Deciphering groundwater quality for irrigation and domestic purposes – a case study in Suri I and II blocks, Birbhum District, West Bengal, India

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Assessment of the hydrochemical characteristics of water and aquifer hydraulic properties is important for groundwater planning and management in the study area. It is not only the basic need for human existence but also a vital input for all development activities. The present hydro-geochemical study of groundwater samples from the Suri I and II blocks of Birbhum district, West Bengal (23.76°–23.99°N; 87.42°–87.64°E) was carried out to assess their suitability for agricultural, domestic and drinking purposes. For this study, samples were collected from 26 locations during the post-monsoon and pre-monsoon sessions spanning over 2012 and 2013. Groundwater samples were analyzed for their physical and chemical properties using standard laboratory methods.

Physical and chemical parameters of groundwater such as pH, electrical conductivity, total dissolved solids, Na, K, Ca, Mg, Fe, Cl, HCO_3, SO_4 and F were determined. Various water quality indices like SAR, SSP, PI, RSC, MAR and KR have been calculated for each water sample to identify the irrigational suitability standard. According to most of these parameters, the groundwater has been found to be well to moderately suitable for irrigation. In the post-monsoon session exceptionally high RSC values for around 80% samples indicate an alkaline hazard to the soil. The ion balance histogram for post-monsoon indicates undesirable ion balance values according to fresh water standards whereas in pre-monsoon, the samples show good ion balance in water. For determination of the drinking suitability standard of groundwater, three parameters have been considered – total hardness (TH), Piper's trilinear diagram and water quality index study. Groundwater of the present study area has been found to be moderately-hard to hard during both sampling sessions and hence poses no health risk which could arise due to excess consumption of calcium or magnesium. Hydrogeochemical facies in the form of Piper's trilinear diagram plot which helps in identification of the water 'type' which can render a particular taste or odour to water, indicates that groundwater in the study area is majorly of $CaMgHCO_3$ and $NaHCO_3$ type (fresh type) during both post-monsoon and pre-monsoon sessions barring a couple of samples which are of $CaMgSO_4$/$CaMgClSO_4$ type in pre-monsoon. Water quality index study reveals that close to 90% of the water samples are suitable for drinking during post-monsoon compared to pre-monsoon during which period only 60% of water samples fall under the suitable drinking water category.

Gibbs' diagrams, which help in identification of natural processes controlling hydrogeochemistry of groundwater indicates that for both post-monsoon and pre-monsoon sessions, the overall hydrogeochemistry of the study area is dominated by rock–water interaction processes.

Keywords. Groundwater quality; irrigation and domestic suitability; ionic balance, Suri I and II blocks; Birbhum District.

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1. Introduction

The competition for water resources has gained importance in recent years, not only in India but also in many places of the world. Groundwater is the purest form of water sourced from natural resources and meets the overall demand of rural and semi-urban people. But the development of human societies and industry result in bioenvironmental problems; pollution puts the water, air and soil resources at risk (Milovanovic 2007). Groundwater has become the major source of water supply for domestic, industrial and agricultural sectors of many countries. In recent years, many cities of developing countries are experiencing rapid demographic growth due to rural exodus. Urbanization and the unregulated growth of the population have altered the local topography and drainage system which directly affect both quality and quantity of the groundwater (Vasanthavigar *et al.* 2010). Inadequate environmental protection measures in coal mining, waste dumps, thermal power plants, steel plants, sugar factories, fertilizer production units and cement plants have resulted in significant water pollution (Chatterjee *et al.* 2010). Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrological and human factors frequently cause periodic changes in groundwater quality (Sreedevi 2004; Milovanovic 2007; Aghazadeh and Mogaddam 2010). Many research publications have come out on evaluation for domestic and industrial activities and related groundwater quality monitoring (Rivers *et al.* 1996; Al-Futaisi *et al.* 2007; Jalali 2007; Pritchard *et al.* 2008; Srinivasamoorthy *et al.* 2008; Vasanthavigar *et al.* 2010; Nag and Ghosh 2013; Nag 2014).

Pollution of groundwater affects water quality, threatens human health and economic development owing to the suitability of water for various purposes (Subramani *et al.* 2005; Schiavo *et al.* 2006). In developing world, 80% of diseases are directly related to poor drinking water and unsanitary conditions (UNESCO 2007). Geochemical studies of groundwater provide a better understanding of possible changes in its quality as development progresses. Therefore, determination of groundwater quality is very important to observe the suitability of water for a particular use.

The aim of the study is to investigate the groundwater quality in the region since groundwater resources are widely used for drinking, agricultural and industrial purposes. It is important to ascertain the groundwater quality of the area for domestic and other uses. The objective of this paper is to use hydrochemical methods to assess the suitability of groundwater in the area for irrigation as well as domestic purposes.

2. Study area

The present study has been carried out in Suri (comprising of two blocks – Suri I and Suri II), the district headquarter of Birbhum district, West Bengal, India. The blocks are located between latitudes 23.76°–23.99°N and longitudes 87.42°–87.64°E (figure 1). The climate of the area is generally dry. Summer temperatures soar to a maximum of 40°C or above whereas in winter, temperatures dip to around 10°C. Majority of the rainfall is limited to the monsoon season from June–October and hovers around an average of 1100 mm. The area is characterized by rural setting and main occupation of the people is agriculture. Water in the area is generally drawn from bore wells and dug wells, and the use of submersible pumps has seen a rise over the last few years for agricultural purposes.

The study area largely comprises of alternating layers of sand and clay, which are soft sediments and part of the Ganga–Kosi Formation. Granite gneiss which are hard and foliated type rocks belonging to the Chotanagpur Gneissic complex, constitute the north-western part of the study area. Hard clays dominate specific parts of the block in the eastern parts of Suri, whereas lateritic soils are scattered mainly in the upper parts of Suri.

3. Methodology and data used

Dry, clean and sterilized plastic bottles were used to get fresh aquifer water for sampling. Before collection, the bottles were well rinsed. For the present study, water samples from 26 borewells have been collected in December 2012 during the post-monsoon period and April 2013 during pre-monsoon period (figure 1). The collected samples were then stored in 500 ml preconditioned high-density polythene bottles and were carefully sealed with proper labelling. For all samples, temperature, pH and electrical conductivity (EC) were determined in the field with standard field equipment – Waterproof Tester Combo by Hanna Instruments. Samples were analyzed in the laboratory of Environmental Science Department of University of Burdwan, West Bengal. For quantitative chemical analysis of major ions in groundwater, standard analytical chemistry procedures, comprising titrimetry and spectrophotometry, were employed following American Public Health Association guidelines (APHA 1995).

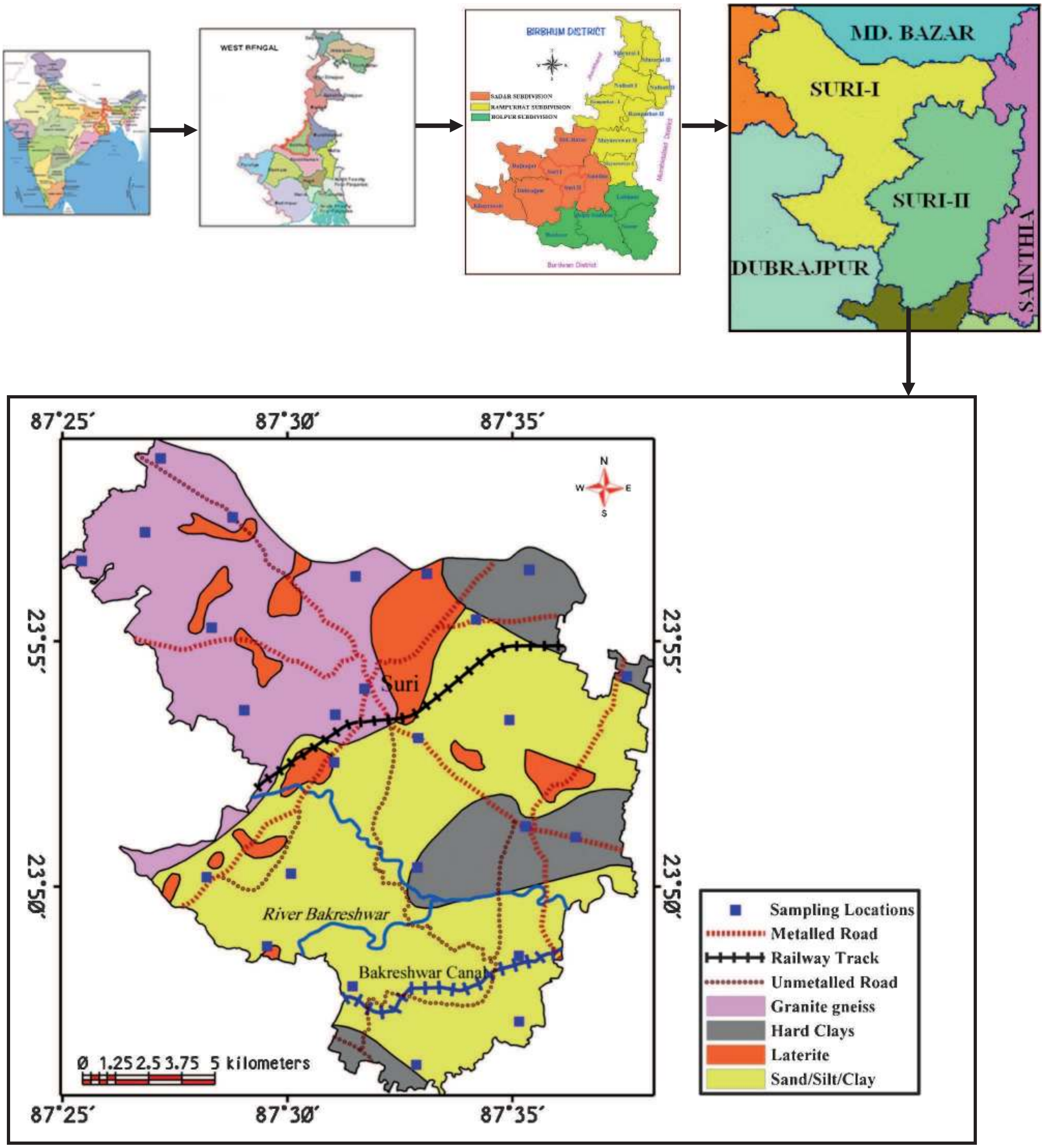


Figure 1. Map of the study area presenting the sampling location points and geology of the area.

