ions, they form insoluble calcium and magnesium carbonate ($CaCO_3$ and $MgCO_3$) salts, or chloride ($CaCl_2$ and $MgCl_2$) salts or sulphates ($CaSO_4$ and $MgSO_4$). TH in the study area ranged from 15 to 700 mg/L (mean value = 107.59 mg/L and SD = 103.50 mg/L). Based on [26] and [30], it was found that 52% of the wells in the study area have soft water, whereas 31% of them have moderately hard water, and around 17% have hard to very hard water (Table 2). Van der Aa [31] reported that hard water greater than 200 mg/L leads to scaling deposits in piped systems. As groundwater in he study area was predominantly soft to moderately hard (around 83%), it is suitable for irrigation purposes.

The cations in groundwater samples analyzed in the study area were Ca^{2+}, Mg^{2+}, Na^+, K^+, and Fe^{2+}. The two dominant soluble cations in the study region are Ca^{2+} and Mg^{2+} with concentration values ranging from 4 mg/L to 142 mg/L (mean value = 26.54 mg/L and SD = 22.46 mg/L) and 1.20 mg/L to 82.80 mg/L (mean value = 9.90 mg/L and SD = 12.24 mg/L), respectively. The third and fourth dominant soluble cations are Na^+ and K^+, their values varied from 2.90 mg/L to 69.50 mg/L (mean value = 20.99 mg/L and SD = 18.07 mg/L) and 0.80 mg/L to 26.50 mg/L (mean value = 6.02 mg/L and SD = 4.74 mg/L), respectively. The Fe^{2+} concentration in the study area ranged from 0 mg/L to 8.89 mg/L (mean value = 0.95 mg/L and SD = 1.97 mg/L).

Sharifi and Safari [32], Nagaraju et al. [33] reported permissible limits for irrigation water of Ca^{2+} as 80 mg/L, 35 mg/L for Mg^{2+}, 200 mg/L for Na^{+}, 30 mg/L for K^{+} and 5 mg/L for Fe^{2+}. According to the limits, all the groundwater samples were suitable for irrigation use except one sampling location with respect to Ca^{2+} and Mg^{2+} concentrations and three sampling locations with respect to Fe^{2+} concentration, which had water unsuitable for irrigation.

Similarly, HCO_3^-, CO_3^{2-}, SO_4^{2-}, and Cl^- were the major groundwater anions in the study area. The concentration of HCO_3^- varied from 12 mg/L to 268 mg/L (mean value = 99.11 mg/L and SD = 66.30 mg/L), while CO_3^{2-} ions were observed only at two sampling locations, namely Bhaisma and Lakhanpur. SO_4^{2-} and Cl^- concentrations ranged from 0.80 mg/L to 104.60 mg/L (mean value = 14.78 mg/L and SD = 18.90 mg/L) and 7.10 mg/L to 223.70 mg/L (mean value = 36.35 mg/L and SD = 36.78 mg/L), respectively. The F^- in sampling locations varied between 0 mg/L and 2.10 mg/L (mean value = 0.24 mg/L and SD = 0.44 mg/L). The permissible limits of HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^- and F^- concentration in irrigation water are 250 mg/L, 15 mg/L, 180 mg/L, 250 mg/L, and 10 mg/L, respectively [32, 33]. Based on these limits, all the locations had water suitable for irrigation use, except one location with regard to HCO_3^- concentration. Besides these, the other important anions analyzed were SiO_2 and PO_4^{3-}, their concentrations in groundwater samples varied from 3.30 mg/L to 118.70 mg/L (mean value = 33.61 mg/L and SD value = 26.80 mg/L) and 0 mg/L to 2.41 mg/L (mean value = 0.36 mg/L and SD value = 0.46 mg/L), respectively.

4.2 Groundwater chemistry based on interaction among ions

Additionally, Na%, SAR, RSC, PI, KR, and MAR were determined to assess the ionic hazards of the groundwater sample and to formulate grading standards of groundwater suitability for irrigation use in the study area.

