



# Hydrogeochemistry and groundwater quality assessment in Ambagarh Chowki, Chhattisgarh, India

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**Abstract** The current study was focused on hydrogeochemistry of Ambagarh chowki groundwater. The main aim of the study was to evaluate the water quality for drinking and irrigation uses, hydrogeochemistry of groundwater. For this purpose, various physicochemical parameters like pH, electrical conductivity (EC), total hardness (TH), chloride ( $\text{Cl}^-$ ), fluoride ( $\text{F}^-$ ), calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), bicarbonate ( $\text{HCO}_3^-$ ), and sulfate ( $\text{SO}_4^{2-}$ ) were analyzed. The major dominating ions in groundwater was found as cation  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$  and as anions in order of  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{F}^-$ .

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The pH of sampled groundwater was ranged from neutral to alkaline in nature (7.0–8.8). Among, all-analyzed parameters in groundwater were safe for drinking purpose except few ions and bicarbonate content was also exceeding the permissible limit which was not suitable for drinking purpose. The potential health hazard element fluoride was varied from 0.1 to 2.2 mg/l and positively associated with the pH,  $\text{Na}^+$ , and  $\text{HCO}_3^-$  content in groundwater. The drinking water quality index (WQI) was fluctuated between 12.22 and 185.56 and reported that most of the groundwater was suitable for drinking purpose except only one sample was unsuitable for drinking. Irrigation water quality assessment of the area was performed by evaluating as sodium adsorption ratio (SAR), permeability index (PI), Kelly ratio (KR), magnesium hazard ratio (MHR), percent sodium (%Na), potential salinity (PS), and residual sodium carbonate (RSC). Whereas most of the groundwater were good and suitable for irrigation use excluding PI (3.70%), MHR (40.74%), RSC (22.22%) and PS (7.41%) were unsuitable for continuous irrigation. Hydrogeochemistry of groundwater evaluated with correlation, Piper, Gibbs, and other geochemical analysis. The Piper triangular diagram reflects the Ca (Mg)- $\text{HCO}_3^-$  type water was mainly contributed approximately 90% of entire sampled groundwater. The different ions in groundwater were originated from the rock water interaction through silicate and carbonate weathering of minerals.

**Keywords** Hydrogeochemistry · Groundwater · WQI · Drinking · Irrigation · Sustainability

## Introduction

Water covers approximately three fourth of the earth's surface and plays a pivotal role in all living beings by fulfilling their fundamental needs of the globe (Kumbhar & Salkar, 2014). However, 96.5% of global water belongs to seawater system which is not suitable for use due to having high total dissolved solid (TDS) value about > 35,000 ppm. Only 2.5% of water is freshwater which can be used for consumption (Atab et al., 2018). In India, about 4000 billion cubic meters water was annual precipitated. Of which, 75% of precipitation occurs from June to September during the south west monsoon season. Where approximately 1986.5 billion cubic meter volumes of water are lost through runoff. A total of 433 billion cubic meters are a total utilizable groundwater resource in India. Similarly, 411 billion cubic meters of water is having groundwater potential to irrigate 64 Mha area of land (CWC, 2019). The per capita water availability in India is about 1720.29 m<sup>3</sup> (CWC, 2019). Water is utilized for many different purposes ranging from drinking, irrigation, industrial, and other allied sectors (Upadhyay, 2013). Approximately 70% of the freshwater is used by humans for agriculture sectors and 80% groundwater is needed for the rural population to fulfillment their domestic use in India (Karthikeyan et al., 2010; Kumbhar & Salkar, 2014).

In the present world, the groundwater level is depleting and polluted day by day due to huge pressure of urbanization and industrialization. Most of the water is not fit for plant and human consumption; hence, the scarcity of good quality water is an emerging problem (Aboelnga et al., 2020; Hassan Rashid et al., 2018). The ionic concentration of EC, TH, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, CO<sub>3</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, nitrate (NO<sub>3</sub><sup>-</sup>), and F<sup>-</sup> were increasing in different groundwater (Ali et al., 2020; Cao et al., 2019; Khan & Jhariya, 2018; Khan et al., 2021; Kumar et al., 2018; Lal et al., 2022; Moussa et al., 2020; Mustafa et al., 2019; Nematollahi et al., 2018). Declining water and its quality degradation is a major challenge for today due to various natural and anthropogenic activities. For example, hydro-geological, atmospheric, climatic, topographic, and litho-logical factors are covered under natural means (Uddin et al., 2021). Anthropogenic activities involve the intensive application of fertilizer and pesticides, mining, effluents from industrial waste, and chemical spills (Chuah et al., 2016; Meena et al., 2020). In this context, assessing the chemical properties of water can help in

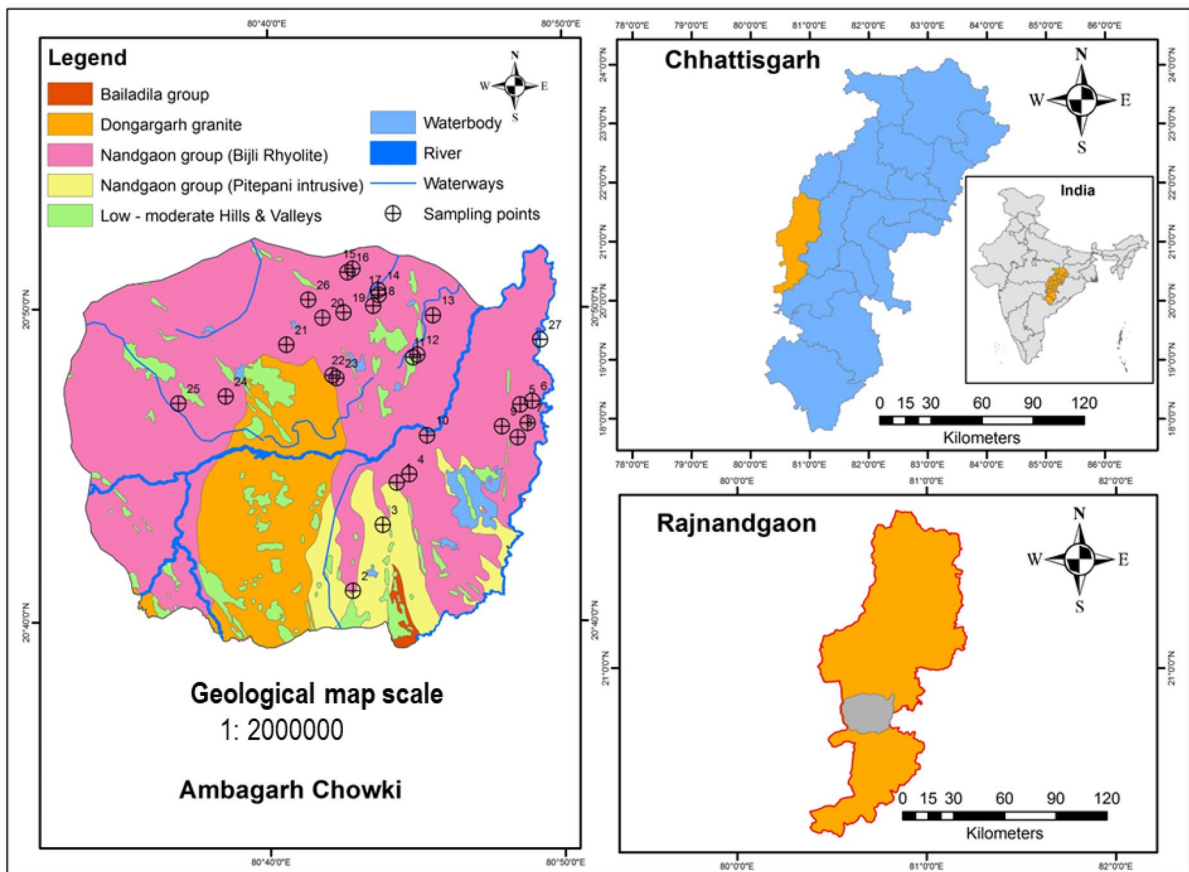
understanding the usefulness of water for a specific need. Determination of water quality concerning their physicochemical parameters is a good measure for alarming human health and other problems (Ewaid & Abed, 2017). In this context, various workers have reported the standard methods for assessing the water quality and its properties. For example, the method of water quality index (WQI) is utilized for assessing the drinking water suitability for humans. Moreover, various geogenic factors are responsible for poor water quality and its unfit use (Gupta & Misra, 2018). Moreover, the groundwater was tested for various parameters pH, EC, TDS, CaCO<sub>3</sub>, phosphate (PO<sub>4</sub><sup>3-</sup>), NO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, F<sup>-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, and HCO<sub>3</sub><sup>-</sup> for calculating the water quality index and drinking water quality (Brhane, 2018; Zakir et al., 2020). Irrigation water suitability was determined by using SAR, RSC, MHR, PI, PS, and EC (Bilali & Taleb, 2020). Sustainable agriculture needs a good quality of irrigation water for generating quality food for the rising population (Jhariya et al., 2019, 2021; Kumar et al., 2020). Similarly, the application of quality irrigation water does not degrade the soil quality of other natural resources that implies a better agriculture production system and environmental quality (Pereira et al., 1996; Uthes & Matzdorf, 2013; Banerjee et al., 2020, 2021; Raj et al., 2020; Haj-Amor et al., 2022). The study area mainly consists of four geological units namely Dongargarh granite, Bailadila group, Nandgaon Bijli Rhyolite, and Nandgaon Pitepani group. Nandgaon Bijli Rhyolite is dominating geology in the study area than the Dongargarh granite and other groups. Pandey et al. (2002, 2004, 2006) found the Lower-Middle Proterozoic age in the area, Dongargarh granite, Nandgaon Pitepani, and Nandgaon Bijli Rhyolite reflected Palaeo Proterozoic age while the Bailadila group was Archaean—Palaeo Proterozoic age. The Nandgaon group comprises with lower Bijli Rhyolite and Pipepani intrusive volcanic and Bailadila group is having phyllitic shales and haematite quartzites. However, Dongargarh granite is overlaying rocks of the area with intrusion of dolerite, dykes, and quarts. The Proterozoic age of the area is having mainly Chhattisgarh supergroup Chilpi, Kotri, Dongargarh, and Iron ore supergroup formation with lithology of limestone, shale arkose, conglomerate, sand stone, shale, schist, phyllite, slate, gneiss, and marble (Shukla et al., 2010). The Chowki area comes under Kotri lineament of Baster in which volcanic rhyolite was dominant which also reported by Prithviraj et al. (2021) where pegmatitic, rhyolite, granite, basalt, dolerite, and pegmatite intrusions rocks were dominant with biotite, chlorite,

illite, kaolinite, and goethite clay minerals are predominant (Acharyya & Shah, 2007; Acharyya et al., 2005; Bhattacharya et al., 2012). The study area is covered with laterite loam and alluvium (Singh et al., 2021).