To evaluate the suitability of the water quality for agricultural purposes, the parameters such as SAR and SSP (soluble Na%), RSC, MAR, PI and KR were calculated using standard formulae mentioned in the text. The SAR values were plotted over the US salinity diagram against the EC values (log scale axis); SSP values were plotted over the Wilcox diagram against the EC values; the PI values were plotted over Doneen's chart against total ionic concentration; the spread of the RSC and MAR values have been represented in the form of spatial distribution maps for both sessions.

Besides total hardness results, the suitability of groundwater for drinking purposes has been determined by the use of hydrogeochemical facies (Piper trilinear diagram) (Piper 1944) and water quality index study (Tiwari and Mishra 1985). GIS software packages TNT Mips 2012 and Golden Software Surfer 7 have been used to map and analyse the data for the evaluation of groundwater data.

4. Results and discussion

4.1 *Physico-chemical parameters of groundwater*

The pH values of the groundwater varies from 7.00–8.40 (in post-monsoon) with an average of 7.50, and 6.4–8.4 (in pre-monsoon) with an average of 7.1, which indicates that except for few samples, all other groundwater samples are alkaline in nature (figure 2a, b). The average concentration of Total Dissolved Solids (TDS) ranged from 244.3 (post-monsoon) to 249.0 (pre-monsoon) mg/L in the study area (figure 3a, b). Normally TDS in water may originate from natural sources and sewage discharges. The electrical conductivity (EC) in the study area varies from 90.00 to 300.00 (in post-monsoon) and 150.00 to 1200.00 (in pre-monsoon) with an average of 212.7 (post-monsoon) and 556.2 (pre-monsoon) µS/cm at 25°C (figure 4a, b). The total hardness (TH) of water is a measure of mainly calcium carbonate and magnesium carbonate dissolved in groundwater. The general acceptance level of hardness is 300 mg/L, although WHO has set an allowable limit of 600 mg/L. The total hardness in the study area ranges between 55 and 365 mg/L in post-monsoon while in pre-monsoon it ranges between 48 and 384 mg/L (figure 5a, b).

Calcium concentration ranged from 12.6 to 109.2 mg/L in post-monsoon and 6.7 to 95.8 mg/L in pre-monsoon periods (figure 6a, b). Acceptable limit of calcium in drinking water is 75 mg/L (200 mg/L in case of no other alternative source) (BIS 2012). Calcium ion is necessary for proper mineralization of bones and bone strength. Deficiency in intake of calcium leads to eventual demineralization of bones for complementing the inadequate amounts of calcium in the body.

Acceptable limit of magnesium in drinking water is 30 mg/L (100 mg/L in case of no other alternative source) (BIS 2012). Magnesium helps in maintaining normal nerve and muscle function, a healthy immune system and helps bones remain strong. It also helps in regulation of blood glucose levels and aid in the production of energy and protein. Deficiency of magnesium in the human diet might lead to anxiety, fatigue or anorexia. The magnesium concentration ranges between 3.2 and 42.5 mg/L in post-monsoon and 7.6–35.3 mg/L in pre-monsoon (figure 7a, b).

Iron is an essential element in the human body and is required physiologically on various aspects (Moore 1973). Although iron has little concern as a health hazard, it is still considered as a nuisance in excessive quantities (Dart 1974). It causes staining of clothes and utensils. It is also not suitable for processing of food, beverages, dyeing, bleaching, etc. The concentration limits of iron in drinking water ranges between 0.3 (maximum acceptable) and 1.0 mg/L (maximum allowable) (Sharma and Chawla 1977). Iron concentrations of Suri I and II blocks range between 0.0–1.8 mg/L in post-monsoon and 0.0–6.1 mg/L in pre-monsoon (figure 9a, b). At Bhagabanbati Primary School, the iron concentration is above the desirable limit (0.30 mg/L) during both post- and pre-monsoon. High iron concentration affects the taste of water, has adverse effects on domestic uses and promotes growth of iron bacteria. Measures should be taken before consumption by installation of iron removing plants.

Sodium concentration in water varies from 7.00–58.3 mg/L with an average of 26.04 mg/L in post-monsoon and 8.0–69.0 mg/L with an average of 30.5 mg/L in pre-monsoon periods (figure 8a, b). Sodium regulates blood pressure levels in the human body and increased levels of sodium in blood leads to rise in blood pressure. Potassium controls body balance and maintains normal growth of the human body. Deficiency of potassium might lead to weakness of muscles and rise in blood pressure. No standard limits have been provided by the Bureau of Indian Standards for level of sodium and potassium in drinking water (figure 9). Bicarbonate ion varies from 48.80 to 1073.60 mg/L and 48.8 to 292.8 mg/L in post- and pre-monsoon, respectively (figure 10a, b). No standard limits have been provided by the Bureau of Indian Standards for level of carbonate and bicarbonate in drinking water.

Acceptable limit of chloride in drinking water is 250 mg/L (1000 mg/L in case of no other alternative source) (BIS 2012). Chloride concentration in groundwater samples in the study area ranged from 15.0 to 124.96 mg/L and 15.0 to 274.9 mg/L in post- and pre-monsoon, respectively (figure 11a, b). Too much of chloride leads to bad taste in water and also chloride ion combines with Na (that is being derived from the weathering of granitic terrains) and forms NaCl, whose excess presence in water makes it saline and unfit for both irrigational and drinking purposes. Increase in chloride levels in our body might lead to increase in blood pressure levels and rise in body fluids. As exhibited by contours, chloride in water is higher in pre-monsoon in comparison with post-monsoon.

The sulfate ion causes no particular harmful effects on soils or plants; however, it contributes in increasing the salinity in the soil solution. Sulfate ion varied from 0.43 to 48.76 mg/L during post-monsoon and 0.1 to 56.7 mg/L in pre-monsoon periods (figure 12a, b). Acceptable limit of sulfate in drinking water is 200 mg/L (400 mg/L in case of no other alternative source) (BIS 2012). Excess sulfate consumption through water might lead to occurrence of diarrhoea in humans.

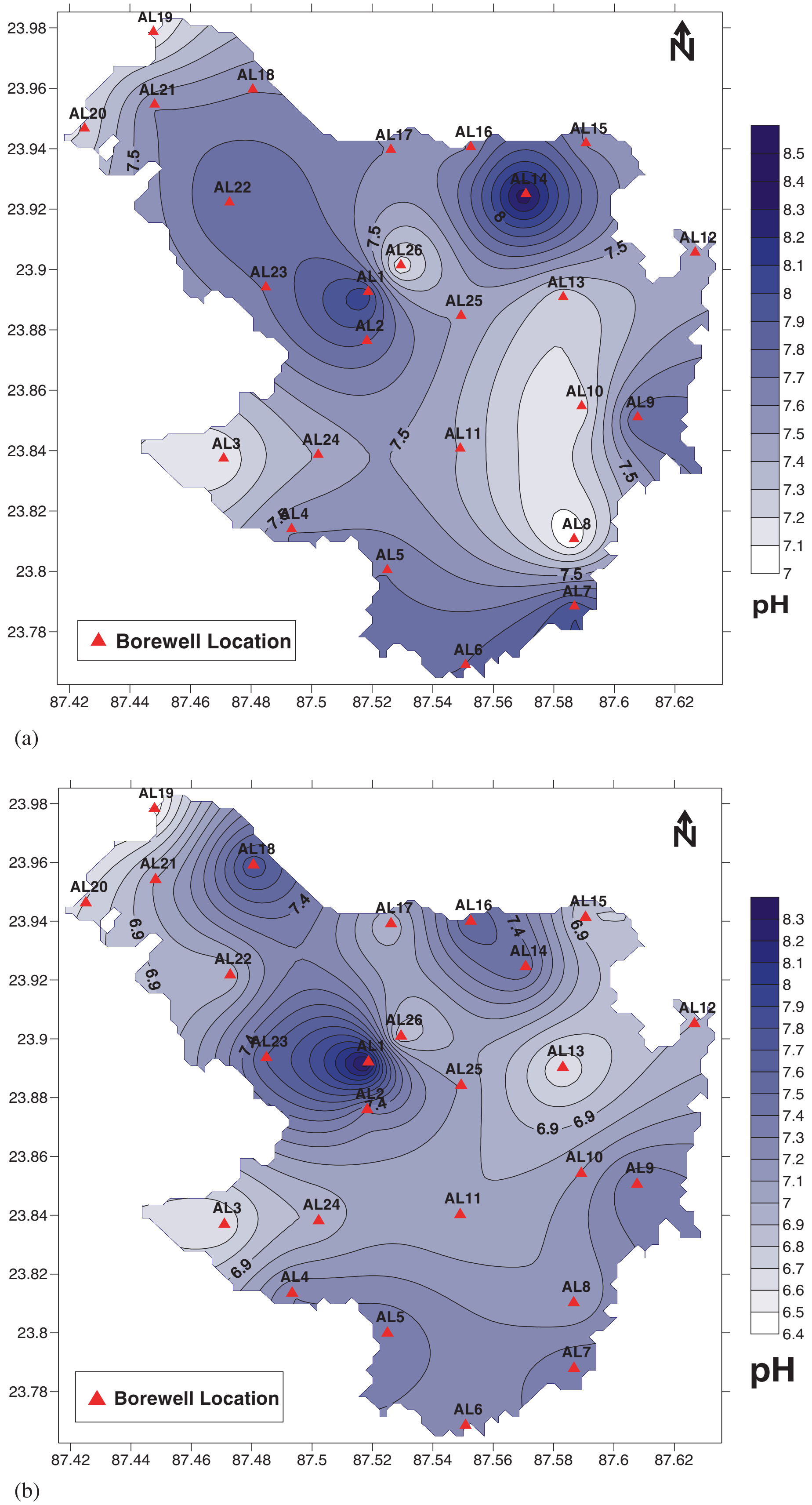


Figure 2. Spatial distribution of pH (**a**) post-monsoon and (**b**) pre-monsoon.

