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Groundwater Quality Mapping of Baragudha Block of Sirsa District, Haryana, India

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Abstract

Proper planning and management of groundwater requires spatial assessment and mapping of groundwater quality, therefore, the present study was planned to characterize the groundwater and delineate its spatial variations in Baragudha block of Sirsa district, Haryana. Seventy six samples were collected from existing tubewells and analyzed for different chemical composition, *i.e.*, Na^+, Ca^{2+}, Mg^{2+}, K^+, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} and the parameters, *i.e.*, pH, EC, SAR and RSC. To study the spatial distribution of different parameters *viz.*, EC, pH and water quality according to AICRP criteria, the maps were prepared through GIS. The results were interpreted according to three different classification criteria, *i.e.*, AICRP, USSL and Piper, to check its suitability for irrigation purpose. According to AICRP criteria, out of seven categories, the maximum (27.6%) samples were found in marginally saline and the minimum (1.3%) in alkali, whereas, no sample was found in marginally alkali and high alkali categories. According to USSL, the groundwater quality of Baragudha block was observed under the categories of C1S1, C2S1, C3S1, C3S2, C4S2, C3S3, C4S3 and C4S4. According to Piper criteria, 11.8% samples were under good category (Ca^{2+}-Mg^{2+}-Cl^- and Ca^{2+}-Na^+-HCO_3^- type) and remaining 88.2% were under poor category (Na^+-Cl^- type). Based on mapping through GIS, the classification of area under different quality of groundwater was more significant than percent samples existed indifferent categories.

Key words: GIS, Groundwater quality, Marginal saline, Alkali, Classification criteria, SAR, RSC

Introduction

The indispensable water resources have proven to be quite resilient, becoming vulnerable and threatened to life on the planet gradually. The utilization of water from ages has led to its over-exploitation coupled with the growing population and improved standard of living. Groundwater is the world's most extracted raw material with a withdrawn rate of approximately 982 km^3 per year (Nickson *et al.*, 2005). Groundwater has contributed significantly towards the growth of irrigated agriculture development in arid and semi-arid regions of North and West India. During the year 1966-67, out of 3.6 million ha cultivated area, about 1.3 million ha was being irrigated (22% from groundwater and 78% from surface water) in Haryana state. By the year 2010-11, the irrigation facilities were developed for about 2.9 million ha area with groundwater irrigation share being more than 57% of the net irrigated area. This shows that groundwater utilization has increased considerably over the years. Some of the regions of Haryana, particularly those underlying good quality groundwater, are facing severe decline in groundwater levels due to it's over exploitation. On the other hand, some of the canal irrigated areas, particularly those underlying with poor quality groundwater, are facing water logging and subsequent soil salinisation problems due to lack of exploitation of poor quality groundwater (Jhorar *et al.*, 2009). The quality of groundwater is deteriorating at a faster pace due to pollution ranging from septic tanks, land fill leachates, domestic sewage, agricultural runoff and industrial wastes. Contamination of groundwater also depends on geology of the area and it is rapid in hard rock areas, especially in lime stone regions where extensive cavern systems are below the water table (Singh, 1982). The changes in quality of groundwater may also take place due to variation in physical, chemical and biological environments through which it passes (Singh *et al.*, 2003). However, research experience in India (Sharma *et al.*, 2013) and worldwide (Hussain *et al.*, 2002) demonstrated that water of much higher salinity than usually being considered unsuitable for irrigation can be used effectively under the precise conditions.

For proper planning and management, spatial assessment of groundwater quality is urgently needed. Regular monitoring of groundwater resources, thus, plays a key role in sustainable management of water resources, which involve the analysis of various ions present in the groundwater, calculation of their related parameters, *i.e.*, sodium percentage, electrical conductivity (EC), pH, sodium adsorption ratio (SAR), residual sodium carbonate (RSC)and preparation of spatial variable maps of their ionic composition and groundwater quality. Geographic Information System (GIS) has emerged as a powerful tool for storing, analyzing and displaying spatial data, which can be easily used by the decision maker in several areas including engineering and environmental fields. In view of above, the present study was undertaken for the spatial assessment of groundwater quality of Baragudha block of Sirsa district, Haryana, where groundwater quality is deteriorating.