The present study has analyzed the groundwater quality of different farmer fields of the Ambagarh Chowki, Chhattisgarh, India. This study was concerned with groundwater quality because most of the farmer families belong to the rural area and they use groundwater for drinking and irrigation uses. Therefore, this study would help to explore water quality and hydrogeochemistry of groundwater. Furthermore, this can be possible through better research, development, and technological inputs which must be included in current policymakers and planners. Thus, quality water ensures healthy and productive lives for a better sustainable world.

### Materials and methods

The experiment was carried out in different farmer fields of the Ambagarh Chowki, Chhattisgarh, India. The study sites were situated at 20°35–20°55 N latitude and 80°35–80°50 E longitude. Approximately < 1200 mm annual rainfall was observed and most of the rainfall comes from the southwest monsoon (June to September). The study area is comprising with four types of geology, i.e., Dongargarh granite, Bailadila group, Nandgaon Bijli Rhyolite, and Nandgaon Pitepani group indicated in Fig. 1. Bhata (Entisol), Matasi (Inceptisol), Dorsa (Alfisol), and Kanhar (Vertisol) types of soil were prevalent in this region. Climate is hot moist to dry sub-humid types and comes under Chhattisgarh plain zone of eastern plateau and hill region (class VII) of agro-climatic zone of India as per the planning



**Fig. 1** Geology and sampling location of the study area

commission (NBSS&LUP, 2018; Agricoop, 2019). The major dominating rock in the study area is Dongargarh granite and rhyolite which contains minerals like quartz, feldspar (plagioclase and orthoclase), ferromagnesium (biotite and muscovite), and rarely pyroxene and iron oxide (Shukla et al., 2010). The district has a 354.21 (000 ha) net sown area and 89.43 (000 ha) is the gross irrigated area (Agricoop, 2019). The groundwater levels and annual groundwater recharge values of Ambagarh chowki were 5–10 m below ground level and 46,385,300 m<sup>3</sup>, respectively (Verma, 2013).

Different tube wells water sources of farmer fields were collected during June month 2016 from 27 groundwater samples in the Ambagarh Chowki (Fig. 2). The samples were collected in a 500-ml capacity of high density cleaned polyethylene plastic bottle rinsing with double distilled water by using handheld Global Positioning System (GPS). Bottles were rinsed properly 2–3 times with running water before samples collection. The samples were tested for various hydro-chemical parameters including pH, EC, TDS, TH as CaCO<sub>3</sub>, Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>-</sup>, and F<sup>-</sup> respectively. The samples were transported immediately into the laboratory where pH and EC were measured by using systronics pH meter model-362 and systronics conductivity meter model-304. The standard ethylenediaminetetraacetic acid (EDTA) titrimetric method was used for the determination of TH and Ca<sup>2+</sup>, whereas the magnesium

ion and TDS was calculated from the obtained TH, Ca<sup>2+</sup>, and EC, respectively. A flame photometer (Systronics flame photometer model-128, India) was used for determining alkali metals such as Na<sup>+</sup> and K<sup>+</sup>, respectively. Chloride (Cl<sup>-</sup>) content in groundwater was analyzed by the AgNO<sub>3</sub> titrimetric method. The value of bicarbonate (HCO<sub>3</sub><sup>-</sup>) and carbonate (CO<sub>3</sub><sup>2-</sup>) were determined by titration with sulphuric acid. Colorimetry method with a UV–visible double beam spectrophotometer (Systronics model – 2201, India) was used for estimating sulfate (SO<sub>4</sub><sup>2-</sup>) in the water samples. Similarly, fluoride (F<sup>-</sup>) was estimated by the SPADNS method by using systronics UV–VIS double beam spectrophotometer model-2201. All the parameters in groundwater were analyzed as per the APHA standards methods (APHA, 1999). The spatial distribution of water quality and study location with geological map were prepared with the help of ArcGIS-10.4, and Pearson correlation study and data visualization R software were used.

The water quality index (WQI) of the collected sample was calculated by using the weighted arithmetic water quality index method (Brown et al., 1970; Horton, 1965). The standard value of the parameters was used from Bureau of Indian Standards (BIS, 2012) and World Health Organization (WHO, 2011) to assess the water quality indices. The relative weight and standard value used for calculation are in Supplementary Table 1.

**Fig. 2** View of groundwater sampling from the study area





$$WQI = \frac{\sum_{i=1}^n WiQi}{\sum Wi}$$

where  $Wi$  is the unit weight of each parameter used in water quality analysis, which was calculated as follows:

$$Wi = \frac{K}{S_{std}} \text{ and } K = \frac{1}{\sum \frac{1}{std}}$$

where  $K$  represents a constant value of proportionality and  $S_{std}$  shows a standard value (BIS and WHO) for different parameters.

Similarly,  $Qi$  represents the quality rating scale of the  $i$ th parameters for all  $n$  water quality parameters. It was computed as follows:

$$Qi = \left[ \frac{Qa - Qi}{S_{std} - Qi} \right] \times 100$$

$Qa$  represents an actual detected value of the parameters whereas,  $Qi$  showed an ideal value of the parameters in pure water. The symbol  $S_{std}$  is the standard value of the parameters.

The ideal value was used for pH=7 and zero for the other parameters (Khatri et al., 2020; Salam & Salwan, 2017). Some studied on WQI had conducted in abroad and India was also reported by various workers (Adimalla et al., 2018; Ahmed et al., 2020; Fahad et al., 2017; Karunanidhi et al., 2020; Kumar et al., 2015; Lal et al., 2022; Tripathi & Singal, 2019; Varol, 2020).

Similarly, various irrigation water quality parameters were assessed. For example, the value of SAR by Richards (1954), Na% by Wilcox (1955), RSC by Eaton (1950), PS by Doneen (1964), KR by (Kelly, 1963), MHR by Raghunath (1987), and PI by Doneen (1962) were adopted for evaluating the irrigation water suitability. However, the computation formulas for irrigation water quality are given below:

$$SAR = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}/2}$$

$$Na(\%) = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100$$

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

$$MHR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

$$KR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})}$$

$$PI(\%) = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100$$

$$PS = Cl^- + \left( \frac{SO_4^{2-}}{2} \right)$$

The calculated values are expressed in meq/l (meq/l is obtained by mg/l divided by an equivalent weight of the respective elements). Piper diagrams was also calculated for understanding the irrigation suitability of groundwater in the study sites (Piper, 1953). The correlation and dendrogram plots were determined for assessing the interrelationship among different attributes (Jhariya & Singh, 2021a, b).

## Results and discussion

### Groundwater chemistry

The hydro-chemical analysis was performed for different sampled groundwater in the study areas is depicted in Tables 1 and 3. From this table, the value of pH, EC ( $\mu$ S/cm),  $F^-$  (mg/l), TH (mg/l),  $HCO_3^-$  (mg/l),  $Ca^{2+}$  (mg/l),  $Mg^{2+}$  (mg/l),  $Na^+$  (mg/l),  $K^+$  (mg/l),  $Cl^-$  (mg/l), and  $SO_4^{2-}$  (mg/l) are varied from 7.0 to 8.8, 390 to 1350, 0.1 to 2.2, 72.79 to 300.15, 213.56 to 500.34, 21.04 to 274.27, 6.30 to 48.64, 6.10 to 29.40, 0.03 to 2.15, 35.16 to 170.80, and 5.0 to 45.0, respectively. This highest pH value of groundwater was reported in Sonsaytola C, whereas the least value was observed in Dongaghat. Therefore, the pH value of water samples was observed neutral to alkaline that represents the presence of very weak basic salts of calcium and magnesium ions in groundwater (Adhikari et al., 2014; Xu et al., 2013).

The value of EC was found maximum in Biharikala and the least in Atargaon village. The mean value of total hardness as  $CaCO_3$  was reported as 145.08 mg/l

**Table 1** Hydro-chemical values of the groundwater samples and BIS and WHO Standards

Parameters	Minimum	Maximum	Mean	BIS standards (2012)		WHO standards (2011)		% SBPL
				DL	PL	DL	PL	
pH	7.0	8.8	7.7	6.5–8.5	No relaxation	6.5	8.5	96.30
EC ( $\mu\text{S}/\text{cm}$ )	390	1350	644.81	-	1500 <sup>b</sup>	-	1500	100.00
TH as $\text{CaCO}_3$ (mg/l)	72.79	300.15	145.08	200	600	100	500	100.00
$\text{Ca}^{2+}$ (mg/l)	21.04	274.27	56.39	75	200	75	200	96.30
$\text{Mg}^{2+}$ (mg/l)	6.30	48.64	21.73	30	100	50	150	100.00
$\text{HCO}_3^-$ (mg/l)	213.56	500.34	340.79	-	-	100	120	00.00
$\text{Cl}^-$ (mg/l)	35.16	170.80	93.83	250	1000	200	600	100.00
$\text{SO}_4^{2-}$ (mg/l)	5.0	45.0	14.18	200	400	200	400	100.00
$\text{F}^-$ (mg/l)	0.10	2.20	0.39	1.0	1.5	0.5	1.5	96.30
$\text{Na}^+$ (mg/l)	6.10	29.40	12.20	-	200 <sup>a</sup>	-	200	100.00
$\text{K}^+$ (mg/l)	0.03	2.15	0.55	-	12 <sup>a</sup>	-	12	100.00

DL desirable limit, PL permissible limit, BIS Bureau of Indian Standards, WHO World Health Organizations, % SBPL % sample below permissible limit (as BIS standards, 2012)

<sup>a</sup>Indicates WHO

in entire villages of study sites. Groundwater was also classified on basis of EC and total hardness in the study area which is depicted in Table 2. From this table, based on EC, most of the groundwater samples were fall under the permissible water type (74.08%) while remaining samples were good (22.22%) and brakish (3.70%) category (Langenegger, 1990). However, all samples were suitable for drinking purposes because they fall beyond the permissible limit as described by the water quality standards (WHO, 2011). Similarly, based on  $\text{CaCO}_3$  (mg/l) presence the total hardness of groundwater was classified into soft water (7.41%), moderately hard water (55.56%), hard water (33.33%), and only one sample (3.70%) fall under the very hard category (Sawyer & McCarthy, 1967). The hard water may be caused health problems such as cardiovascular

disorders, prenatal mortality, urolithiasis, and some cancer when it consumes continuously for a long time (Ahamed et al., 2015).