Na^{+} content has the ability for cation exchange reactions with calcium and magnesium ions, thereby making the soil structure impervious. These cationic exchange reactions may also result in deficiency of essential nutrient ions (calcium and magnesium) to the plants. Thus, the presence of excess sodium in water reduces permeability, thereby reducing water availability to plants for their growth. Na content (%) in groundwater samples varied from 13.82 to 74.69% (mean value = 34.65% and SD = 12.31%) (Table 1). Based on sodium percentage values [34], irrigation water in the study area was categorized into four subclasses, i.e., 10.3% of samples had excellent water quality (0–20%), 60.71% had good quality (20–40%), 26.79% fell within the permissible range for irrigation use (40–60%), and 1.79% came under the doubtful category (60–80%) (Table 2). Khodapanah [35] reported that water with more than 60% of Na may cause accumulation of Na^{+} resulting in the breakdown of the physical properties of soils. Wilcox diagram plotted between EC as abscissa and Na as the ordinate showed that 98.21% of groundwater samples (55) fell within the excellent to good category and 1.79% (1) fell within the good to permissible category (Fig. 3). Hence with respect to Na percentage, the Wilcox plot confirms that the groundwater samples are suitable for irrigation usage.

SAR assesses sodic hazard to crops and water suitability for irrigation use [36]. High SAR values in irrigation water may need soil amendments to prevent long term damage to the soil as Na^{+} concentration in water can displace the Ca^{2+} and Mg^{2+} ions in the soil. SAR values ranged from 0.17 to 2.46 (mean value = 0.88 and SD = 0.61) in the entire study area indicating all the samples were of excellent quality and suitable for irrigation (Table 2). For more details and accurate analysis, US Salinity Laboratory's (USSL) diagram [5] (Fig. 4) was plotted between EC representing salinity hazard as abscissa and SAR posing alkali hazard as ordinate to help define the extent of salinity/alkalinity effect on crops. Higher EC concentrations in water lead to saline soil whereas high Na^{+} levels lead to formation of alkaline soil. Salinity hazard was categorized as C_1 = low salinity, C_2 = medium salinity, C_3 = high salinity,