Materials and Methods

Study area

Baragudha block lies between 29°34′36″ and 29°51′00″ N latitude and 74°50′15″ and 75°14′ 30″ E longitude angles with a total geographical area of 50945 ha in Sirsa district (Fig. 1).

The topography of the area is almost flat with a gentle slope towards southwest direction. A seasonal river Ghaggar passes through Baragudha, Ellenabad, Rania and Sirsa blocks of the district from eastern to western side. Physiographically, Sirsa district is characterized by three distinct features, *i.e.*, upland plain, alluvial bed (flood plain) of river Ghaggar and sand dune clusters.

Water sampling and parameter estimation formula

A total of 76 groundwater samples were collected from the existing tubewells during September 2014, and their locations (Fig. 1) were recorded through Global Positioning System (GPS). Water samples were analyzed (Richards, 1954) for pH, EC, anions (CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+). To categorizethe quality of groundwater, SAR and RSC were calculated by using the following formulae:

$$SAR\,(mmol\,l^{-1})^{1/2} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

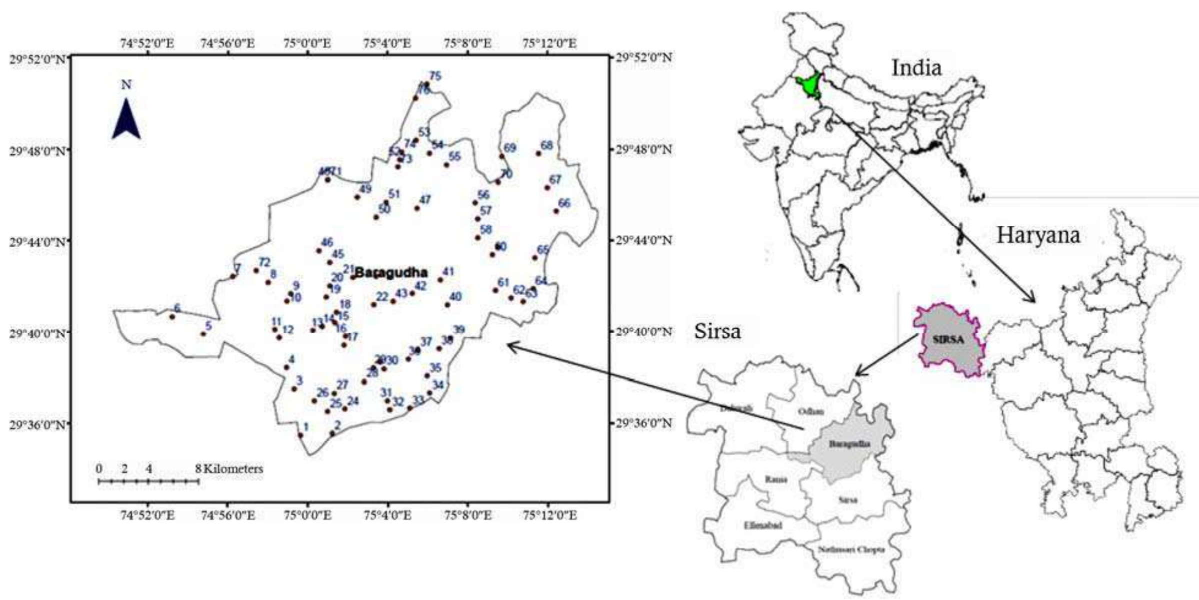


Fig. 1 Location map of study area along with the sampling points

RSC (me l^{-1}) = (CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+})