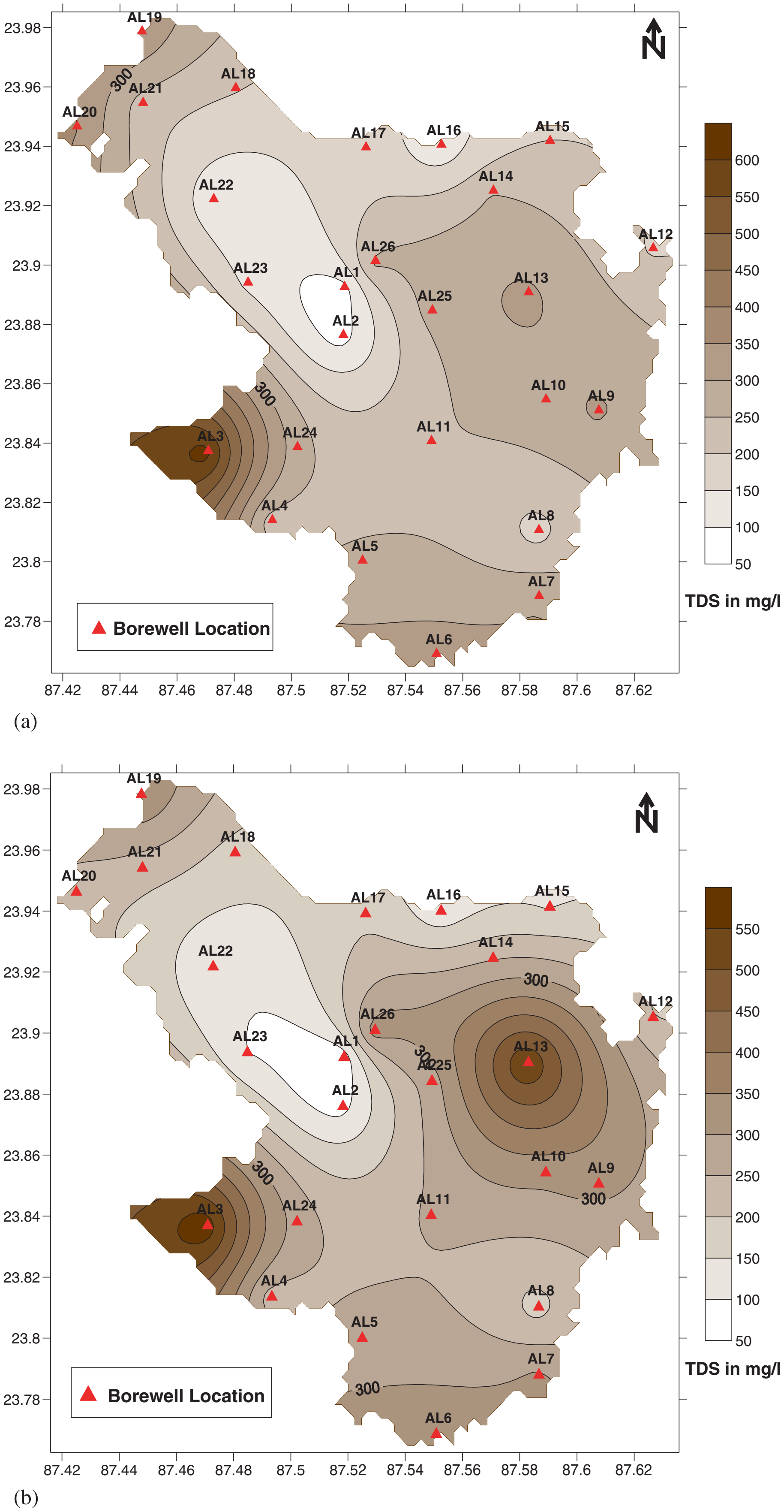


Figure 3. Spatial distribution of TDS (**a**) post-monsoon and (**b**) pre-monsoon.

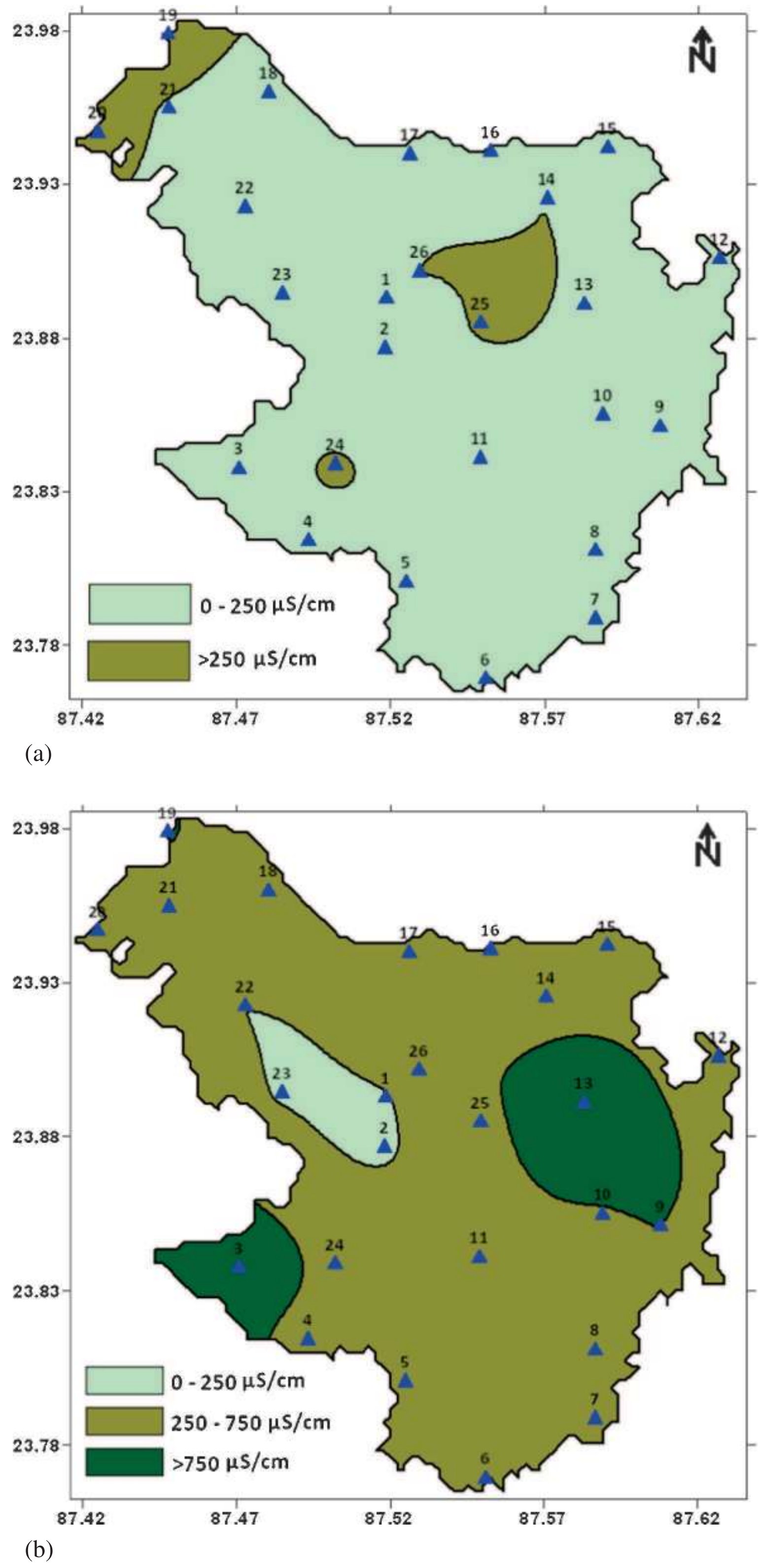
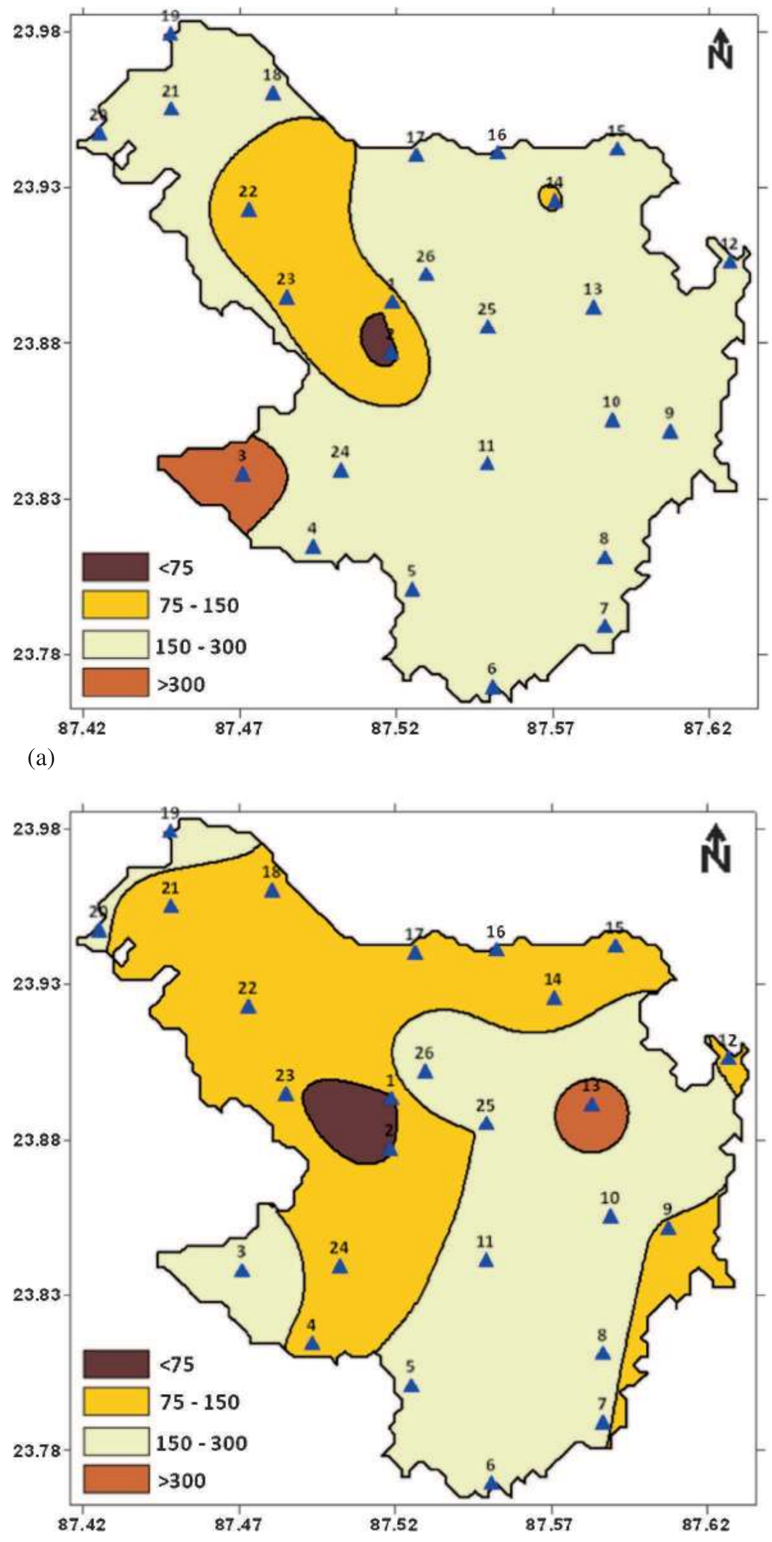


Figure 4. Spatial distribution of EC (**a**) post-monsoon and (**b**) pre-monsoon.