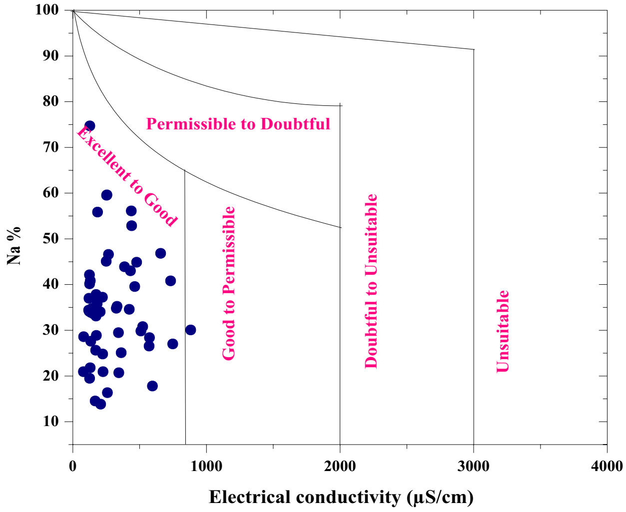

Fig. 3 Wilcox diagram showing the suitability of groundwater for irrigation

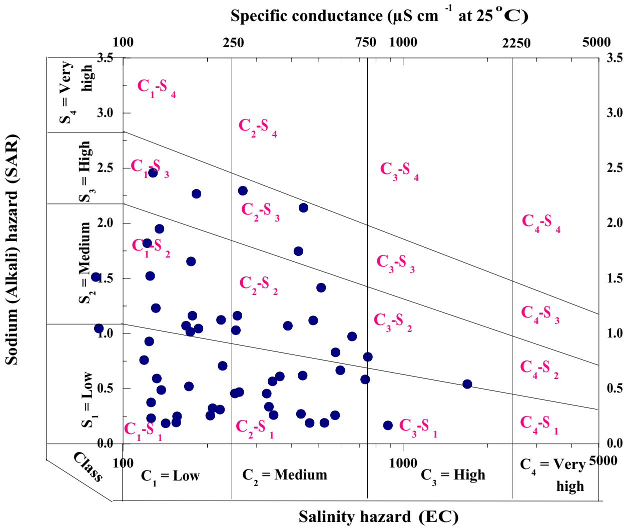

Fig. 4 USSL diagram for classifying irrigation waters on the basis of SAR and EC

and C_4 = very high salinity and alkali hazard as S_1 = low alkalinity, S_2 = medium alkalinity, S_3 = high alkalinity, and S_4 = very high alkalinity. Around 27% of the samples fell in the C_1-S_1 zone and 27% under C_2-S_1, indicating low-medium salinity with low alkali hazard. Only one sample fell in the C_3-S_1 zone, indicating high salinity and low alkali hazard. Hence, groundwater falling within the C_1-S_1 and C_2-S_1 zones can be used to irrigate all kinds of soils with the slight risk of increased levels of exchangeable Na^+ [37], while those in the C_3-S_1 zone can only be used to irrigate certain semi-tolerant crops [38]. Around 18% of the samples fell within the C_1-S_2 zone (low salinity-medium alkali hazard), 14% fell in the C_2-S_2 zone while only 4% fell within the C_3-S_2 zone, indicating medium to high salinity with medium alkali hazard. Groundwater in these areas can be used for irrigation when moderate amount of leaching takes place. However, continuous use of groundwater that falls under the C_3-S_2 zone can in the long run lead to both elevated salinity and alkalinity hazards in the soil. Around 10% of the samples fell under the C_1-S_3 and C_2-S_3 zones. The USSL plot thus indicated that the groundwater samples were suitable for irrigation.

When groundwater containing excessive HCO_3^- and CO_3^{2-} ions react with Ca^{2+} and Mg^{2+} ions, it causes precipitation of respective cations and forms calcite and magnesite that make the soil solution more concentrated, leading to increased Na^+ concentration in water due to the formation of $NaHCO_3$ and Na_2CO_3 [6, 39]. The presence of excess anions (HCO_3^- and CO_3^{2-}) is denoted by RSC, which in turn necessitates its evaluation with regard to irrigation suitability. Higher RSC in water reduces soil infiltration capacity, soil aeration, increases pH, and inhibits root penetration, etc. [40, 41]. From Table 1, it can be observed that groundwater samples in the study area showed RSC values ranging from − 10.29 to 0.81 (mean value = − 0.51 meq/L and SD = 1.53 meq/L), indicating all the sampling locations to be safe (Table 2) for irrigation use. While a negative RSC value denotes excess Ca^{2+} and Mg^{2+} concentration, a positive RSC denotes possible Na^+ presence in the soil. RSC is also important in calculating the amount of gypsum or sulphuric acid required per acre/foot in irrigation water to neutralize residual carbonate effect.

Soil permeability is affected in the long run because of irrigated water, which in turn reduces crop yield, necessitating the assessment of water suitability for irrigation based on the PI. PI is an essential parameter to evaluate bicarbonate and carbonate hazards in groundwater. Based on Doneen's classification, groundwater with > 75% PI comes under Class I, indicating excellent water for irrigation use. PI values between 25 and 75% are grouped under Class II indicating good water for irrigation use while PI < 25% come under Class III, indicating water unsuitable for irrigation. PI values of the samples in the study area varied between 27.60 and 129.24% (mean value = 81.50% and SD = 19.84%), as shown in Table 1. From Table 2, based on PI values it can be inferred that 66% of the samples belonged to Class I and 34% to Class II, which demonstrated that all groundwater sampling locations were suitable for irrigation use.