Methodology

Based on chemical constituents of groundwater samples and other computed quality parameters, the groundwater samples were categorized as per AICRP (1989), USSL (1954) and Piper (1944) criteria. Based on EC, SAR and RSC, the AICRP (1989) classify the groundwater into three categories, *i.e.*, good, saline (sub-categorized as marginally saline, saline and highly SAR saline) and alkali (sub-categorized as marginally alkali, alkali and highly alkali). Based on salinity and sodium hazards, USSL (1954) classified the groundwater into sixteen classes, which were further divided into three groups (I, II and III). Group I (suitable for irrigation) consisted of C1S1 and C2S1, group II (conditionally suitable) C1S2, C2S2, C3S1 and C3S2 and group III (unsuitable) C1S3, C1S4, C2S3, C2S4, C3S3, C3S4, C4S1, C4S2, C4S3 and C4S4 categories. Piper (1944) diagram was prepared through the available software, which (based on tri-linear diagram by representing dominating ions) classifies the water samples into the following six categories:

- Ca^{2+}-HCO_3^- type: This is found in typical shallow fresh groundwater and suitable for irrigation.
- Na^+-Cl^- type: This is found in typical of marine and deep ancient groundwater (high saline), which is unsuitable for irrigation.
- Ca^{2+}-Mg^{2+}-Cl^- type: Not found dominating in chemical composition.
- Ca^{2+}-Na^+-HCO_3^- type: Not found dominating in chemical composition.
- Ca^{2+}-Cl^- or Ca^{2+}-SO_4^{2-}type: This is found in typical of gypsum ground and mining drainage water. Its continuous uses can increase salinity in the field so it should be applied after mixing with canal or good water.
- Na^+-HCO_3^- type (high alkali): This is found there in typical of deeper groundwater influenced by ion exchange, and it is not good for irrigation purpose.

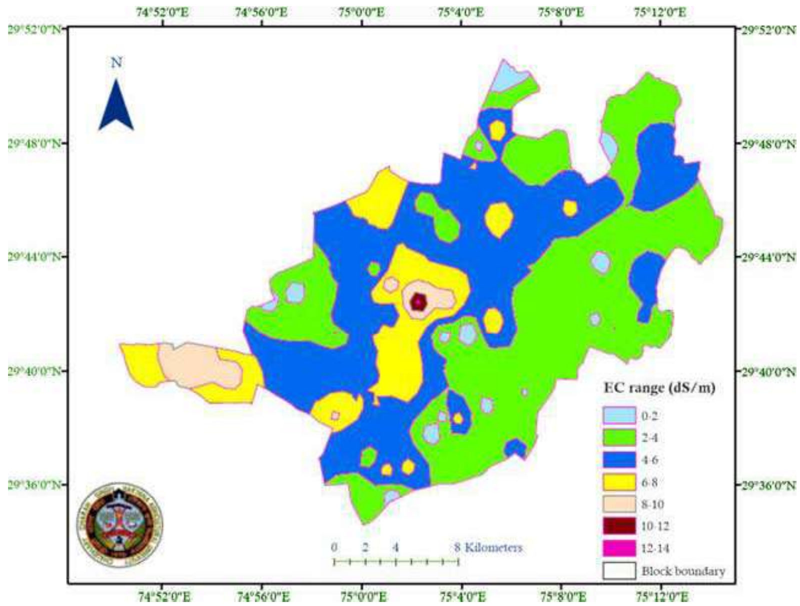
Results and Discussion

Chemical analysis of 76 groundwater samples of Baragudha block showed lot of variation in terms of chemical composition. The range and mean of their major chemical components and parameters,*i.e.*,CO_3^{2-}, HCO_3^- , Cl^- , SO_4^{2-}, Ca^{2+}, Mg^{2+},Na^+, K^+, EC, pH, RSC and SAR, were worked out and have been presented in Table 1. Chloride and sodium were the major anion and cation in different groundwater samples, respectively. The electrical conductivity reflected variation in salt concentration and ultimately in salinity of the groundwater samples.