Mahud village with having highest value of calcium ion concentration in groundwater while least value was observed in Aatargaon village. Most of the tested water samples were having  $\text{Ca}^{2+}$  content below the permissible limits as prescribed by BIS standards. The percolating water consists of  $\text{CO}_2$  which produced  $\text{H}_2\text{CO}_3$  and reacted with  $\text{CaCO}_3$  containing minerals it formed  $\text{Ca}^{2+}$  in the groundwater. This process has enriched the value of  $\text{Ca}^{2+}$  in the groundwater of the study sites. Similarly, magnesium hazard was negligible in the groundwater samples, where all samples below the permissible limit were observed which ranged from 6.3 to 48.64 mg/l, whereas sodium and potassium ion concentrations in

**Table 2** Classification of groundwater based on EC and total hardness in the study area

Parameters	Category	Water types	No of samples	% samples
Electrical conductivity as $\mu\text{S}/\text{cm}$ (Langenegger, 1990)	0–333	Excellent	0	0
	333–500	Good	6	22.22
	500–1100	Permissible	20	74.08
	1100–1500	Brakish	01	3.70
	1500–10,000	Saline	0	0
Total hardness as $\text{CaCO}_3$ in mg/l (Sawyer & McCarthy, 1967)	< 75	Soft	2	7.41
	75–150	Moderately hard	15	55.56
	150–300	Hard	9	33.33
	> 300	Very hard	1	3.70

groundwater were also estimated under the permissible limit as described by the drinking water quality standards (WHO). However, the presence of silicate clay minerals may increase the  $K^+$  concentration in groundwater but lower potassium was detected due to more resistance of K-bearing minerals (feldspars) to chemical weathering (Mondal et al., 2013; Rao et al., 2015). Bicarbonate content in groundwater was the most dominating anions it might be released through organic matter decomposition and silicate rocks weathering process. The minimum value of  $HCO_3^-$  was reported in Jadutola B village whereas the maximum in Hoditola village. Moreover, chloride ( $Cl^-$ ) was also reported in water samples as an ionic form of chlorine. In this study, groundwater samples were safe for drinking uses with respect to the presence of  $Cl^-$  under the permissible limit as per the standards of BIS. Sulfate is also a major anion that was observed in the water samples it entered in groundwater through the natural process of weathering of S-bearing and other fertilizer sources. All the groundwater samples were observed below the permissible limit with respect to sulfate ion in groundwater and safe for drinking purposes.

The fluoride ( $F^-$ ) content in groundwater was analyzed with lowest in Aatargaon village to highest in Hoditola village, respectively. Fluoride ( $F^-$ ) is the toxic elements when it presents in higher concentration in drinking water and produce toxicity symptoms on human and animals since it continuously consumes for a longer period. The acceptable range of  $F^-$  in drinking water is 0.5–1.5 mg/l and dental cavity occur  $<0.5$  mg/l  $F^-$  in drinking water. However, the  $F^-$  content in drinking water is  $>1.5$  mg/l because dental fluorosis and having  $>4$  mg/l are also responsible to cause skeletal fluorosis. However, various possible sources of  $F^-$  in groundwater from minerals such as apatite, biotite, muscovite, hornblende, and fluorite. Phosphatic fertilizers are also having  $F^-$  content but it negligible contributed particularly it may be possible source of heavy P-fertilization zone. Furthermore, most of the analyzed groundwater sample (77.78%) was fall under 0.5 mg/l of  $F^-$  concentration, whereas 18.52% of water sample fallen between 0.5 to 1.0 mg/l while only 3.70% of water sample was having above the permissible limit ( $>1.5$  mg/l) of fluoride content in groundwater (Table 4 and Fig. 4). The higher value of fluorides in groundwater is due to prevailing hydro-geological conditions and the process of weathering of fluoride-bearing minerals (Arveti et al., 2011; Brahman et al., 2014; Nirmala et al., 2012).

A cluster diagram of different sampled groundwater of the study area is indicated in Fig. 3. This hierarchical cluster analysis (HCA) was evaluated for eleven water quality parameters namely pH, EC, TH,  $Na^+$ ,  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $HCO_3^-$ ,  $F^-$ ,  $Cl^-$ , and  $SO_4^{2-}$  of collected groundwater samples from a different village. Four villages were separated as the contaminated village namely Atargaon (8), Teliatola (13), Hoditola (20), and Mangatola (21), whereas Hoditola was separated for higher fluoride content (2.2 mg/l) in groundwater while the other village Atargaon, Teliatola, and Mangatola were due to high content of EC and TH in groundwater. These water samples were not recommended for long-term consumption or unsafe for drinking water and it may create many problems in the future.

Drinking water quality index (WQI)

Water quality index (WQI) is a quantitative measure to assess the quality of water for its suitability for drinking purposes. WQI is used to classifying different groundwater and assessing their fitness for drinking purposes based on comparison with BIS and WHO guidelines (Tables 3, 4 and 5). From this table, groundwater was classified into five different categories as excellent, good, poor, very poor, and unsuitable for drinking based on WQI values as 0–25, 25–50, 50–75, 75–100, and  $>100$ , respectively as indicated in Fig. 4. The WQI value of groundwater samples was ranged from 12.22 in Jadutola B village to 185.56 in Hoditola village, respectively. Moreover, 44.44%, 29.63%, and 22.22% groundwater were reported as excellent, good, and poor water categories among all the estimated WQI of selected groundwater samples in study sites. The sample from Hoditola village was reported unsuitable for

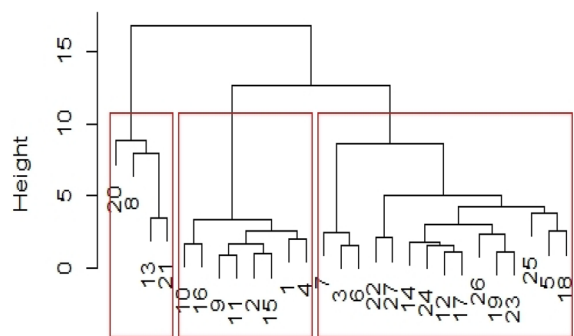


Fig. 3 Cluster diagram of groundwater in the study area

**Table 3** Hydro-chemical parameters in different groundwater samples of the study area

Sample no.	Village	pH	EC	F <sup>-</sup>	TH	HCO <sub>3</sub> <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	WQI
1	Metepar	7.4	510	0.23	131.71	317.29	65.06	16.2	7.5	1.1	80.48	7	25.80
2	Arajkund	8.1	550	0.53	102.53	262.37	25.15	18.8	7.9	0.66	59.23	12	52.72
3	Kaudikasa	7.7	650	0.15	138.95	305.08	21.49	28.54	6.1	1.56	114.66	5	22.19
4	Bihrikala	7.7	390	0.69	73.54	256.27	25.45	11.70	7.2	1.33	68.23	7	62.35
5	Gorratola	7.8	630	0.20	169.36	256.27	31.67	33.46	12.4	0.74	64.87	15	26.56
6	Mahud	7.7	690	0.18	136.88	372.20	21.04	28.15	11.3	1.8	120.53	12	25.06
7	Machandur	7.9	580	0.16	149.5	353.90	22.86	30.77	10.7	2.15	54.56	18	24.91
8	Aatargaon	7.3	1350	0.10	300.15	341.69	274.27	6.30	29.4	0.45	170.8	45	17.94
9	Aatargaon B	7.2	440	0.42	72.79	237.97	25.82	11.41	11.4	0.5	79	6	37.62
10	Dongaghat	7.0	400	0.18	76.91	219.66	28.44	11.78	7.5	0.18	65.45	23	17.37
11	Sanghli A	7.5	450	0.40	78.28	250.17	31.57	11.35	9.1	0.54	48.3	7	38.03
12	Sanghli B	7.6	660	0.21	152.66	384.41	56.15	23.45	11.12	0.15	56.27	12	25.95
13	Teliatola	7.6	880	0.12	264.8	433.22	132.59	32.13	10.45	0.08	150.96	9	21.35
14	Joratarai	7.7	560	0.37	174.49	475.93	46.36	31.00	9.3	0.33	80.04	14	40.17
15	Jadutola A	8.0	500	0.47	108.04	256.27	44.15	15.53	9.6	0.3	75.31	12	47.09
16	Jadutola B	7.2	540	0.10	76.10	213.56	37.97	9.26	10.14	0.06	40.4	11	12.22
17	Dhadutola A	8.1	570	0.42	164.36	414.91	76.22	21.42	10.78	0.35	64	7	45.78
18	Dhadutola B	7.9	840	0.52	177.78	402.71	41.28	33.17	17.52	0.5	35.16	15	53.18
19	Toyagondi	7.8	600	0.48	120.52	433.22	45.42	22.62	12.88	0.4	100.2	10	48.48
20	Hoditola	8.1	730	2.20	138.77	500.34	80.8	14.10	26.51	0.72	145.3	13	185.56
21	Mangatola	7.6	1100	0.15	286.48	396.61	88.70	48.64	14.2	0.17	136.77	32	24.62
22	Sonsaytola B	7.8	710	0.55	136.8	414.91	29.11	26.17	15.3	0.05	150.26	20	53.95
23	Sonsaytola C	8.8	680	0.48	130.67	402.71	58.12	17.63	13.48	0.08	95.24	16	54.12
24	Jhitiya	7.7	560	0.20	156.91	378.30	26.54	31.68	9.35	0.03	68.5	7	25.90
25	Chilhathi	7.3	790	0.20	160.88	280.68	121.21	9.64	16.53	0.22	98	13	22.69
26	Bital	7.9	470	0.30	123.69	347.80	33.32	21.96	9.18	0.32	145.63	8	34.20
27	Kahadkasa	7.8	580	0.52	113.78	292.88	31.82	19.92	12.5	0.31	166.2	27	50.44

drinking purposes due to scoring more WQI with having elevated fluoride content.