The physico-chemical parameters determined along with range of analysed parameters as well as their mean and standard deviation values are presented in table 1.

4.2 *Ionic balance*

Ionic balance of a water sample is calculated to identify the dominant ionic type, i.e., cationic or


(a)

(b)

Figure 5. Spatial distribution of TH (**a**) post-monsoon and (**b**) pre-monsoon.

anionic in the water sample. For calculation of ion balance in water, concentration of each cation and anion in groundwater sample is calculated in meq/L. The standard formula for calculating ion balance in water is as follows (Huh *et al.* 1998):

$$\text{Ion balance} = \left[100 * \left(\sum \text{cation} - \sum \text{anion}\right)\right] \Big/ \left[\sum \text{cation} + \sum \text{anion}\right].$$

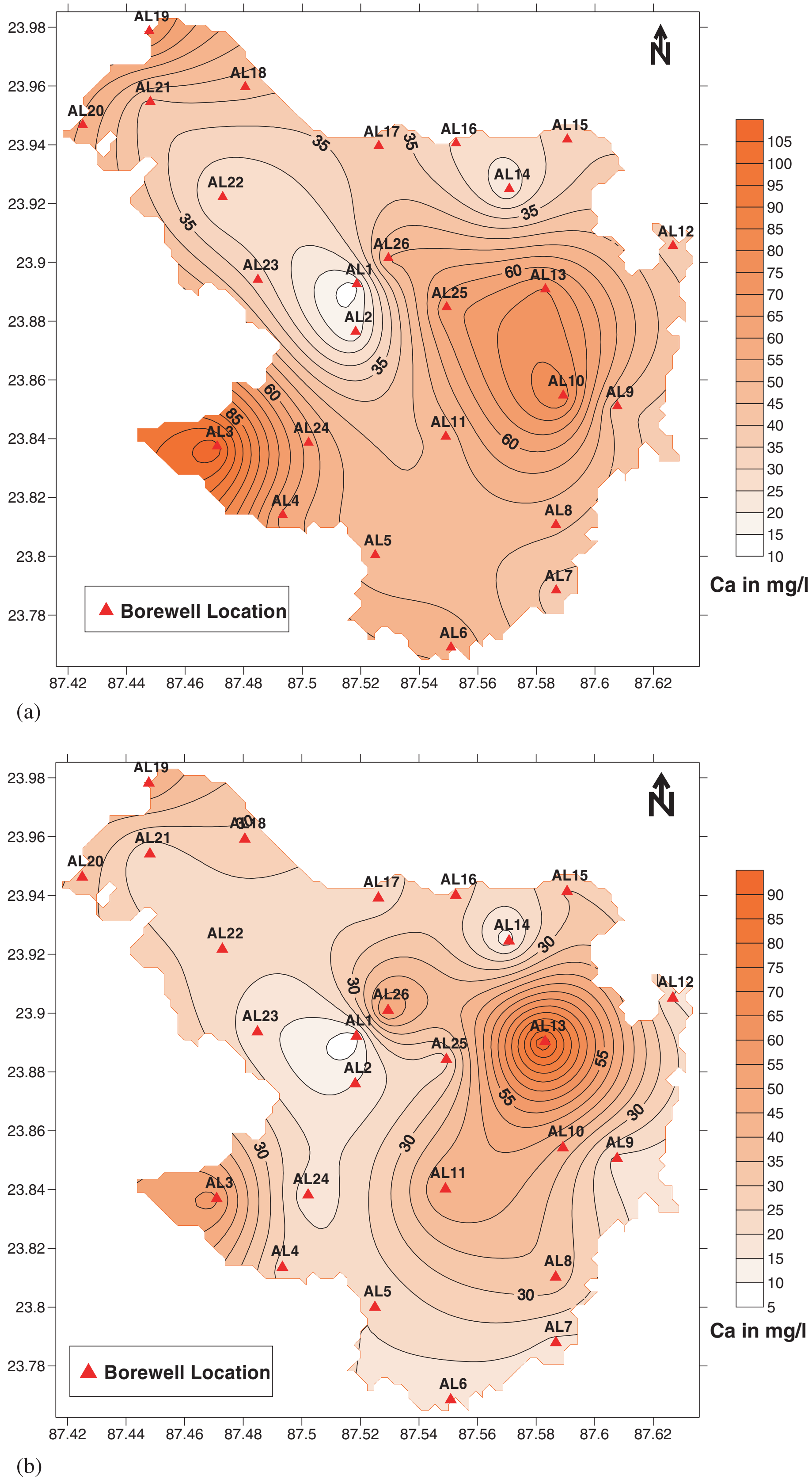


Figure 6. Spatial distribution of Ca^{2+} (**a**) post-monsoon and (**b**) pre-monsoon.

Ion balance of groundwater represents the fractional difference between the total cations and total anions and also indicates quality of water keeping in mind the total dissolved solids of a water sample. According to standard rules, the ion balance of a fresh water sample with low TDS is considered

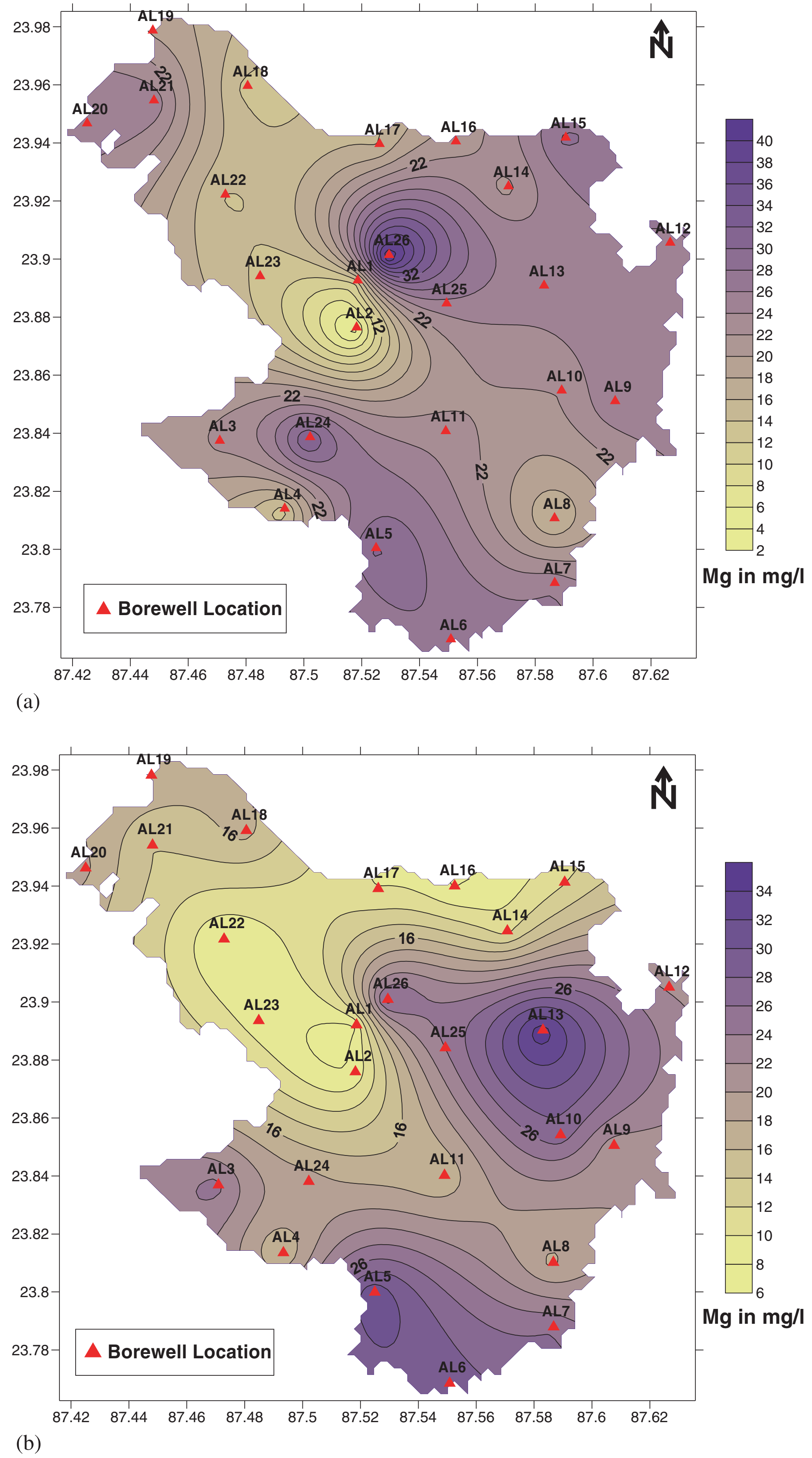
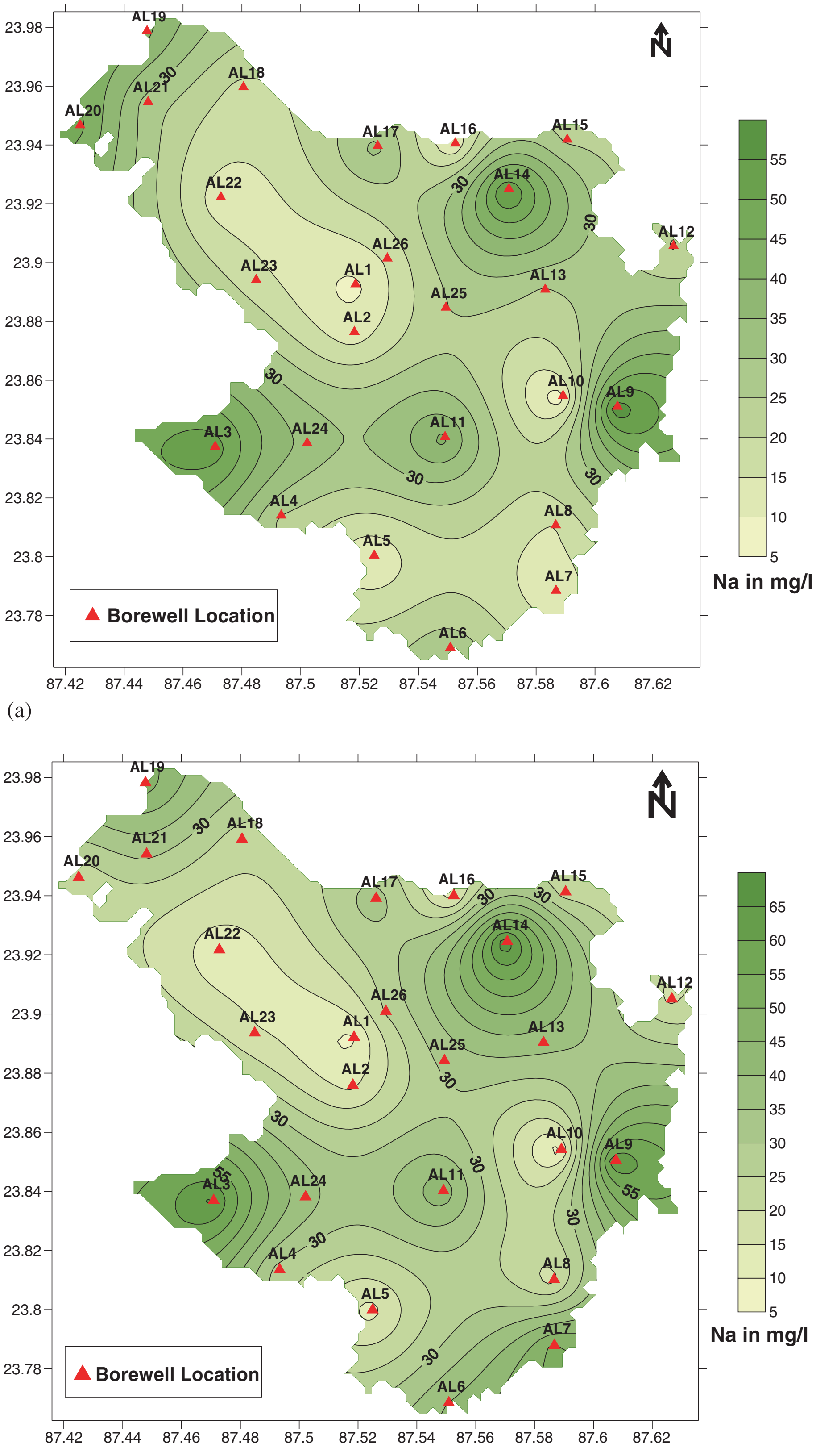