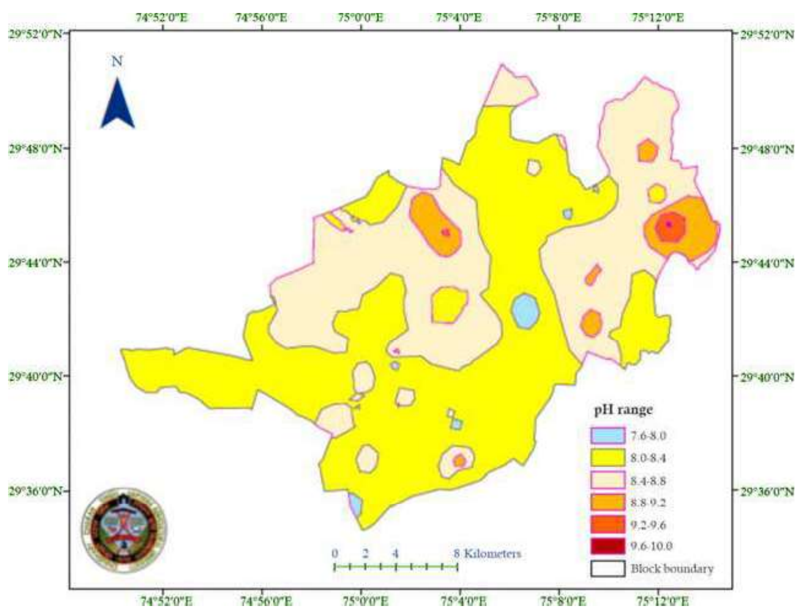
Table 1. Range of different chemical components and parameters in groundwater samples of Baragudha block

Parameter/chemical components	Range	Mean
EC (dS m^{-1})	0.2- 12.1	4.3
pH	7.7- 9.6	8.4
CO_3^{2-} (me l^{-1})	0.0- 3.1	0.1
HCO_3^- (me l^{-1})	0.5 - 13.9	5.5
Cl^- (me l^{-1})	1.4 -97.6	29.4
SO_4^{2-} (me l^{-1})	0.4- 29.1	8.3
Na^+ (me l^{-1})	0.8-75.4	26.2
Ca^{2+} (me l^{-1})	0.3-9.9	3.9
Mg^{2+} (me l^{-1})	0.9-34.2	12.5
K^+ (me l^{-1})	0.1-1.2	0.3
RSC (me l^{-1})	0.0- 4.7	0.1
SAR (m mol l^{-1})$^{1/2}$	1.0 - 19.9	8.9

To study the spatial distribution of EC and pH, the maps were prepared by using ArcGIS (Fig. 2). In the block, EC range was from 0.2 to 12.1 with an average of 4.3 (Table 1). In spatial variability map of EC (Fig. 2a), the samples were grouped into seven classes with a class interval of 2 dS m^{-1}. The lowest EC range (0-2 dS m^{-1}) was observed in small patches in the block. The most dominating range of groundwater EC was 2-4 dSm^{-1}, lying in east to southern parts of the block. Electric conductivity in this part of the block was lower than other parts because it was lying adjoining to Ghaggar River. The next dominating EC range was 4-6 dS m^{-1}, which was covering major portion of central and southern parts of the block, having patches of even higher EC. In study area, the pH ranged from 7.7 to 9.6 with an



(a) EC (dS m^{-1})



(b) pH

Fig. 2. Spatial variability of (a) EC and (b) pH of Baragudha block of Sirsa district

average of 8.4 (Table 1). The pH of the irrigation water and soil solution is very important since they actually determine the success or failure of the crop. The suitable pH range was from 6.5 to 7.5. The lower limit of groundwater in the study area did not have harmful impact on crop because it laid in suitable range but the upper limit was very high as compared to the desired limit. The most dominating range of pH in the block was 8.0-8.4 (Fig. 2b) and the highest range (9.6-10.0) was observed at one spot on eastern side of the block.

In study area, RSC ranged from 0.0 to 4.7 (Table 1) and was absent in all samples having EC greater than 2 dS m^{-1}.Sodium adsorption ratio ranged from 1.0 to 19.9 with an average of 8.9 (m mol l^{-1})$^{1/2}$. The SAR increased with the increase in electrical conductivity. Its average value in the samples having EC>10 was recorded as 16.6 (m

Table 2. Percentsamples and persent area in different categories of groundwater according to AICRP criteria