#### Groundwater suitability for irrigation purpose

Assessing groundwater is a key step for determining irrigation water suitability for cultivating crops in the study areas. Farmers of the study area were cultivating many crops like rice, wheat, mustard, chickpea, lentil, lathyrus, and other vegetable crops like tomato, brinjal, Knolkhol, and cauliflower in these regions. Therefore, the purpose of assessing irrigation water quality in the study areas was important for understanding water quality and its suitability for crops in this region. Thus, irrigation water quality can be assessed by using various standards calculative methods such as SAR, PI, KR, MHR, %Na, and RSC along with the well-established

method of United State Salinity Laboratory (USSL, 1954).

The water levels declined due to evaporations in the summer season that increased the solute concentrations of various chemical elements in the groundwater.

The calculated sodium adsorption ratio varied from 0.2 to 0.72 with an average value of 0.36, whereas the

**Table 4** Fluoride content and drinking water suitability in groundwater as per BIS standards

Category	F-concentration (mg/l)	No of sample	% of samples
Low	<0.5	21	77.78
Desirable	0.5–1.0	05	18.52
Permissible	1.0–1.5	00	00
Harmful	> 1.5	01	3.70



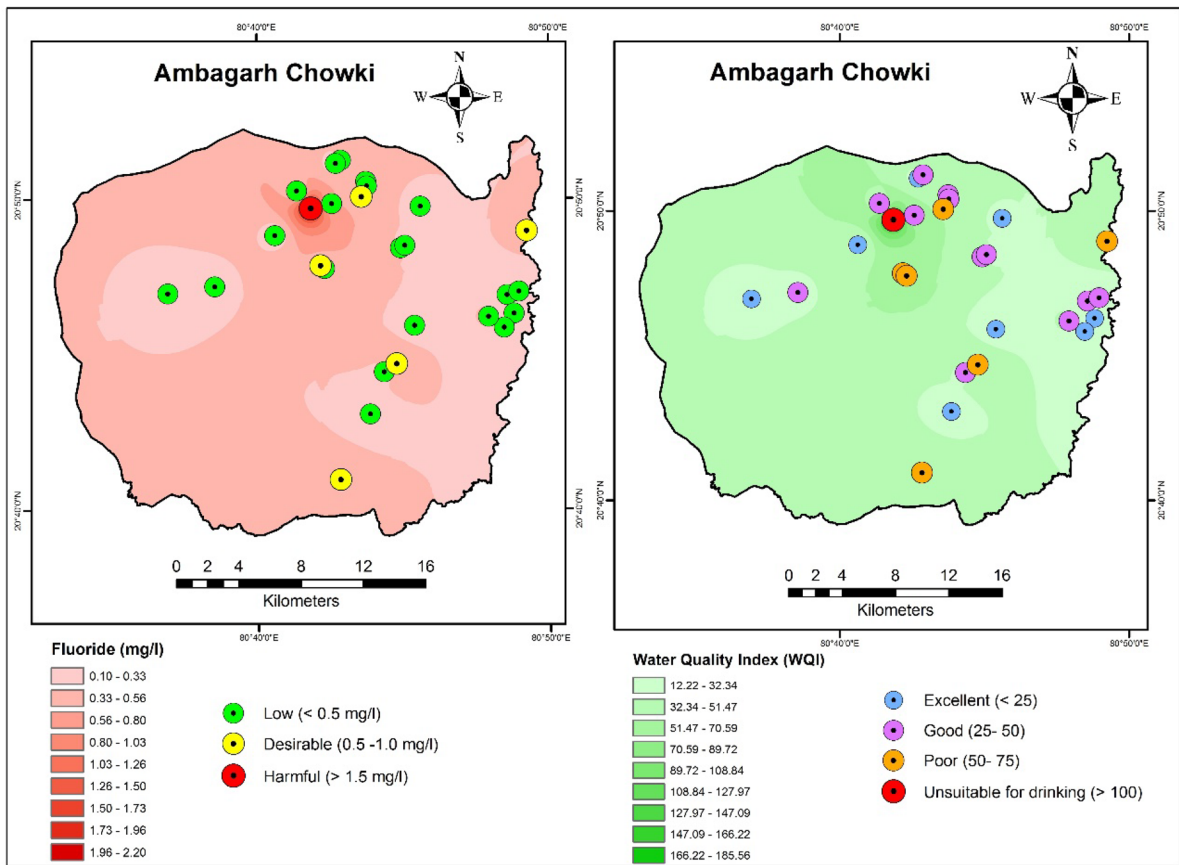
**Table 5** Water quality index (WQI) for drinking groundwater in the study area

WQI value	Class	No of sample	% of sample
0–25	Excellent	12	44.44
26–50	Good	8	29.63
51–75	Poor	6	22.22
76–100	Very poor	00	0.0
> 100	Unsuitable for drinking	1	3.70

salinity hazard as EC ranged between 390 and 1350  $\mu\text{S}/\text{cm}$  in groundwater. SAR and EC values were used for classifying irrigation water which is illustrated in Table 6. These both the parameters were used for USSSL (1954) diagram are in Fig. 5. Moreover, 81.48% of groundwater samples were under the low sodium hazard (C2S1) and medium value of salinity. Only 18.52% of samples were reported under the

low sodium hazard (C3S1) category and high value of salinity. The high salinity irrigation water was unsuitable for continuous irrigation and it may responsible for poor soil quality and other drainage problems due to heavily accumulation of soluble salts in soil when this salty water applies for long period. Assessing the sodium ion concentration in groundwater is another important step that determines the quality of irrigation water.  $\text{Na}^+$  acts as deflocculating/dispersing agents which is able to destroy the soil aggregation and affect the various physicochemical properties of soil. In this context, irrigation water quality parameters and their percent contribution of groundwater are depicted in Table 7.

As table suggested that the value of sodium percent in groundwater was fluctuated between 4.68 and 18.2% with a mean value of 11.11%. Therefore, all calculated % Na was under the excellent and safe water category which is depicted in Fig. 6 (Eaton, 1950; Wilcox,



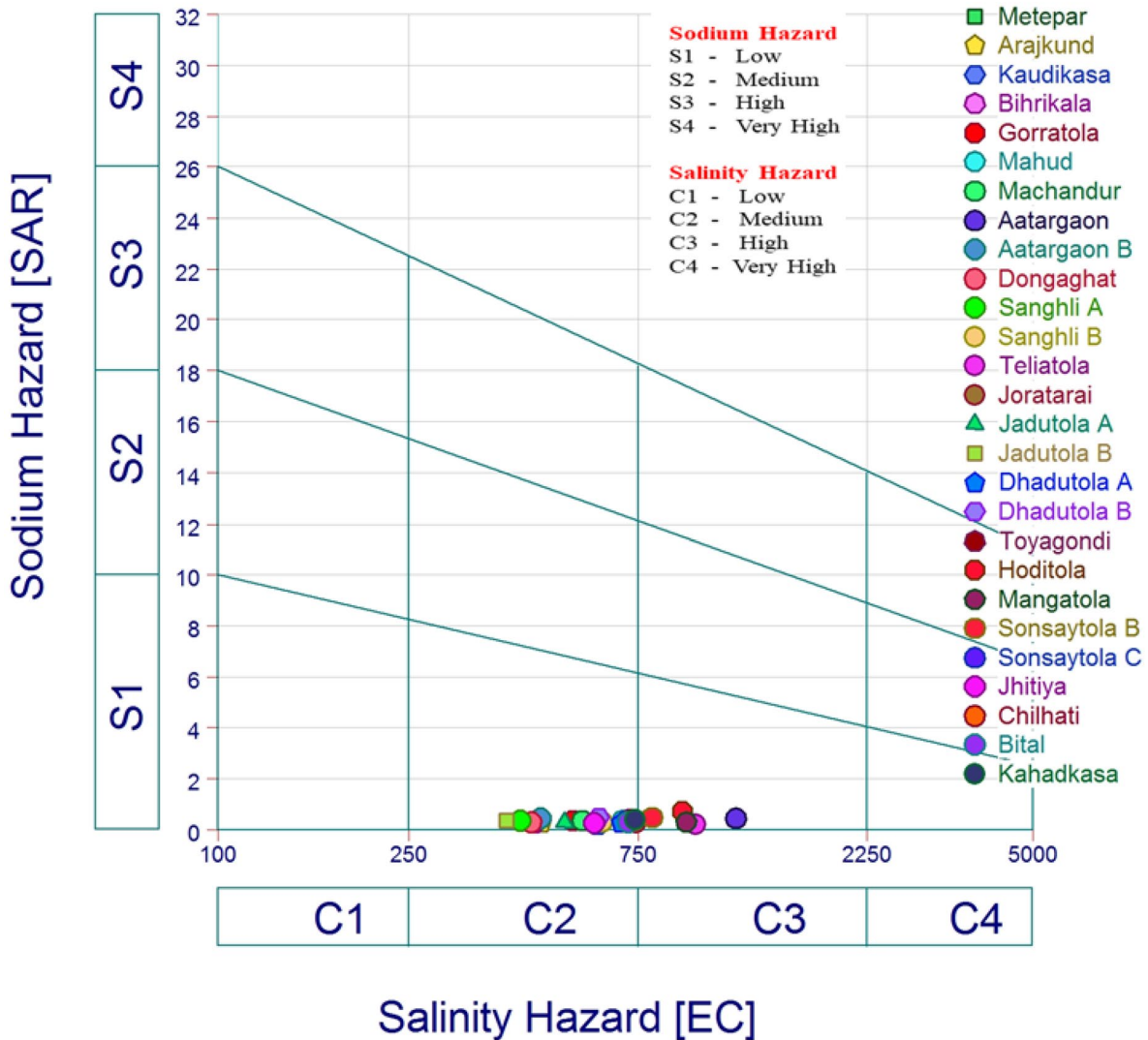
**Fig. 4** Spatial distribution of fluoride and WQI in groundwater of Ambagarh Chowki