Figure 7. Spatial distribution of Mg^{2+} (**a**) post-monsoon and (**b**) pre-monsoon.



(a)

(b)

Figure 8. Spatial distribution of Na^+ (**a**) post-monsoon and (**b**) pre-monsoon.

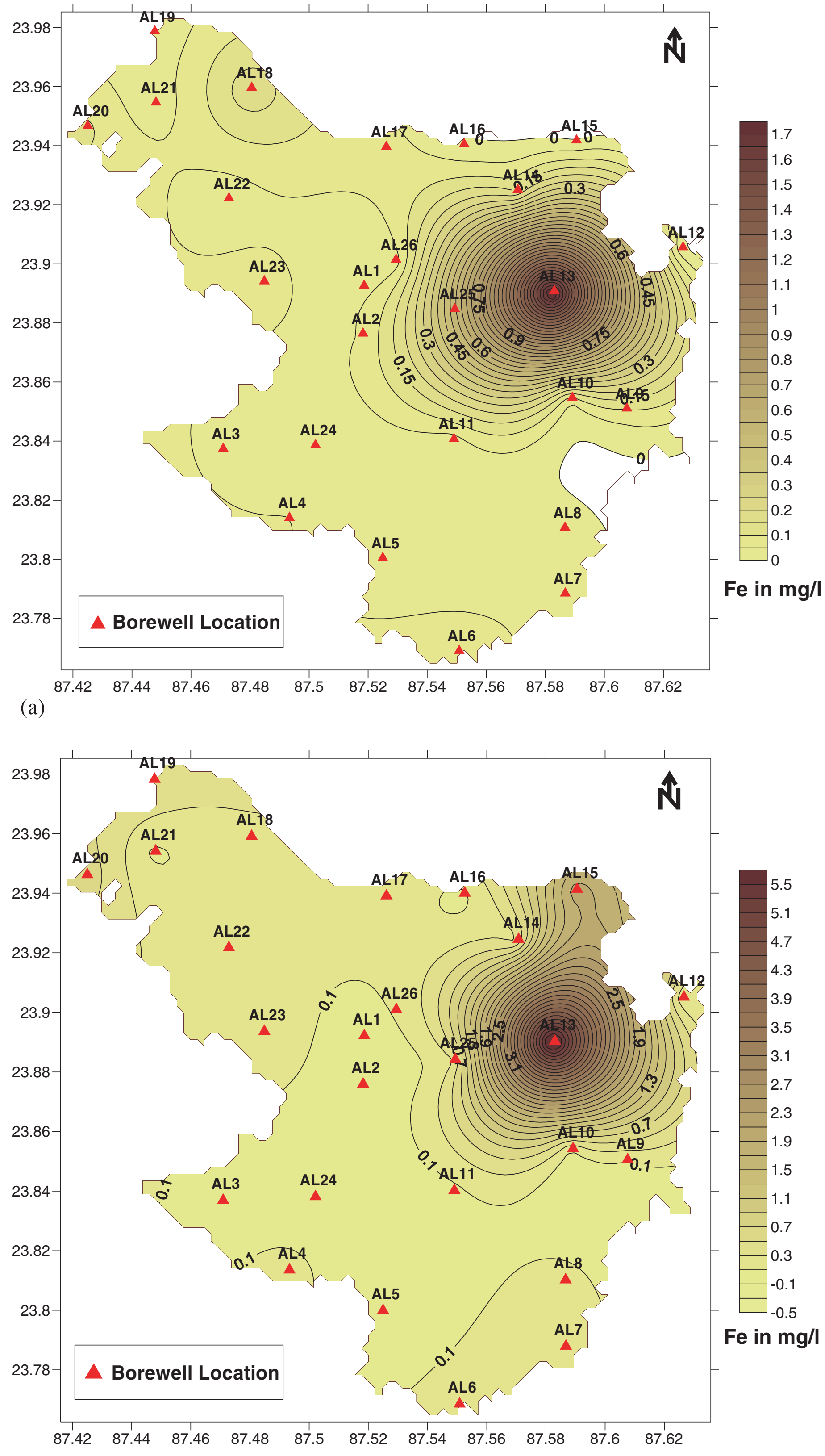


Figure 9. Spatial distribution of Fe^{2+} (**a**) post-monsoon and (**b**) pre-monsoon.

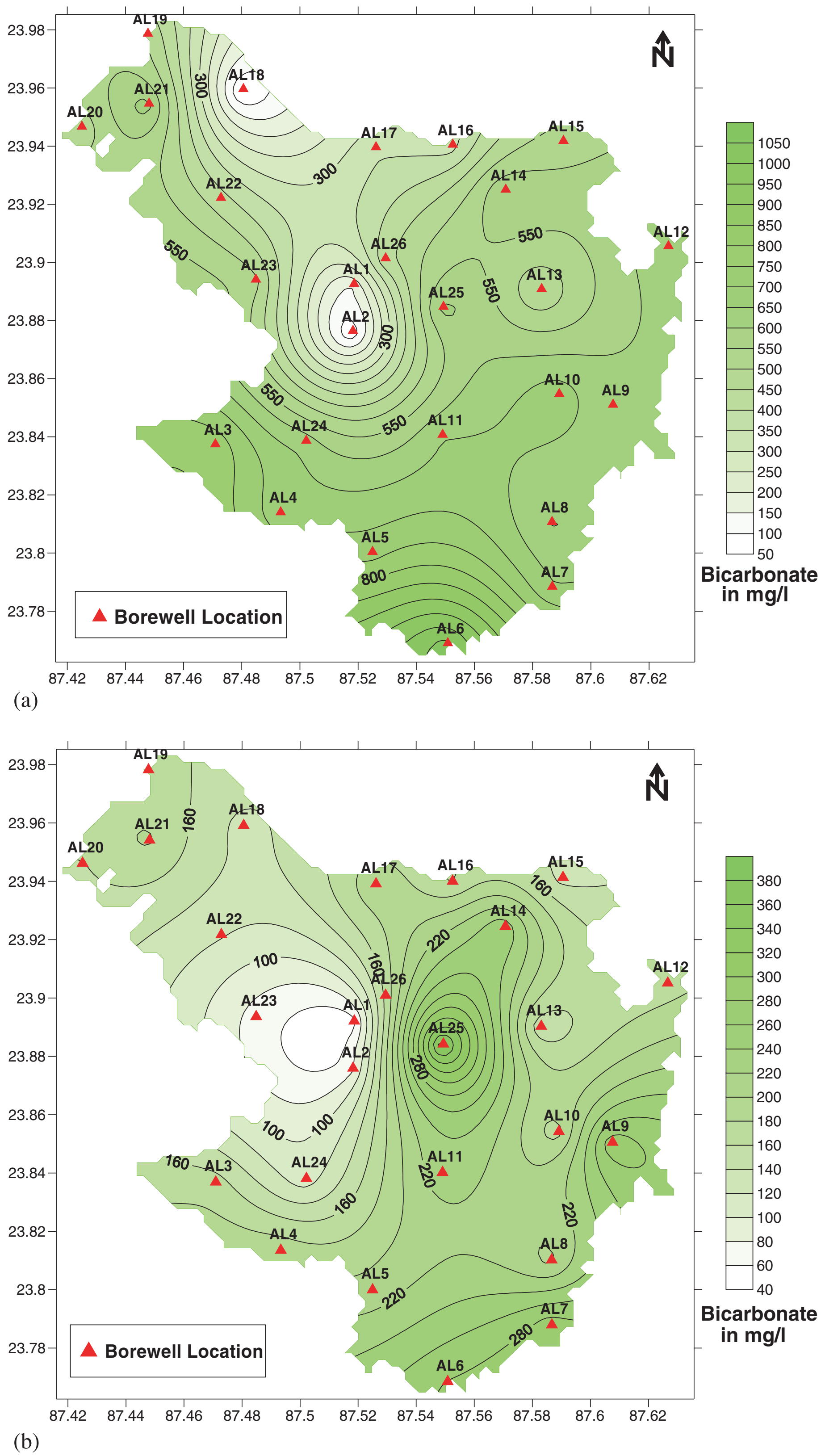


Figure 10. Spatial distribution of HCO_3^- (**a**) post-monsoon and (**b**) pre-monsoon.