Category	Symbol	No of samples	Percent samples	Area under different categories (ha)	Percent area
Good	A	16	21.1	2363	4.6
Marginally saline	B1	21	27.6	18344	36.0
Saline	B2	19	25.0	3767	7.4
High SAR saline	B3	19	25.0	26273	51.6
Marginally alkali	C1	0	0.0	0	0.0
Alkali	C2	1	1.3	198	0.4
High alkali	C3	0	0.0	0	0.0

mol $l^{-1})^{1/2}$. With the increase in EC, Na^+ content increased with a higher rate as compared to Ca^{2+} and Mg^{2+} due to which SAR increased with the increase in EC. The presence of sodium (Na^+) in irrigation water might react with soil to make the soil impermeable, sticky in wet condition and form clods and crust on drying, while high sodium leads to the development of alkali soil (Moore, 2001).

According to AICRP criteria, out of seven categories, the maximum 27.6% (Table 2) of samples were found in marginally saline and the minimum 1.3% in alkali category, whereas, no sample was found in marginally alkali and high alkali categories. To study the spatial variability in quality of groundwater, a map was prepared according to AICRP criteria (Fig. 3). On comparing the spatial variable map of EC (Fig. 2a) with water quality (Fig. 3), it was observed that most of the area where EC was more than 4 dS m^{-1} went under high SAR saline in comparison to saline condition, whereas, in both the conditions, EC was more than 4 dS m^{-1} but under saline category, the SAR was measured <10 and under high SAR category, the SAR was recorded >10. As observed earlier, Na^+ increased at a higher rate in comparison to Ca^{2+}+ Mg^{2+} with the increase in electrical conductivity. With this fact, the area increased under high SAR saline, whereas, the area reduced under saline condition with the increase in EC of groundwater. Marginally alkali category was found scattered in areas surrounded by good water category because in both categories, EC is less than 2 dS m^{-1} but the area where RSC ≥2.5 me l^{-1} went under marginally alkali category.

By using different features of GIS, the area of Baragudha block under different categories was calculated and their percentage has been presented in Table 2. It was found that out of seven categories, the maximum area (26273 ha) was estimated under high SAR saline category, which comprised of 51.6% area of the block followed by marginally saline category with estimated area of18344 ha. The minimum area (198 ha) of the block was estimated under alkali category, whereas, no area was estimated under marginally alkali and high alkali since no sample was found under this category. In good category, the percent sample (21.1) was much more as compared to the percent area (4.6), whereas, in marginally saline category, the percent area (36.0) was much more as compared to the percent samples (27.6). In good category, more number of tubewells was installed in comparison to other categories, and simultaneously, more number of samples was collected from these tubewells. Thus, the percentage of samples in good category was higher than the percent area under this category. Therefore, it is important to prepare maps of groundwater quality to have true picture of groundwater quality distribution in an area by using suitable tool such as GIS, which worked on the principle of spatial distribution. Similar observations were also recorded by Ramprakash *et al.* (2013)and Senthilkumar and Jeyavel (2014). Ibrikci*et al.*(2012) were also used GIS to develop the spatial and temporal variability maps for groundwater depth and NO_3 concentration. Todorovic and Steduto (2003) developed the spatial model by applying Geographic Information Systems (GIS) to manage irrigation system for the Apulia region in Southern Italy.

The groundwater samples were categorized according to salinity and sodium hazard as per