**Table 6** Classification of irrigation water based on SAR and EC

Parameters	Water type	Quality	Suitability for irrigation	Range	% samples
SAR (Richards, 1954)	Low sodium water (S1) < 10	Excellent	Suitable for all crops and soil except sodium sensitive crops	0.2–0.72	27 (100%)
	Medium sodium water (S2) 10–18	Good	Suitable for coarse texture/organic soil with good permeability		
	High sodium water (S3) 18–26	Doubtful	Harmful for almost all types of soil, required good drainage, high leaching, and gypsum addition		
	Very high sodium water (S4) > 26	Unsuitable	Unsuitable for irrigation		
EC (Wilcox, 1955)	Low salinity water (C1) < 250	Excellent	Suitable for all types of crops and soils	390–1350	-
	Medium salinity water (C2) 250–750	Good	Can be used if a moderate amount of leaching occurs. Normal salt tolerant plant can be grown without much salinity control		
	High salinity water (C3) 750–2250	Doubtful	Unsuitable for soil with restricted drainage		
	Very high salinity water (C4) > 2250	Unsuitable	Unsuitable for irrigation		

1955). The permeability index was also calculated by the developed equation of Doneen (1964) and used for assess the water permeability in soil which directly related to drainage activity. As per this, the value of PI was varied from 23.49 (minimum) to 92.40% (maximum). Similarly, 70.37% of groundwater samples fall in good water and 25.93% are recorded as excellent water while only one sample falls in unsuitable groundwater for irrigation. The selected groundwater samples were suitable for irrigation purposes as per calculation made under KR (Kelly, 1963). Magnesium hazard ratio is also a key parameter used for evaluating the irrigation quality of the groundwater. The MHR values of the study region were 3.65–68.93 meq/l with an average value of 43.90 meq/l. However, 59.26% of groundwater samples were suitable for irrigation (MHR < 50 meq/l) and 40.74% water sample unsuitable for irrigation (MHR > 50 meq/l) (Raghunath, 1987). When carbonate content in groundwater exceed, it combines with calcium and magnesium ions which precipitated and solid material is formed. The residual sodium carbonate in groundwater was ranged from –8.61 to 3.19 meq/l. The 40.74% of total groundwater samples fall under the doubtful water category (1.25–2.25), 37.07% in good water (< 1.25), and 22.22% groundwater samples were

unsuitable for irrigation concerning RSC (> 2.25) as described by Eaton (1950). The negative value of RSC was also observed in the few groundwater samples of the study area which was confirmed by Adimalla and Venkatayogi (2018) due to incomplete precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  content in groundwater. Potential salinity is an indication of the salinity hazard of groundwater-related to  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  content. The results ranged from 1.15 to 5.29 meq/l with a mean value of 2.90 meq/l. Moreover, 62.96% of groundwater samples were suitable for irrigation and 29.63% fell under the good to injurious water category. Only two samples were found in the injurious to unsatisfactory water category (Doneen, 1962). When high PS irrigation water is applied for a long time to field, it may cause accumulation of soluble salts and become salt-affected soil. However, irrigation water applied with high sodium and bicarbonate content may lead to deterioration of soil health and quality in terms of various physicochemical and biological properties of soil. This has also affected overall nutrient availability to plant and their production. Thus, poor water quality affects both water use efficiency (WUE) and nutrient use efficiency (NUE) severely which affects overall plant health and productivity.



**Fig. 5** Salinity and sodium hazard diagram of groundwater in the study area

**Hydrogeochemistry of groundwater**

For the hydrogeochemical evaluation of different sampled groundwater correlation, Piper, Gibbs, and other bivariate plot were performed in the study area. Correlation analysis was also performed among the tested parameters in groundwater is represented in Fig. 7. The correlation matrix showed correlation coefficient (*r*) among the various eleven parameters namely pH, EC, TH, HCO<sub>3</sub><sup>-</sup>, Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and F<sup>-</sup> in groundwater. The relationship between the parameters were classify into three different categories according to the obtained

value of correlation coefficient (*r*), i.e., strong relationship ( $1 > r > 0.75$ ), moderate relationship ( $0.5 < r < 0.75$ ), and weak relationship ( $0.25 < r < 0.5$ ). As figure suggested that the value of pH was weak but significantly correlated with F<sup>-</sup> ( $r=0.39, p=0.05$ ) and HCO<sub>3</sub><sup>-</sup> ( $r=0.46, p=0.05$ ). EC was strongly correlated with TH ( $r=0.89, p=0.001$ ) and Ca<sup>2+</sup> ( $r=0.80, p=0.001$ ), whereas moderately correlated with Na<sup>+</sup> ( $r=0.73, p=0.001$ ), Cl<sup>-</sup> ( $r=0.52, p=0.05$ ), and SO<sub>4</sub><sup>2-</sup> ( $r=0.70, p=0.001$ ). Total hardness of the groundwater was also having moderately relation with HCO<sub>3</sub><sup>-</sup> ( $r=0.51, p=0.05$ ), Ca<sup>2+</sup> ( $r=0.73, p=0.001$ ), Na<sup>+</sup> ( $r=0.50, p=0.05$ ), SO<sub>4</sub><sup>2-</sup> ( $r=0.56, p=0.05$ ),

**Table 7** Irrigation water quality parameters and their suitability for irrigation uses

Parameters	Ranges	Category	Water types	No of samples	% samples
PI (Doneen, 1964)	23.49–92.40	> 75	Excellent	7	25.93
		75–25	Good	19	70.37
		< 25	Unsuitable	1	3.70
KR (Kelly, 1963)	0.05–0.22	< 1	Suitable	27	100
		> 1	Unsuitable		
MHR (Raghunath, 1987)	3.65–68.93	< 50	Suitable	16	59.26
		> 50	Unsuitable	11	40.74
% Na (Wilcox, 1955)	4.68–18.20	< 20	Excellent	27	100
		20–40	Good		
		40–60	Permissible		
		60–80	Doubtful		
		> 80	Unsuitable		
% Na (Eaton, 1950)	4.68–18.20	< 60	Safe	27	100
		> 60	Unsafe		
RSC (Eaton, 1950)	0.0–3.19	< 1.25	Good	10	37.04
		1.25–2.25	Doubtful	11	40.74
		> 2.25	Unsuitable	6	22.22
PS (Doneen, 1962)	1.15–5.29	< 3	Suitable	17	62.96
		3–5	Good to injurious	8	29.63
		> 5	Injurious to unsatisfactory	2	7.41

and weak association with  $Mg^{2+}$  ( $r=0.49$ ,  $p=0.05$ ) and  $Cl^-$  ( $r=0.47$ ,  $p=0.05$ ). Calcium ions have significantly positive relation with  $Na^+$  ( $r=0.70$ ,  $p=0.001$ ),  $SO_4^{2-}$  ( $r=0.59$ ,  $p=0.001$ ), and  $Cl^-$  ( $r=0.47$ ,  $p=0.05$ ) in groundwater. Sodium was significant correlated with  $SO_4^{2-}$  ( $r=0.61$ ,  $p=0.001$ ),  $HCO_3^-$  ( $r=0.39$ ,  $p=0.05$ ), and  $Cl^-$  ( $r=0.47$ ,  $p=0.05$ ), respectively. Similarly, a weak relationship was reported between  $HCO_3^-$  and  $Mg^{2+}$  ( $r=0.48$ ,  $p=0.05$ ) and  $Cl^-$  and  $SO_4^{2-}$  ( $r=0.46$ ,  $p=0.05$ ) while other parameters were observed as non-significant relationship. Therefore, a major variable constituting ions in groundwater is related to the hydro-chemical variables originating from mineralization of groundwater (Kumar et al., 2017; Patel et al., 2015; Usman et al., 2014).

The fluoride ion in groundwater was having positive correlation with pH ( $r=0.39$ ),  $Na^+$  ( $r=0.44$ ), and  $HCO_3^-$  ( $r=0.36$ ), whereas negative relation was also observed among the TH, EC,  $Ca^{2+}$ , and  $Mg^{2+}$ . The alkaline pH of water enhanced the fluoride content in groundwater. The alkaline pH of water was due to high  $HCO_3^-$  content in water and having ability to mobilize the  $F^-$  ion from the  $F^-$  bearing minerals by the replacement of  $OH^-$  to the groundwater (Jia et al., 2019; Li

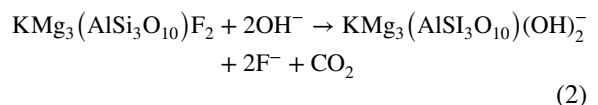
et al., 2018; Rao, 2009; Singh et al., 2019). Moreover, clay minerals were also responsible for  $F^-$  concentration in the groundwater sample due to the process of occurring ion exchange where the  $F^-$  were replaced by  $OH^-$  ions with supported by high  $HCO_3^-$  content in groundwater.

The possible source of  $HCO_3^-$  content in groundwater was enriched with production of carbonic acid (Eq. 1) and weathering of silicate minerals (Eqs. (5) and (6)).