to be good if the value is between –10% and +10%. In the post-monsoon session, ion balance of all water samples barring one, from Singur area, are all negative and less than −10%, the lowest values being even lesser than –50%. In pre-monsoon, the results are completely opposite. Majority of the water samples (88.5%) have ion balance values between –10% and +10%. Only three groundwater

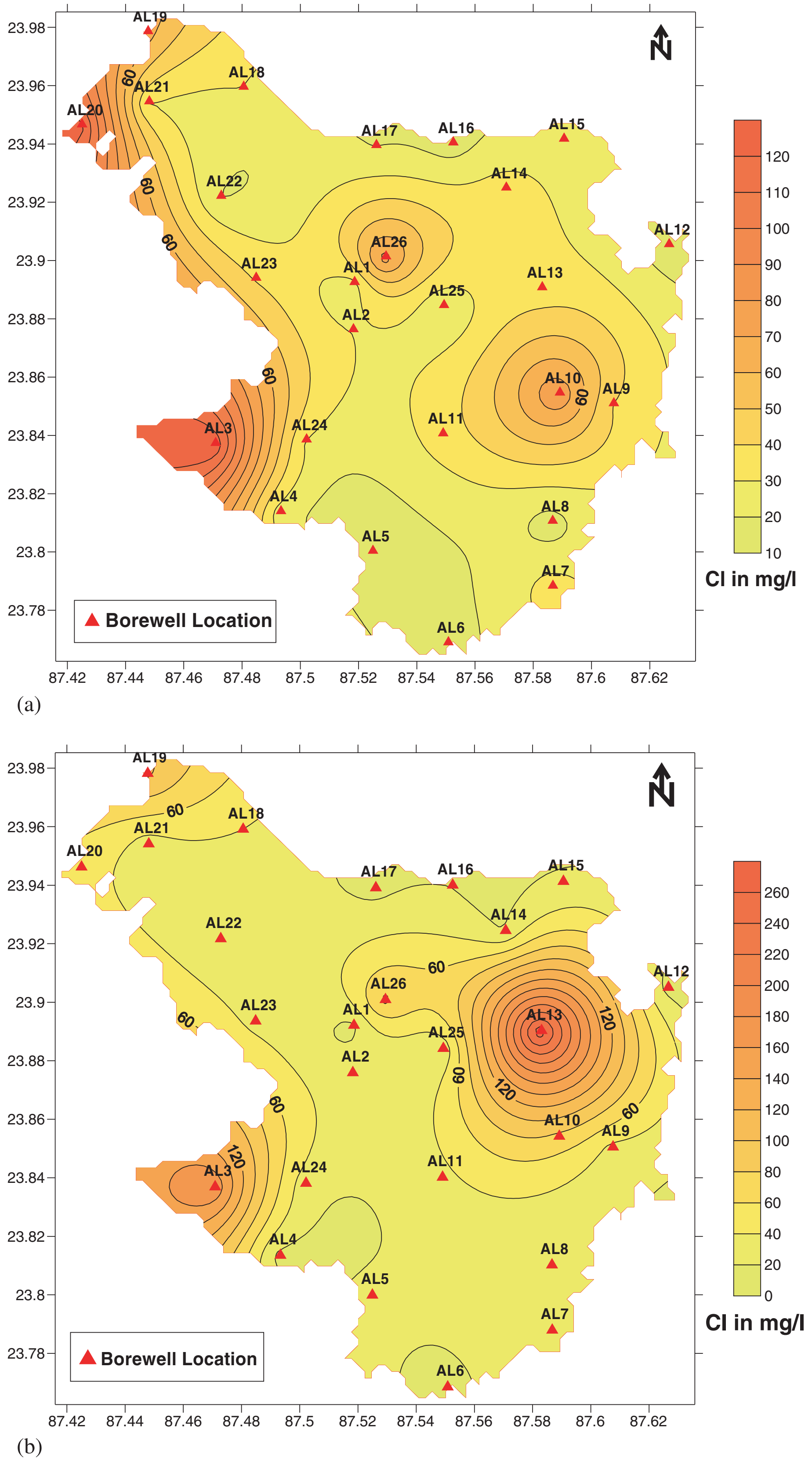


Figure 11. Spatial distribution of Cl^- (**a**) post-monsoon and (**b**) pre-monsoon.

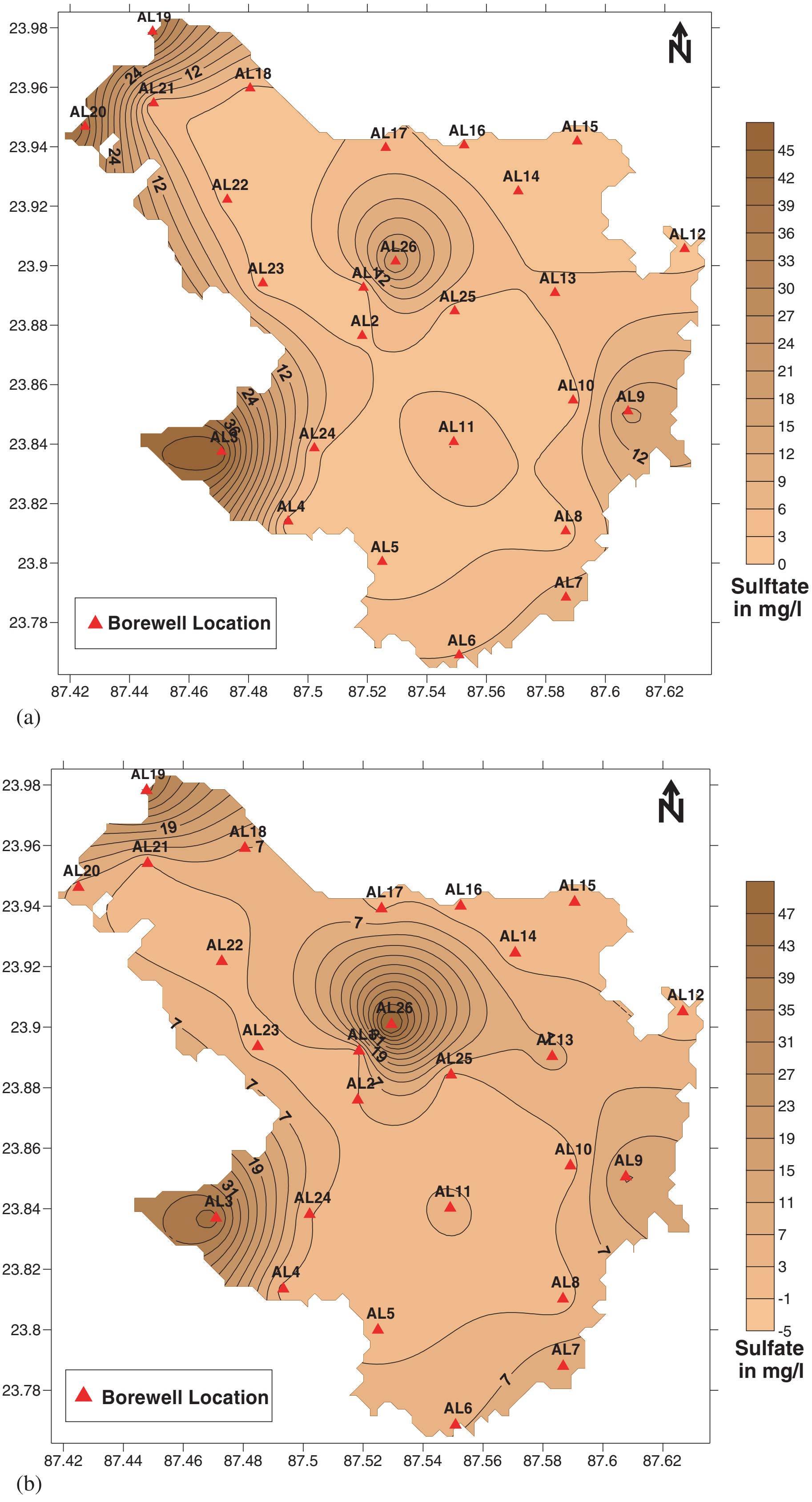


Figure 12. Spatial distribution of SO_4^{2-} (**a**) post-monsoon and (**b**) pre-monsoon.

samples (Bhagabanbati, Gobindopur and Agar) have ion balance values falling outside the desirable range.

4.3 *Water quality for irrigation purposes*

To assess the overall irrigational water quality of the samples collected, six computed water quality parameters have been considered; namely – Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Permeability Index (PI), Residual Sodium Carbonate (RSC), Magnesium Adsorption Ratio and Kelly's Ratio (Ishaku *et al.* 2011; Obiefuna and Sheriff 2011). Table 2 represents evaluated values of these parameters for all 26 sampling locations. Table 3 shows classification of samples according to standards specified for different water quality parameters.

4.4 *Sodium adsorption ratio (SAR)*

Sodium adsorption ratio is a measure of the sodicity of the soil determined through quantitative chemical analysis of water in contact with it. An excess of HCO_3^- and CO_3^{2-} ions in water react with Na^+ in soil, resulting in a sodium hazard (Wadie and Abduljalil 2010). SAR values are plotted against EC values (in μS/cm) on the US salinity diagram to categorize analyzed water samples according to their irrigational suitability quotient. The sodium adsorption ratio (SAR) was calculated using the following equation given by Richards (1954):

$$\mathrm{SAR} = \left[\mathrm{Na}^+\right] / \left\{\left(\left[\mathrm{Ca}^{2+}\right] + \left[\mathrm{Mg}^{2+}\right]\right)/2\right\}^{1/2} \quad (1)$$

where concentrations of all ions have been expressed in meq/L.