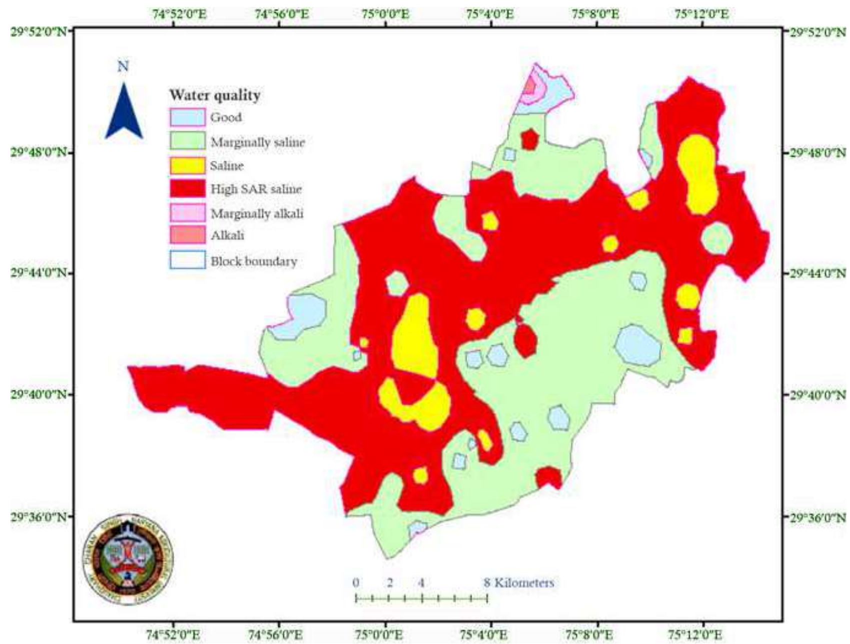


Fig. 3. Spatial variability of groundwater quality of Baragudha block according to AICRP criteria

USSL criteria (Fig. 4). The samples were found highly scattered in C1S1, C2S1, C3S1, C3S2, C4S2, C3S3, C4S3 and C4S4 categories by covering eight classes out of 16 classes. Among the salinity hazard, the maximum percentage (76.3) of samples was found under C4 categories (EC >2250 micro-mhos cm^{-1}). In the sodium hazard, the maximum percentage (32.9) of samples was found under S4 category. In both salinity and sodium hazards, the maximum percentage (32.9) of samples was found under C4S4 category (EC>2250 and SAR>26). To check