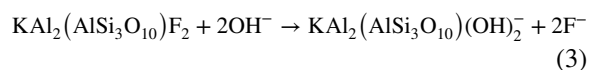


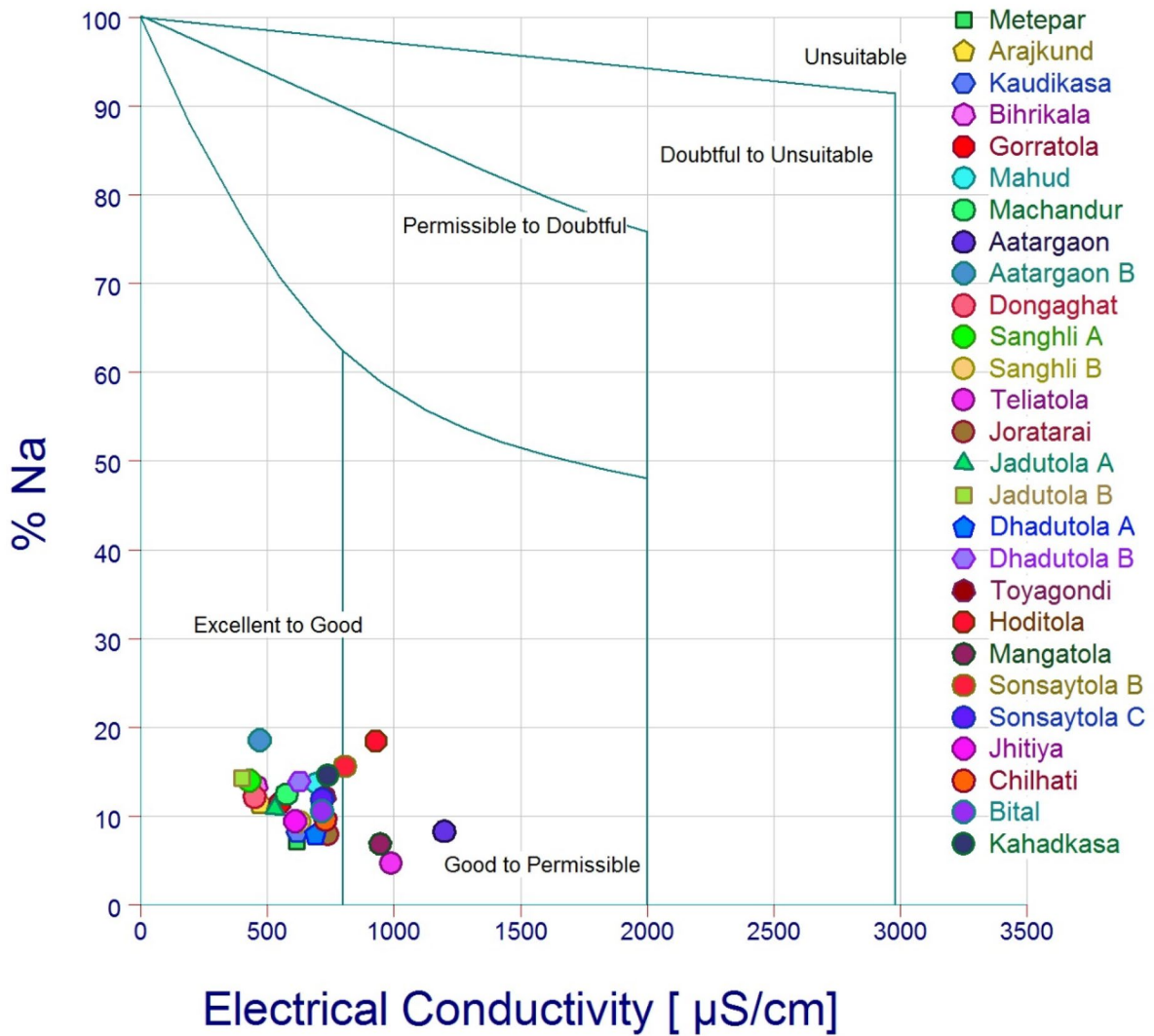
High pH and  $HCO_3^-$  involves in the following hydrolysis of minerals by replacement of  $OH^-$

Biotite



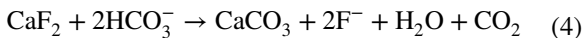
Muscovite





**Fig. 6** Wilcox diagram of the groundwater samples of the study region

Fluorite



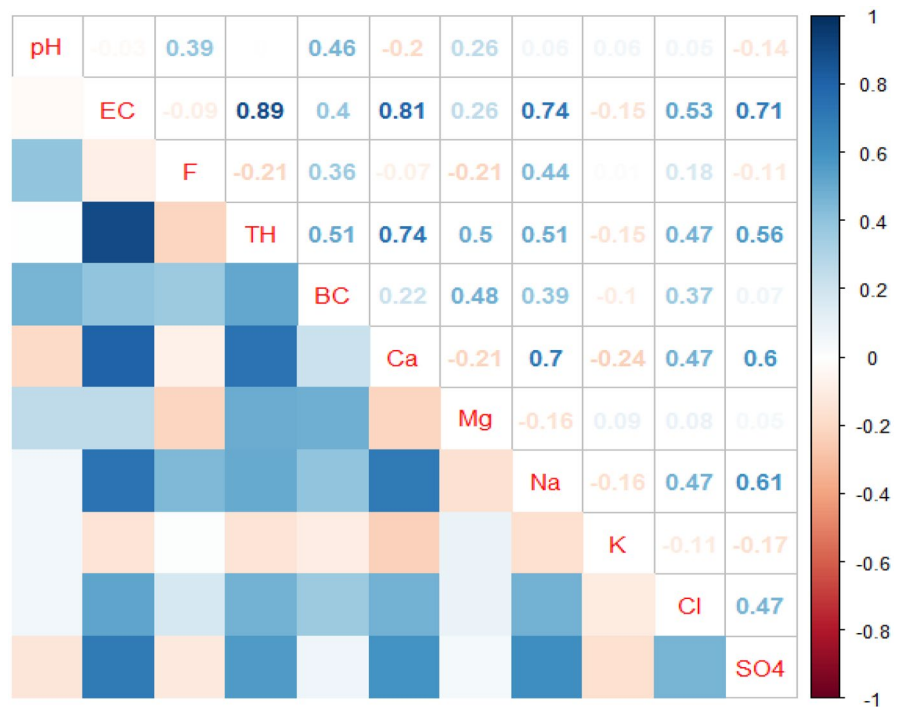
The negative relation of  $\text{F}^-$  and  $\text{Ca}^{2+}$  was also confirmed by Liu et al. (2021) and Rao et al. (2016), whereas  $\text{Ca}^{2+}$  was reduced with the increasing pH because precipitation of calcite was also explaining the positive relation between  $\text{F}^-$  and  $\text{HCO}_3^-$ . Therefore, higher concentration of  $\text{HCO}_3^-$  in groundwater was possible source

of high  $\text{F}^-$  in Hoditola village. The positive relationship with  $\text{F}^-$  and pH,  $\text{Na}^+$ , and  $\text{HCO}_3^-$  were also reported by Reddy et al. (2010), Adimalla and Venkatayogi (2017), and Su et al. (2019).

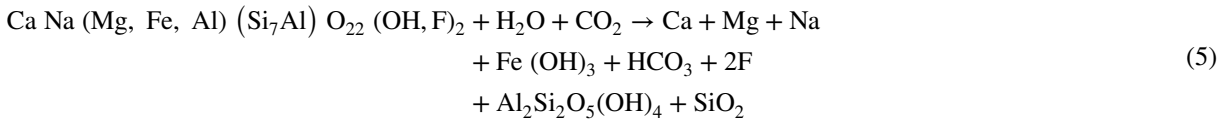
Equation (5) suggested that weathering of hornblende mineral was responsible for the different ions source in groundwater and Eq. (6) explains the possible source for releasing fluoride and other ions in groundwater.



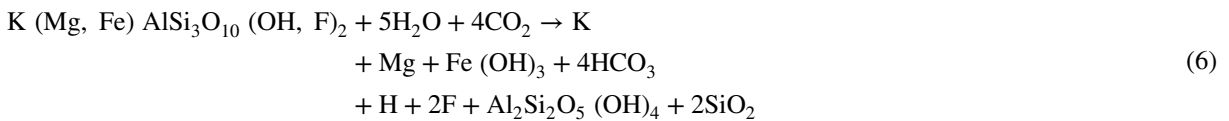
**Fig.7** Correlation matrix of different parameters in sampled groundwater