In the present study, the SAR values range from 0.18 to 2.07 in post-monsoon and 0.24–3.24 during pre-monsoon. Based on the SAR values all samples have low sodium hazard and on plotting over the US salinity diagram Lab () (figure 13), the water samples fall in the C1-S1 and C2-S1 classes (post-monsoon) and C1-S1, C2-S1 and C3-S1 classes (pre-monsoon), and hence can be considered moderately suitable for irrigation.

4.5 *Soluble sodium percentage (SSP)*

Soluble sodium percentage (SSP) is used to evaluate sodium hazard. High sodium ion concentration in soil can take a toll on internal drainage patterns in soil as release of calcium and magnesium ions are facilitated due to absorption of sodium by clay particles. Water with an SSP greater than 60% may result in sodium accumulations that will cause a breakdown in the soil's physical properties (Khodapanah *et al.* 2009). Soluble sodium percentage (SSP) (Raghunath 1987) was calculated using the following equation:

$$\mathrm{SSP} = \frac{\left[\left(\mathrm{Na}^+ + \mathrm{K}^+\right) * 100\right]}{\left[\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+\right]} \quad (2)$$

where concentrations of all ions have been expressed in meq/L.

The SSP values range from 5.62 to 47.31 in post-monsoon and 7.84–66.3 during pre-monsoon. The SSP values and the EC values have been plotted on the Wilcox diagram (Wilcox 1955) (figure 14) and are found to fall under the 'Very Good to Good' and 'Good to Permissible' categories during post- and pre-monsoon, respectively.

4.6 *Permeability index (PI)*

A modified criterion has been evolved based on the solubility of salts and the reaction occurring in the soil solution from cation exchange for estimating the quality of agricultural waters (Gupta and Gupta 1987). The soil permeability of an area eventually decreases due to continuous irrigational practices and is defined based on quantity of bicarbonate, sodium, calcium and magnesium in water. Doneen (1964) had empirically developed a term called, 'Permeability Index' after conducting a series of experiments for which he had used a large number of irrigation waters varying in ionic relationships and concentration. The permeability index is calculated by the following formula:

$$\mathrm{PI} = \frac{\left(\mathrm{Na}^+ + \mathrm{HCO}_3^-\right) \times 100}{\left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+\right)} \quad (3)$$

where concentrations of all ions have been expressed in meq/L.

Permeability index varies from 23.07 (at Khatangadi) to 90.06 (at Aamgachi) in post-monsoon and from 18.20 (at Bhagabanbati) to 66.09 (at Abdarpur) in pre-monsoon. PI is classified under Class I (>75% permeability), Class II (25–75% permeability) and Class III (<75% permeability) orders. Class I and Class II water are categorized as good for irrigation and Class III water is unsuitable with 25% of maximum permeability. Doneen (1964) had prepared a chart to classify water based on its permeability index (defined by equation 3) value and according to Doneen's chart (figure 15), all water samples of the study area fall under Class I and II during both post- and pre-monsoon; which indicates overall the water is moderately good for irrigation.

4.7 *Residual sodium carbonate (RSC)*

Residual sodium carbonate (RSC) index of irrigation/soil water is used to indicate the alkalinity

Table 1. *Physico-chemical analysis results for both post- and pre-monsoon sessions.*

Location	pH		TDS		EC		TA		TH		Ca^{2+}		Mg^{2+}		Na^{+}		K^{+}		Fe^{2+}		CO_3^{2-}		HCO_3^{-}		Cl^{-}		SO_4^{2-}	
no.	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
AL1	8.1	8.4	74.0	150.0	90.0	55.0	120.0	40.0	80.0	48.0	12.6	6.7	11.8	7.6	8.7	9.0	1.0	0.2	0.03	0.01	0.0	0.0	146.4	48.8	24.9	15.0	0.7	0.5
AL2	7.8	7.3	82.0	180.0	110.0	83.0	50.0	60.0	55.0	72.0	16.8	15.1	3.2	8.3	123	14.0	1.0	0.28	0.05	0.04	0.0	0.0	61.0	73.2	29.9	30.0	2.8	2.8
AL3	7.1	6.6	622.0	1200.0	190.0	590.0	650.0	140.0	365.0	244.0	109.2	57.1	22.5	24.7	53.3	66.0	3.0	0.76	0.0	0.01	0.0	0.0	793.0	170.8	129.9	179.9	48.8	45.7
AL4	7.6	7.3	225.0	510.0	191.0	227.0	670.0	180.0	200.0	124.0	58.8	23.5	12.9	15.9	24.7	28.0	1.3	0.32	0.05	0.16	72.0	12.0	671.0	195.2	24.9	15.0	1.8	1.9
AL5	7.7	7.4	266.0	600.0	200.0	277.0	600.0	190.0	240.0	180.0	46.2	20.2	30.4	31.6	10.0	13.0	1.7	0.32	0.03	0.00	0.0	12.0	732.0	207.4	15.0	25.0	1.2	1.4
AL6	7.8	7.2	325.0	720.0	210.0	333.0	880.0	230.0	250.0	160.0	54.6	16.8	27.7	28.8	29.3	40.0	4.0	1.08	0.07	0.15	0.0	0.0	1073.6	280.6	15.0	15.0	6.1	6.6
AL7	8.0	7.4	294.0	690.0	220.0	309.0	620.0	240.0	200.0	152.0	37.8	18.5	25.7	25.8	11.7	51.0	4.7	1.28	0.04	0.20	48.0	0.0	658.8	292.8	34.9	40.0	7.6	10.4
AL8	7.0	7.1	182.0	420.0	190.0	182.0	550.0	180.0	180.0	156.0	46.2	33.6	15.7	17.6	14.7	18.0	0.7	0.24	0.03	0.20	36.0	12.0	597.8	195.2	15.0	20.0	1.7	1.2
AL9	7.8	7.4	306.0	750.0	240.0	317.0	800.0	240.0	210.0	132.0	42.0	18.5	25.6	20.9	58.3	64.0	5.3	1.32	0.09	0.11	180.0	0.0	610.0	292.8	39.9	35.0	15.9	15.6
AL10	7.1	7.1	280.0	710.0	210.0	316.0	560.0	140.0	290.0	208.0	79.8	38.6	22.1	27.2	7.0	8.0	1.7	0.36	0.06	0.10	0.0	0.0	683.2	170.8	79.9	75.0	0.8	0.6
AL11	7.4	7.0	247.0	580.0	220.0	256.0	670.0	250.0	210.0	180.0	46.2	45.4	23.1	16.3	41.7	44.0	4.3	1.2	0.02	0.05	84.0	36.0	646.6	231.8	34.9	35.0	6.2	4.3
AL12	7.4	6.9	196.0	470.0	200.0	203.0	540.0	160.0	200.0	140.0	37.8	20.2	25.7	21.9	19.7	19.0	1.0	0.24	0.02	0.16	12.0	12.0	634.4	170.8	15.0	15.0	1.5	0.7
AL13	7.2	6.6	309.0	1150.0	240.0	552.0	370.0	120.0	280.0	384.0	71.4	95.8	24.8	35.3	24.0	37.0	1.0	0.28	1.81	6.06	0.0	0.0	451.4	146.4	34.9	274.9	3.6	8.0
AL14	8.4	7.5	250.0	550.0	250.0	248.0	790.0	250.0	140.0	76.0	21.0	11.8	21.4	11.4	56.7	69.0	3.0	0.8	0.16	0.27	180.0	24.0	597.8	256.2	34.9	20.0	0.6	1.1
AL15	7.6	6.8	202.0	420.0	190.0	148.0	430.0	150.0	200.0	124.0	33.6	30.2	28.3	11.8	24.7	23.0	0.7	0.2	0.01	2.01	0.0	24.0	524.6	134.2	24.9	25.0	0.4	2.1
AL16	7.6	7.6	111.0	280.0	160.0	115.0	270.0	130.0	160.0	104.0	29.4	28.6	21.11	8.0	10.3	13.0	0.7	0.32	0.02	0.06	0.0	0.0	329.4	158.6	15.0	20.0	0.7	0.1
AL17	7.6	6.9	188.0	420.0	230.0	194.0	620.0	180.0	160.0	96.0	37.8	21.8	15.9	10.1	317	33.0	1.0	0.2	0.08	0.25	204.0	12.0	341.6	195.2	19.9	15.0	4.1	2.5
AL18	7.6	7.8	203.0	420.0	210.0	181.0	380.0	130.0	160.0	140.0	42.0	28.6	13.4	16.7	18.3	22.0	3.0	0.72	0.19	0.26	204.0	12.0	48.8	134.2	29.9	40.0	2.1	6.7
AL19	7.1	6.4	344.0	790.0	300.0	353.0	670.0	140.0	260.0	184.0	71.4	45.4	19.9	17.2	41.7	48.0	10.0	2.48	0.01	0.50	156.0	0.0	500.2	170.8	64.9	105.0	37.9	41.4
AL20	7.2	6.7	355.0	480.0	299.0	219.0	420.0	130.0	240.0	160.0	54.6	33.6	25.3	18.5	46.7	21.0	2.7	0.36	0.11	0.63	24.0	0.0	463.6	158.6	124.9	50.0	39.6	5.7
AL21	7.6	7.0	229.0	510.0	240.0	224.0	510.0	150.0	200.0	108.0	37.8	20.2	25.7	14.1	28.0	31.0	1.3	0.28	0.02	0.06	0.0	0.0	622.2	183.0	29.9	30.0	3.5	2.0
AL22	7.8	6.9	119.0	250.0	170.0	113.0	350.0	100.0	120.0	92.0	25.2	23.5	13.9	8.1	12.3	12.0	2.0	0.24	0.02	0.18	0.0	0.0	427.0	122.0	19.9	25.0	2.3	2.1
AL23	7.7	7.6	143.0	230.0	190.0	102.0	490.0	60.0	140.0	80.0	33.6	16.8	13.7	9.3	17.3	16.0	2.0	0.16	0.08	0.25	36.0	0.0	524.6	73.2	39.9	35.0	1.9	1.8
AL24	7.4	6.9	280.0	650.0	270.0	286.0	620.0	90.0	280.0	120.0	58.8	16.8	32.5	19.0	34.0	38.0	1.3	0.36	0.01	0.01	60.0	0.0	634.4	109.8	29.9	30.0	4.1	3.5
AL25	7.5	7.1	264.0	600.0	260.0	270.0	800.0	320.0	260.0	152.0	63.0	21.8	25.0	23.8	24.7	31.0	1.3	0.28	0.0	0.28	180.0	0.0	610.0	390.4	19.9	20.0	1.2	1.5
AL26	7.1	6.8	256.0	730.0	251.0	322.0	350.0	130.0	300.0	240.0	50.4	52.1	42.5	26.8	15.3	25.0	3.7	1.12	0.02	0.11	0.0	0.0	427.0	158.6	74.9	85.0	22.1	56.7
Min.	7.0	6.4	74.0	55.0	90.0	150.0	50.0	40.0	55.0	48.0	12.6	6.7	3.2	7.6	7.0	8.0	0.7	0.2	0.0	0.0	0.0	0.0	48.8	48.8	15.0	15.0	0.43	0.1
Max.	8.4	8.4	622.0	590.0	300.0	1200.0	880.0	320.0	365.0	384.0	109.2	95.8	42.5	35.3	58.3	69.0	10.0	2.5	1.8	6.1	204.0	36.0	1073.6	390.4	129.9	274.9	48.8	56.7
Mean	7.5	7.1	244.3	556.1	212.7	249.0	530.0	158.8	206.9	148.3	46.8	29.3	21.9	18.3	26.04	30.5	2.4	0.6	0.12	0.47	56.8	6.0	531.2	181.6	39.4	49.0	8.4	8.7
Median	7.6	7.1	248.5	530.0	210.0	237.5	555.0	145.0	200.0	140.0	44.1	22.7	22.8	17.4	24.3	26.5	1.7	0.3	0.03	0.16	18.0	0.0	597.8	170.8	30.0	30.0	2.6	2.3
Std. dvn	0.34	0.43	109.2	125.9	48.65	256.6	204.2	66.7	70.5	68.7	21.1	18.4	8.0	7.9	15.4	17.8	2.1	0.54	0.35	1.21	75.5	9.75	222.6	76.2	31.15	58.65	13.43	15.03