Kelly [16] determined the hazardous effect of Na^+ in groundwater for irrigation in terms of Kelly's ratio. It is computed based on the presence of Na^+, Ca^{2+}, and Mg^{2+} ions in the water. Kelly's ratio exceeding 1 (KR > 1) signifies elevated Na^+ level in water and that it is unsuitable for irrigation use, while KR < 1 exhibits suitable quality water for irrigation. The KR values of groundwater varied between 0.10 and 2.77 (mean value = 0.48 and SD = 0.43) within the study area (Table 1). The analysis (Table 2) showed that overall only 5 locations (9%) had water with KR > 1, indicating unfit water quality, whereas the rest of the locations (91%) have KR < 1 indicating good quality of water for irrigation.

Szaboles and Darab [42] proposed MAR to evaluate magnesium hazard in groundwater for irrigation purposes. In general, both Ca^{2+} and Mg^{2+} ions in water sustain an equilibrium condition. But the presence of excess Mg^{2+} ions in irrigation water changes soil quality, thereby reducing crop yields. It also damages the soil structure when water has high salinity and Na^+ content. Gupta and Gupta [43] reported that water with MAR value higher than 50% leads to the formation of alkaline soil, which in turn adversely affects crop yield. The MAR value of the samples in entire study area ranged from 9.90 to 62.24% (mean value = 35.92% and SD = 12.11%) (Table 1). In this study, 9% of the total samples were found to having MAR value exceeding 50%, rendering the water samples unsuitable for irrigation while majority of the total samples (91%) are within limits (< 50%) and are considered suitable for irrigation purpose.

4.3 Mechanism controlling hydrogeochemistry

The Gibbs ratio for cations Na + K/(Na + K+Ca) and anions Cl/(Cl + HCO_3) were plotted separately on X-axis and respective TDS concentration (mg/L) on Y-axis. The Gibbs ratio for cations (Fig. 5a) varied between 0.23 and 0.80 (mean value = 0.47) and for anions (Fig. 5b) between 0.10 and 0.85 (mean value = 0.38). From the plots (Figs. 5a,b), it can be inferred that the groundwater samples in the region fell in the rock dominance field, indicating the influence of rocks on groundwater in the aquifers.

The Piper plot (Fig. 6) demonstrated that the groundwater samples fell in the field of Ca–HCO_3 type (64%), Ca–Mg–Cl type (25%), Na–Cl type (5%), Ca–Na–HCO_3 type (4%), and Ca–Cl type (2%). The results reveal that groundwater is significantly dominated by Ca-HCO_3 type which may be due to rock-water interactions and associated dissolution of carbonates in the aquifer system. The prevailing of groundwater Ca-HCO_3 type in the aquifer system mainly due to the dissolution of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)$) minerals present in bedrocks and soils which are described in Eqs. 8 and 9, respectively.

$$CaCO_3 + H^+ \rightleftarrows HCO_3 + Ca \tag{8}$$

$$CaMg(CO_3) + H^+ \rightleftarrows HCO_3 + Ca + Mg \tag{9}$$

It can be inferred from Chadha's plot (Fig. 7) that 66% of the samples fell in the field of Ca–Mg–HCO_3 type followed by Ca–Mg–Cl/SO_4 type (25%), Na–Cl type (5%), and Na–HCO_3 type (4%). Overall, results revealed that the alkaline earth (Ca^{2+} and Mg^{2+}) type water was dominant over alkalis (Na^+ and K^+), and the anionic weak acids (HCO_3^- and CO_3^{2-}) were predominant over anionic strong acids (Cl^- and SO_4^{2-}). The Ca–Mg–HCO_3 type was the dominant hydrogeochemical facies in the groundwater which was responsible for its temporary hardness, whereas the permanent hardness and lack of residual sodium carbonate in irrigation water were mainly due to Ca–Mg–Cl/SO_4 type of groundwater in the study region.