Hornblende

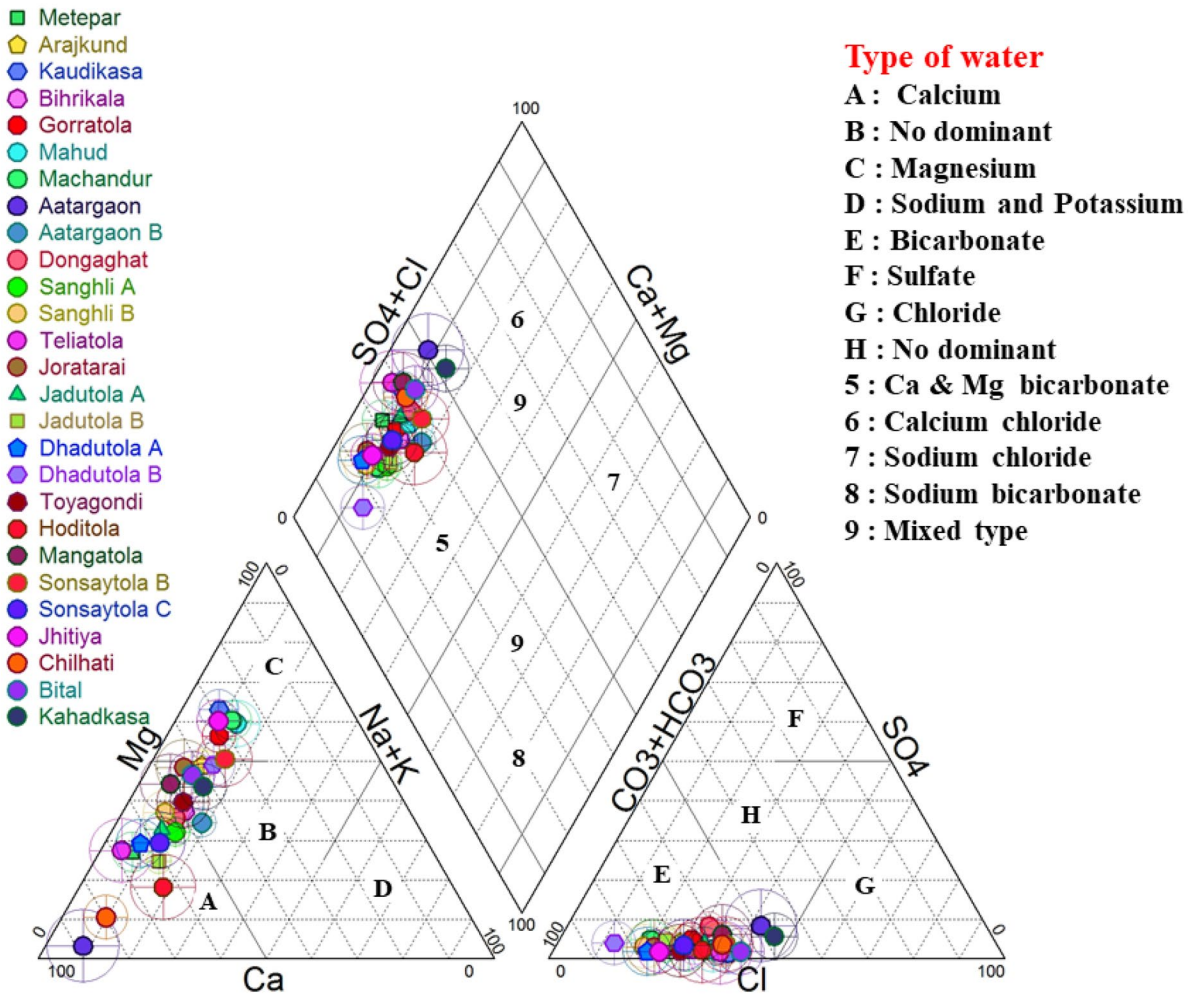


Biotite



The Piper trilinear diagram (Piper, 1953) plotted to know the different cation and anion concentration in groundwater of the study area is depicted in Fig. 8. The cation concentration in groundwater was having sequence of  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$  and anions in order of  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{F}^-$ . The major cations in groundwater were clustered within the plot was approximately 40–50% of  $\text{Ca}^{2+}$ , 30–40% no dominant type, and 10–20% of  $\text{Mg}^{2+}$  dominant type water, whereas anion concentration was majorly contributed by the  $\text{HCO}_3^-$  (90–95%) and remaining were no dominant type 5–10% in sampled

groundwater. The groundwater was mainly dominated with  $\text{Ca(Mg)-HCO}_3^-$  and mixed type water.  $\text{Ca(Mg)-HCO}_3^-$  type groundwater was dominated which contributed approximately 90% of entire sampled water. The source of calcium and magnesium in groundwater was assumed from the weathering of different calcium and magnesium bearing minerals in soil. The possible ionic group in mixed type of water was mainly associated with  $\text{Mg-Ca-Na-HCO}_3\text{-Cl}^-$ ,  $\text{Ca-Mg-Na-HCO}_3^-$ ,  $\text{Na-Ca-Mg-HCO}_3^-$ ,  $\text{Na-Mg-Ca-HCO}_3^-$ ,  $\text{Na-Mg-Ca-K-HCO}_3^-$ ,  $\text{Na-Ca-HCO}_3^-$ ,  $\text{Ca-Mg-K-HCO}_3\text{-Cl}^-$ ,  $\text{Mg-K-Ca-Na-HCO}_3^-$ , and  $\text{K-Mg-Na-HCO}_3^-$ .



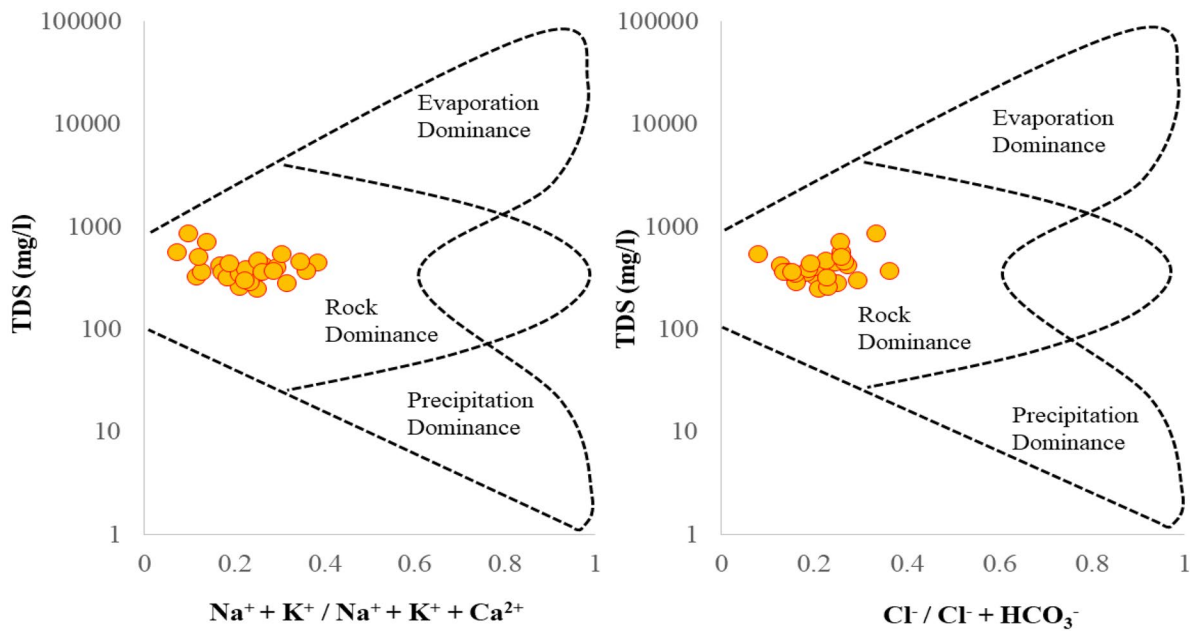
**Fig. 8** Piper trilinear diagram of sampled groundwater in the study area

The Ca-Mg-HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> type water may be able to dissolve the silicate minerals with the presence of CO<sub>2</sub>, dissolution of calcite and weathering of silicate minerals were enriched with Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, and HCO<sub>3</sub><sup>-</sup> (Kumar & Singh, 2015; Kumar et al., 2017) content in groundwater. The possible source of Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and HCO<sub>3</sub><sup>-</sup> from the weathering and exchange phenomena of different clay minerals.

The Gibbs diagram (Gibbs, 1970) was plotted against the TDS and Na<sup>+</sup> + K<sup>+</sup>/Na<sup>+</sup> + K<sup>+</sup> + Ca<sup>2+</sup> and TDS vs Cl<sup>-</sup>/Cl<sup>-</sup> + HCO<sub>3</sub><sup>-</sup> as suggested in Fig. 9. The Gibbs plot defines the dominant mechanism of groundwater geochemistry and it basically describes three processes of ion contribution in water (a) evaporation dominance, (b) weathering dominance or rock water interaction, and

(c) precipitation dominance which helps to understand the ion sources in groundwater, as the plot indicated that all the sample points of groundwater were aggravated in the rock weathering zone or rock water interaction zone. Moreover, the source of different ions including fluoride in groundwater was mainly originated from the weathering/dissolution of minerals through rock water interaction and cation exchange from the adsorbed site of different present clay minerals in soil. The process is completed when water molecules contacted with the rock and minerals in soil profile through percolating water, water can leach different ions from soil to groundwater by exchange phenomena.

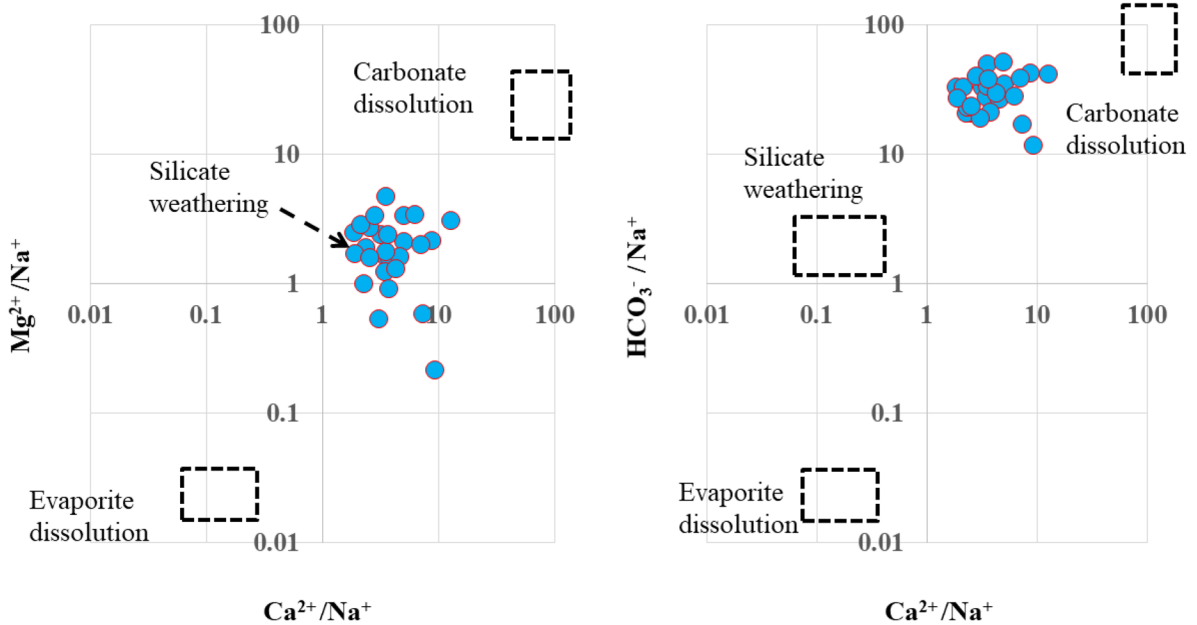
The plot Ca<sup>2+</sup>/Na<sup>+</sup> against Mg<sup>2+</sup>/Na<sup>+</sup> and Ca<sup>2+</sup>/Na<sup>+</sup> vs HCO<sub>3</sub><sup>-</sup>/Na<sup>+</sup> (Gaillardet et al., 1999) was also



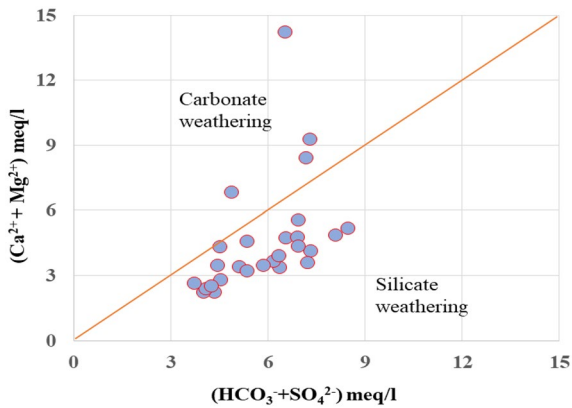
**Fig. 9** Gibbs plot of the different collected groundwater samples of the study area

support to determine the geochemistry of solute contribution in different groundwater sample either by weathering or dissolution of the silicate, carbonate, and evaporite process. As Fig. 10 elaborated that the most of the groundwater samples data were clustered

within the silicate weathering site and few were reported under carbonate dissolution, which indicates the origin of different ions in groundwater including fluoride was from weathering of the silicate and carbonate clay minerals present in the soil. The different