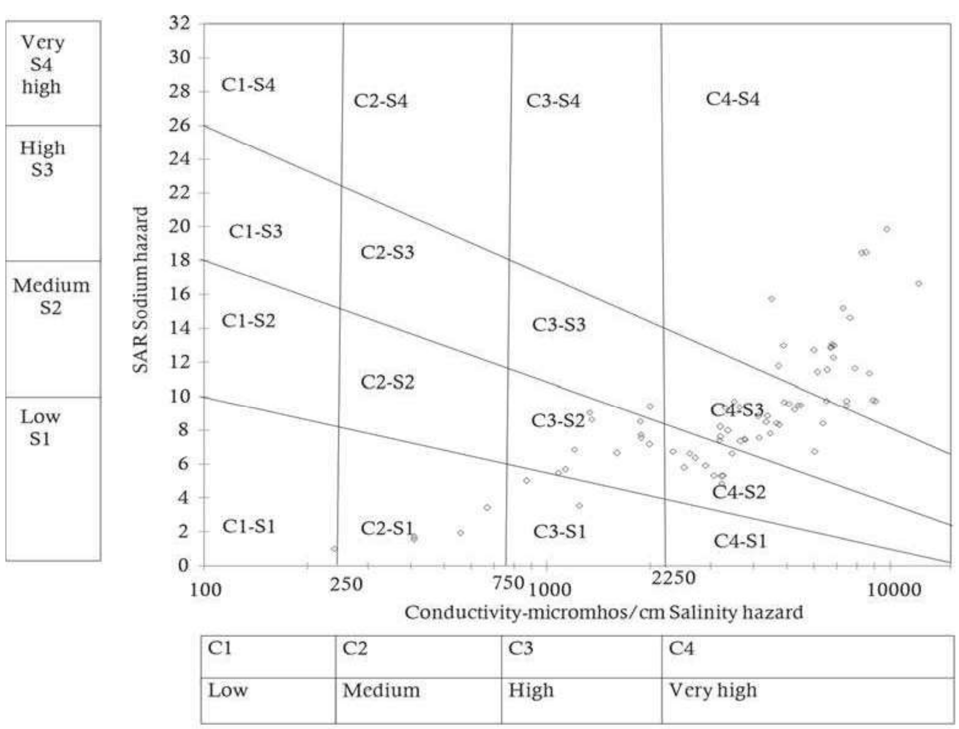


Fig. 4 Groundwater quality of Baragudha block according to USSL criteria

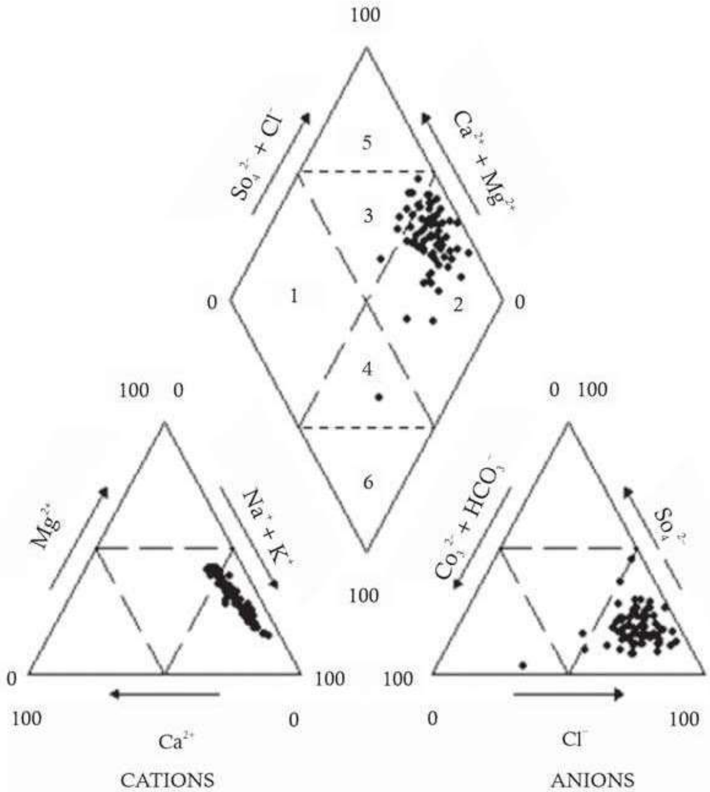


Fig. 5 Groundwater quality of Baragudha block according to Piper criteria

the suitability of the groundwater samples, these categories were further distributed into three groups, and 6.6, 14.5 and 78.9% samples were found in I, II and III groups, respectively. According to Piper diagram, 78.9% samples designated under the group III were unsuitable for irrigation.

Piper tri-linear diagram was prepared by using the percentage of anions and cations presenting in different samples of groundwater (Fig.5) and the diamond shaped field between the two triangles was used to represent the category of water. Under Piper criteria, groundwater quality was confined only in three categories (2, 3 and 4). No sample was found in type 6 category (Na^+-HCO_3^- type, high alkali influenced by ion exchange), meaning that groundwater of the area did not have any problem of high alkali as it was also observed under AICRP criteria. The maximum percentage (88.2) of samples was found under Na^+-Cl^- category. According to Piper criteria, 11.8% samples were found under good quality, which comprised of two categories, *i.e.*, Ca^{2+}-Mg^{2+}-Cl^- and Ca^{2+}-Na^+-HCO_3^-.

Among the three classification criteria, the good category groundwater in Baragudha block was found highest (21.1%) according to AICRP criteria, whereas, according to USSL and Piper criteria, the good quality groundwater was found 6.6 and 11.8%, respectively. In AICRP criteria, the good water is considered when EC is <2 dS m^{-1}, whereas, in USSL criteria, the good water is considered when EC is <0.75 dS m-1 and in Piper criteria, the classification of water is done based on ionic composition of the water. Due to this reason, the percentage of good quality water was extremely high in AICRP criteria in comparison to USSL and Piper criteria.

Conclusions

In present study, the 76 samples of groundwater were collected from farmers' fields of Baragudha block and their quality was evaluated based on various guidelines. According to AICRP criteria, 51.6, 36.0, 7.4, 4.6 and 0.4% area was found under high SAR saline, marginally saline, saline, good and alkali categories, respectively. The area observed under high SAR saline in spatial variability of groundwater quality in the block requires major attentions of the planner to maintain the water table below the root zone and provide irrigation water to grow crops. The patched observed under marginal and good quality water are also under higher risk of lowering of water table due to higher tubewell density and subsequent environmental issues, thus, needs attention.

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