The Chloro Alkaline Indices values ranged between − 3.39 and 0.59 (mean value = -0.36 and SD = 0.86). The calculated CAI values of groundwater cations and anions showed both positive and negative values. A total of 60.71% (34 samples) of negative CAI values indicated the possible reverse ion exchange process and 39.29% (22 samples) of positive values (Fig. 8), inferred the direct base-exchange reaction of groundwater with Na^+ and K^+ with Ca^{2+} and Mg^{2+} of aquifer material. In the surrounding groundwater environment, where the dissolution of calcite, gypsum, and dolomite are dominant, the relation was observed in the vicinity of 1:1 between $Ca^{2+} + Mg^{2+}$ and $HCO_3^- + SO_4^{2-}$ ions [44]. Abundance of

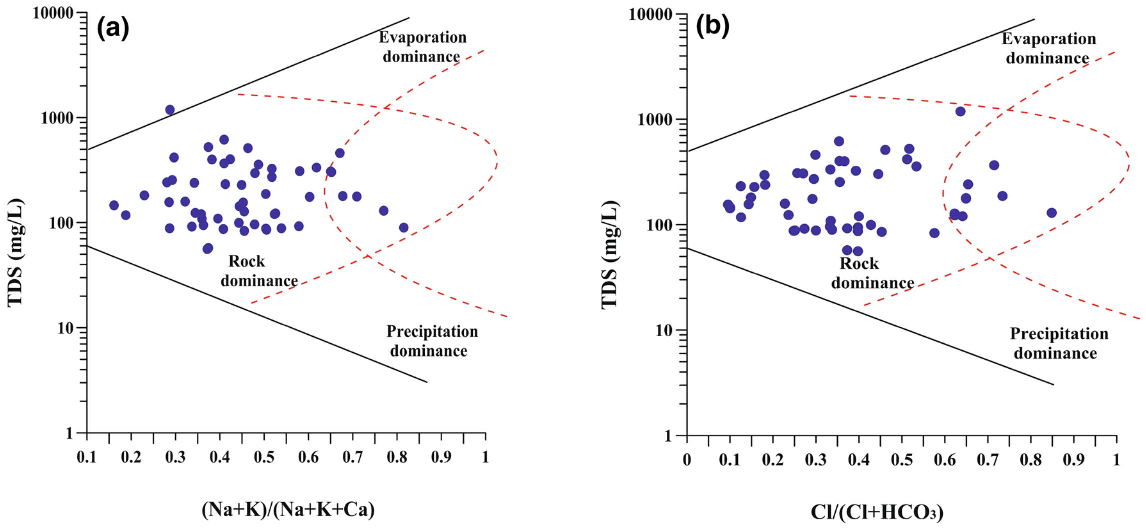

Fig. 5 Gibbs plots **(a)** cations **(b)** anions

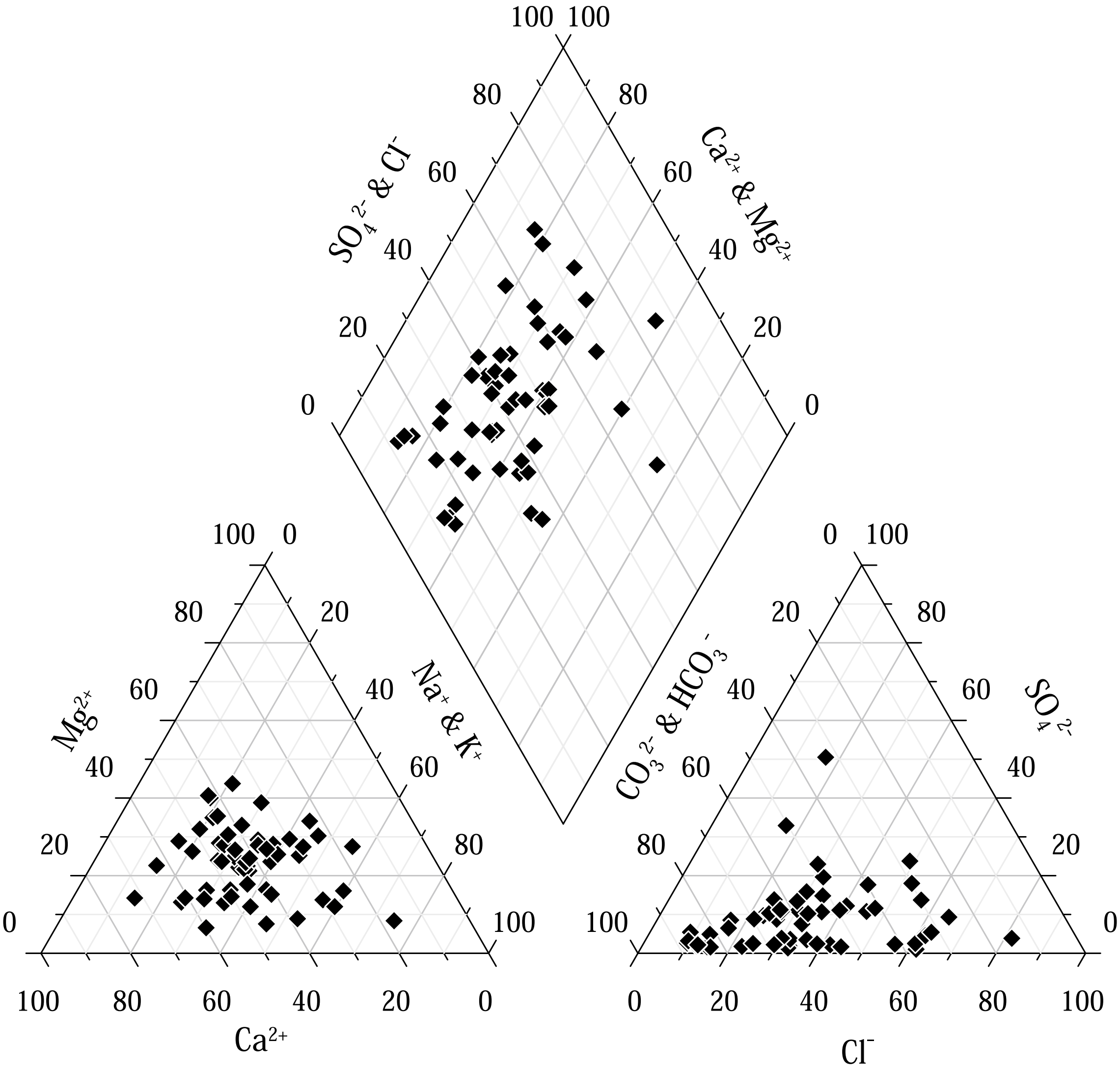

Fig. 6 Piper trilinear diagram of the study area

Ca^{2+} and Mg^{2+} ions in the groundwater environment are mainly due to the cation–anion exchange process which shift the points to the left, while due to the process of direct ion exchange, the availabile anions ($HCO_3^- + SO_4^{2-}$) dominate over $Ca^{2+} + Mg^{2+}$ and the points are shifted to the right [45]. Figure 9 showed that in 17 locations (30.36%) groundwater samples lay below the 1:1 line while the samples in 39 locations (69.64%) fell above the 1:1 line, indicating the dominance of reverse ion exchange process.

5 Concluding remarks

This study examined the suitability of groundwater for irrigation use and groundwater hydrogeochemistry in 56 groundwater samples in Korba district. The Na%, SAR, RSC, PI, KR, and MAR irrigation water quality indices were determined. Except the KR and MAR, the other indices revealed groundwater to be suitable for irrigation purposes. The physico-chemical analysis showed the predominance of the alkaline nature of groundwater within the study region. The dominant soluble cations observed were in the following order: Ca^{2+}>Mg^{2+}>Na^+>K^+ and anions as HCO_3^- > Cl^- > SO_4^{2-}. Results of the hydrogeochemical model suggested that the influence of rock-water interaction phenomena prevailed in the groundwater and the reverse ion exchange between alkalies in the groundwater and earth metal of the aquifer materials were the governing factors which regulates the groundwater chemistry. Groundwater hydrogeochemical facies observed through Piper plot followed by Chadha's diagram highlights that Ca–Mg–HCO_3 type water dominates the groundwater. Overall, results