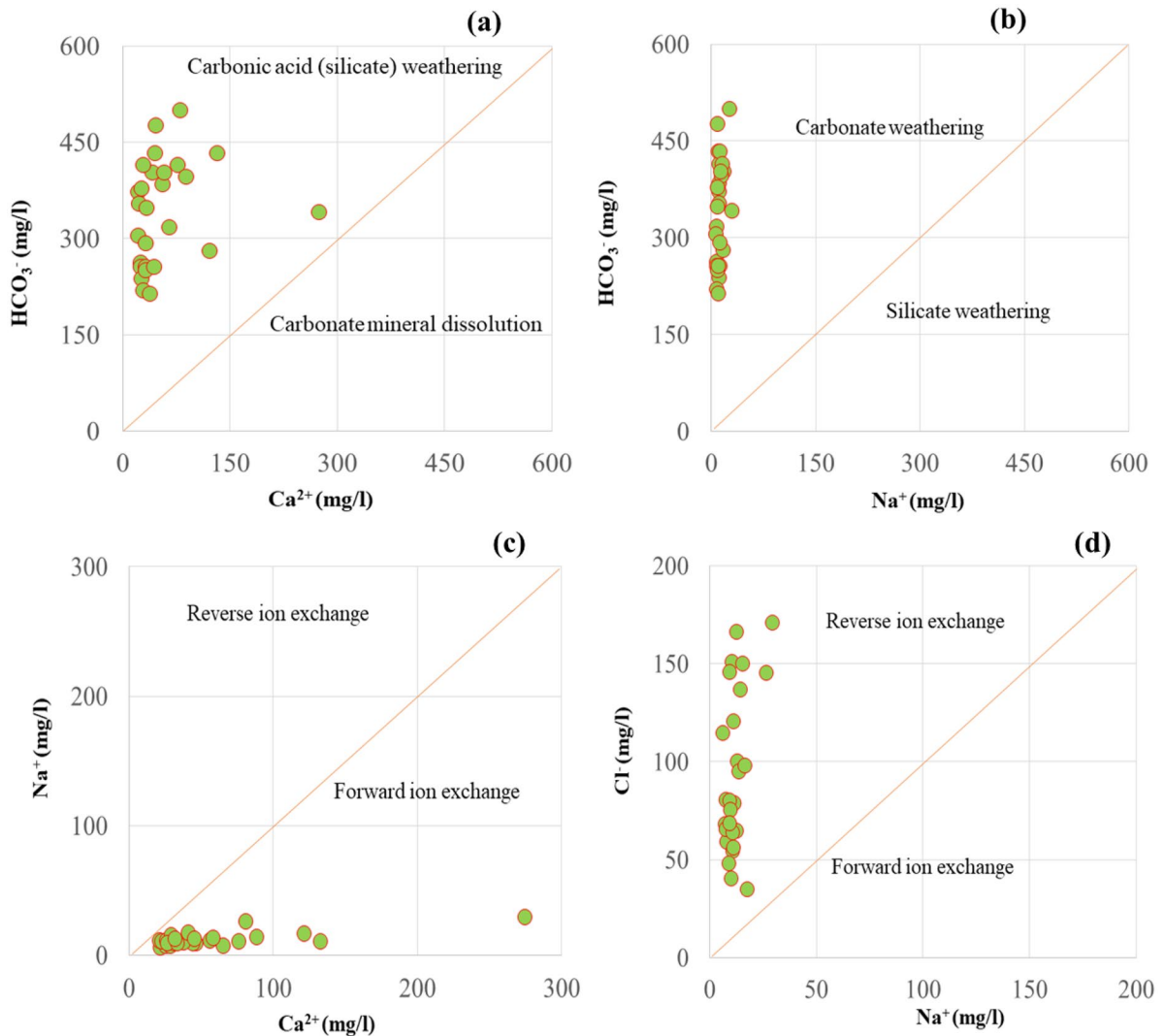
**Fig. 10** Plot of  $\text{Ca}^{2+} / \text{Na}^+$  vs  $\text{Mg}^{2+} / \text{Na}^+$  and  $\text{Ca}^{2+} / \text{Na}^+$  vs  $\text{HCO}_3^- / \text{Na}^+$  of groundwater samples in the study area



**Fig. 11** Relation among  $\text{HCO}_3^- + \text{SO}_4^{2-}$  against  $\text{Ca}^{2+} + \text{Mg}^{2+}$  in groundwater

ions in groundwater were generated by silicate weathering were also confirmed by Adimalla and Qian (2019) and Marghade et al. (2019). However, plot  $\text{HCO}_3^- + \text{SO}_4^{2-}$  against  $\text{Ca}^{2+} + \text{Mg}^{2+}$  were also supported for ions were majorly oriented from weathering of silicate minerals except few samples were drop under carbonate weathering (Fig. 11).

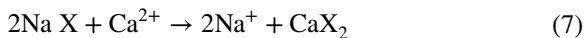
Hydrogeochemical indices and ratio were also calculated for plotting bivariate plot which helps to understand the various geochemistry processes involved in sampled groundwater. As Fig. 12a was plotted between  $\text{Ca}^{2+}$  against  $\text{HCO}_3^-$  which indicated that  $\text{Ca}^{2+}$  in groundwater was mainly associated with the weathering of calcium bearing silicate mineral, whereas the



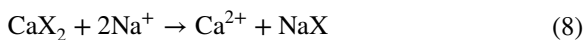
**Fig. 12** Relation between **a**  $\text{Ca}^{2+}$  vs  $\text{HCO}_3^-$ , **b**  $\text{Na}^+$  vs  $\text{HCO}_3^-$ , **c**  $\text{Ca}^{2+}$  vs  $\text{Na}^+$ , and **d**  $\text{Na}^+$  vs  $\text{Cl}^-$  in groundwater

plot between  $\text{Na}^+$  vs  $\text{HCO}_3^-$  depicted that the occurrence of  $\text{Na}^+$  in groundwater sample was from weathering of carbonated minerals (Fig. 12b). The plot  $\text{Ca}^{2+}$  vs  $\text{Na}^+$  explains the ion exchange phenomena of by two ways via forward ion exchange which is replacement of  $\text{Na}^+$  or  $\text{K}^+$  by  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$  and reverse ion exchange is replacement of  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$  by  $\text{Na}^+$  or  $\text{K}^+$ . However, Fig. 12c indicates that forward exchange was dominated over reverse ion exchange and it was possible source of cations concentration in groundwater (Eq. (7)), as Fig. 12d plotted against the  $\text{Na}^+$  and  $\text{Cl}^-$  which suggest  $\text{Na}^+$  in groundwater was mainly by the action of reverse ion exchange process which was supported by Eq. (8). It is also suggested that  $\text{Na}/\text{Cl}$  ratio, when the ratio exceeds  $> 1$  silicate weathering, is responsible for  $\text{Na}^+$  in groundwater while it equal to 1 indicates halite dissolution. However, the  $\text{Na}/\text{Cl}$  ratio of all sampled groundwater were reported  $< 1$  which also explains  $\text{Cl}^-$  was dominated over  $\text{Na}^+$  in groundwater and its  $\text{Na}/\text{Cl}$  ratio  $< 1$  reflects the reduction of  $\text{Na}^+$  by reverse ion exchange process which is supported by reverse ion equation and possible factor for more  $\text{Ca}^{2+}$  content in groundwater (Egbueri et al., 2020; Saha & Rahman, 2020; Su et al., 2021; Xu et al., 2019).

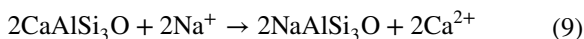
Forward ion exchange



Reverse ion exchange



The lower concentration of  $\text{Na}^+$  in groundwater with compare to  $\text{Ca}^{2+}$  was due to sodium was consumed for the replacement of  $\text{Ca}^{2+}$  ion exchange in groundwater (Eq. (9))



## Conclusions

Water is a key natural resource that governs all essential ecosystem services for a sustainable environment. Hydrogeochemical analysis for assessing water quality is a major concern today from environmental management perspective. Water quality assessment is essential for understanding chemical behaviors and geochemistry for drinking and irrigation purposes. Therefore,

twenty-seven groundwater samples were collected from the Ambagarh Chowki, Chhattisgarh, India which was used for assessing water quality and hydrogeochemistry of groundwater. The groundwater of the study area was neutral to alkaline in nature with moderately hard-hard water. Calcium was dominating cations among all cations whereas, bicarbonate was revealed most dominant anions in groundwater. The pH,  $\text{Ca}^{2+}$ ,  $\text{HCO}_3^-$  and  $\text{F}^-$  were exceeding the permissible limit of Bureau of Indian Standards (BIS, 2012) and World Health Organizations (WHO, 2011) in drinking water. Fluoride was ranging from 0.10 to 2.2 mg/l in groundwater and positively associated with pH,  $\text{Na}^+$ , and  $\text{HCO}_3^-$  in groundwater. WQI of the study area is fluctuated from 12.22 to 185.56 and reported most of groundwater fall under excellent (44.44%) and good (29.63%) water while poor (22.22%) and only one sample was unsuitable for drinking use due to heavy loading of fluoride content in groundwater. For irrigation water quality assessment, various indices were used and found that PI, MHR, RSC, and PS exceed the limit which was mainly describe the salinity and magnesium hazards in groundwater. Piper diagrams shows that most of the groundwater was dominated with  $\text{Ca}(\text{Mg})\text{-HCO}_3^-$  type water in the study area. Gibbs and other bivariate plot explain that different ions in groundwater was originated from silicate weathering through rock water interaction and ion exchange phenomena. Thus, the above study concludes the silicate weathering was main source of ions in groundwater through rock water interaction of the study area. Therefore, monitoring of the groundwater quality is needed and helpful for the local, scientific, and policymaker's people for the future decisions.

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