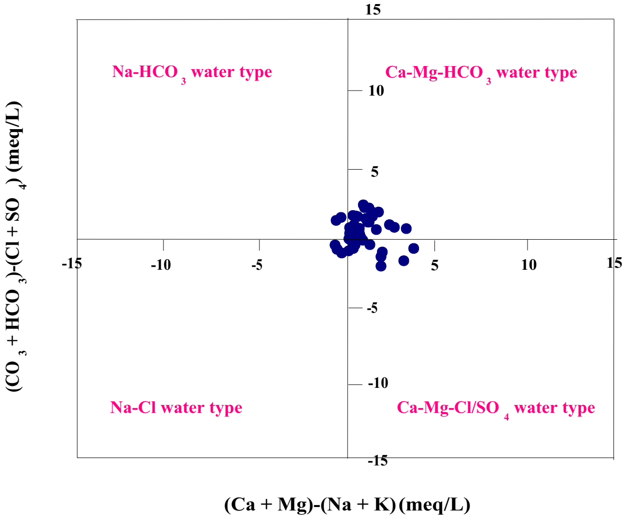

Fig. 7 Classification of groundwater samples according to Chadha's plot

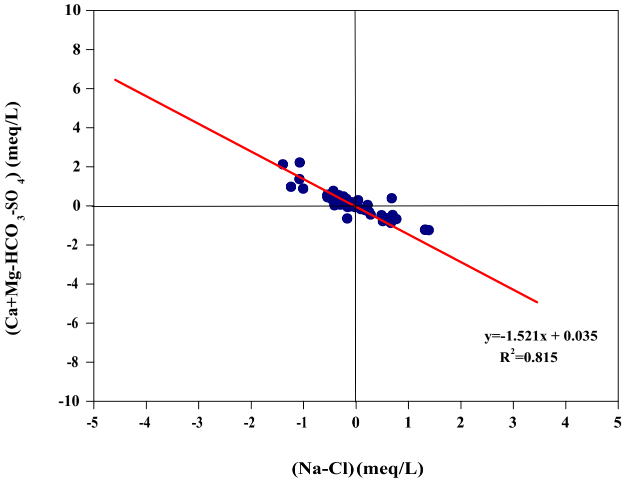

Fig. 8 Scatter plot of CAI

revealed that the existing groundwater was mostly suitable for irrigation purposes in the study area.

Future studies can be focused considering various hydrogeometeriological dataset to establish a groundwater quality prediction model. In addition inclusion of seasonal groundwater physico-chemical data can be used for the model validation purpose to chechk model performance and reliability.

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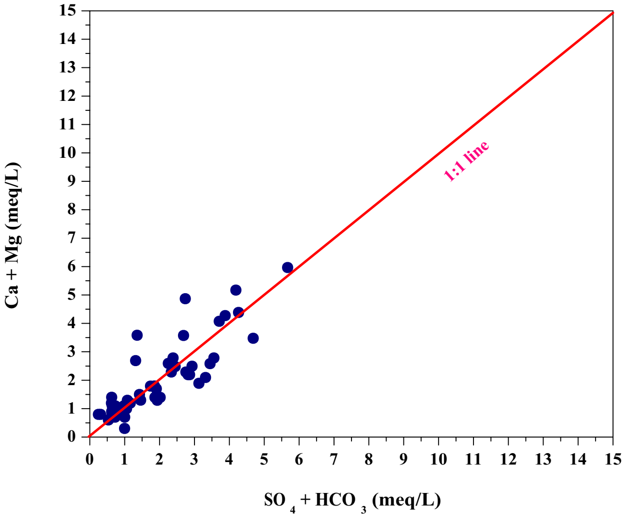

Fig. 9 Showing cross plots between $(Ca^{2+} + Mg^{2+})$ and $(SO_4^{2-} + HCO_3^{-})$

Compliance with ethical standards

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

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