Abbreviations: TDS – total dissolved solids (mg/L); EC – electrical conductivity (μS/cm); TA – total alkalinity (mg/L); TH – total hardness (mg/L); Ca – Calcium (mg/L); Mg – Magnesium (mg/L); Na – Sodium (mg/L); K – Potassium (mg/L); Fe – Iron (mg/L); CO_3^{2+} – Carbonate (mg/L); HCO_3^{-} – Bi-carbonate (mg/L); Cl^{-} – Chloride (mg/L); SO_4^{2-} – Sulfate (mg/L).

Table 2. *Values of calculated water quality parameters/indices.*

Location no.	Location name	SAR		SSP		PI		RSC		MAR		KR	
		Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre
AL1	Abdarpur	0.42	0.56	19.94	29.01	78.12	66.09	0.78	0.46	61.01	65.37	0.23	0.40
AL2	Singur	0.72	0.71	33.72	29.80	61.50	53.79	−0.10	0.44	23.92	47.90	0.49	0.42
AL3	Kochujor	1.21	1.83	24.63	37.03	39.68	24.37	5.67	−0.06	25.52	41.87	0.32	0.58
AL4	Lalmohanpur	0.76	1.09	21.60	32.88	66.23	49.31	9.38	2.02	26.82	52.99	0.27	0.49
AL5	Bonsonka	0.28	0.42	8.98	13.60	66.09	44.38	7.16	2.39	52.29	72.33	0.09	0.16
AL6	Talibpur	0.80	1.37	21.48	35.29	67.73	44.82	12.56	3.76	45.81	74.07	0.25	0.54
AL7	Kubirpur	0.36	1.79	13.45	42.25	72.86	43.61	8.37	3.88	53.16	69.96	0.13	0.72
AL8	Abinashpur	0.47	0.62	15.31	20.06	74.13	46.34	7.38	1.52	36.22	46.57	0.18	0.25
AL9	Piasala More	1.74	2.41	38.69	51.34	49.24	42.97	11.77	3.88	50.41	65.38	0.60	1.04
AL10	Purandarpur	0.18	0.24	5.62	7.84	54.86	37.17	5.37	0.87	31.56	53.97	0.05	0.08
AL11	Gangta	1.25	1.42	31.24	34.92	55.69	37.13	9.17	1.53	45.41	37.39	0.43	0.53
AL12	Majhigram	0.60	0.69	17.92	22.73	66.80	46.60	6.77	1.79	53.16	64.38	0.21	0.29
AL13	Bhaganbati	0.62	0.82	15.95	17.29	41.78	18.20	1.77	−2.39	36.64	38.04	0.19	0.21
AL14	Dhalla	2.07	3.42	47.31	66.30	61.61	48.19	12.97	3.61	62.89	61.71	0.87	1.95
AL15	Saktipur	0.75	0.90	21.25	28.71	58.45	43.42	4.56	0.69	58.40	39.43	0.27	0.40
AL16	Ajaypur	0.35	0.55	12.62	21.53	63.62	61.28	2.17	1.17	54.48	31.69	0.14	0.27
AL17	Joka	1.08	1.46	30.33	42.68	52.84	54.54	9.18	2.11	41.33	43.53	0.43	0.74
AL18	Khatangadi	0.63	0.81	21.36	25.67	23.07	40.20	4.38	0.77	34.75	49.42	0.25	0.34
AL19	Kendulia	1.12	1.53	28.35	36.73	42.49	30.98	8.17	0.53	31.71	38.77	0.35	0.56
AL20	Lataboni	1.31	0.72	30.26	22.24	42.20	39.88	3.57	0.92	43.53	47.91	0.42	0.28
AL21	Nabagram	0.86	1.29	23.67	38.34	62.02	50.46	6.17	1.99	53.16	53.74	0.30	0.62
AL22	Aamgachi	0.49	0.54	19.54	22.19	90.06	60.12	4.58	0.82	47.92	36.47	0.22	0.28
AL23	Gobindopur	0.63	0.77	22.21	30.26	82.85	48.16	6.98	0.36	40.39	47.91	0.27	0.43
AL24	Agar	0.88	1.50	21.13	40.65	46.76	34.55	6.76	0.96	47.91	65.37	0.26	0.68
AL25	Ekdala More	0.66	1.09	17.45	30.60	51.21	58.58	10.77	5.31	39.82	64.46	0.20	0.44
AL26	Suri Town	0.38	0.70	11.16	18.74	40.01	28.31	0.94	0.00	58.40	46.16	0.11	0.22
	Min.	0.18	0.24	5.62	7.84	23.07	18.20	−0.10	−2.39	23.92	31.69	0.05	0.08
	Max.	2.07	3.42	47.31	66.30	90.06	66.09	12.97	5.31	62.89	74.07	0.87	1.95
	Mean	0.79	1.13	22.12	30.72	58.15	44.36	6.43	1.51	44.49	52.18	0.29	0.50
	Median	0.69	1.42	21.31	30.03	59.98	44.60	6.77	1.07	45.61	48.67	0.26	0.43
	Std. dvn	0.45	0.69	9.33	12.37	15.27	11.42	3.61	1.60	11.21	12.42	0.17	0.36

Abbreviations: SAR – Sodium adsorption ratio; SSP – Soluble sodium percentage; PI – Permeability index; RSC – Residual sodium carbonate; MAR – Magnesium adsorption ratio; KR – Kelly's ratio.

Table 3. *Classification of samples according to standards specified for different water quality parameters.*

Parameters	Range	Class	No. of samples		Percentage of samples	
			Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon
SAR	<20	Excellent	26	26	100	100
	20–40	Good	0	0	0	0
	40–60	Permissible	0	0	0	0
	60–80	Doubtful	0	0	0	0
	>80	Unsafe	0	0	0	0
EC WHO (2008)	<250	Excellent	20	14	77	54
	250–750	Good	6	12	23	46
	750–2000	Permissible	0	0	0	0
	2000–3000	Doubtful	0	0	0	0
	>3000	Unsuitable	0	0	0	0
TH (Sawyer and McCarty 1967)	<75	Soft	1	2	4	8
	75–150	Moderate	4	12	15	46
	150–300	Hard	19	11	73	42
	>300	Very hard	2	1	8	4
RSC	<1.25	Safe	16	14	61	54
	1.25–2.50	Marginally suitable	9	7	35	27
	>2.50	Unsuitable	1	5	4	19
MAR	<50	Suitable	19	14	73	54
	>50	Unsuitable	7	12	27	46
SSP	200	Suitable	26	26	100	100
	>200	Unsuitable	0	0	0	0
KR	<1.0	Suitable	26	24	100	92
	>1.0	Unsuitable	0	2	0	8
PI	<80	Good	26	26	100	100
	80–100	Moderate	0	0	0	0
	100–120	Poor	0	0	0	0
WQI	0–25	Excellent	19	8	73	31
	26–50	Good	4	8	15	31
	51–75	Poor	2	3	8	12
	76–100	Very Poor	–	4	–	15
	>100	Unfit for drinking	1	3	4	11

hazard of soil. RSC index is used to find the suitability of water for irrigation in clay soils which has high cation exchange capacity. When dissolved sodium in comparison with dissolved calcium and magnesium is high in water, clay soil swells or undergoes dispersion which drastically reduces its infiltration capacity. The residual sodium carbonate index (defined by equation 4) of water/soil signifies the alkalinity hazard posed by it and it finds the suitability of water for irrigation in case of clay soils (Raghunath 1987).

$$\mathrm{RSC} = \left(\mathrm{HCO}_3^- + \mathrm{CO}_3^{2-}\right) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right) \qquad (4)$$

where concentrations of all ions have been expressed in meq/L.

Residual sodium carbonate values should be preferably <1.25 to be rendered suitable for irrigation purposes and hence, in the present study where RSC values range between –0.10 and 12.97 and >80% of the water samples have RSC >2.5 (figure 16a and b); it can be concluded that water in this area poses an alkaline hazard to the soil during post-monsoon period. In the pre-monsoon period, 76% of RSC values fall in the safe category, indicating localised hazard.

4.8 *Magnesium adsorption ratio (MAR)*

Generally in most groundwaters, Ca^{2+} and Mg^{2+} maintain a state of equilibrium (Hem 1985). During equilibrium, more Mg^{2+} in groundwater adversely affects the soil quality rendering it alkaline which result in decrease of crop yield (Kumar *et al.* 2007). Paliwal (1972) developed an index for calculating the magnesium hazard called magnesium adsorption ratio (MAR). Magnesium adsorption ratio (defined by equation 5) indicates the magnesium hazard that can be caused when magnesium remains in equilibrium in groundwater. This index was devised by Paliwal (1972) where the calcium and magnesium ratios are taken into consideration,

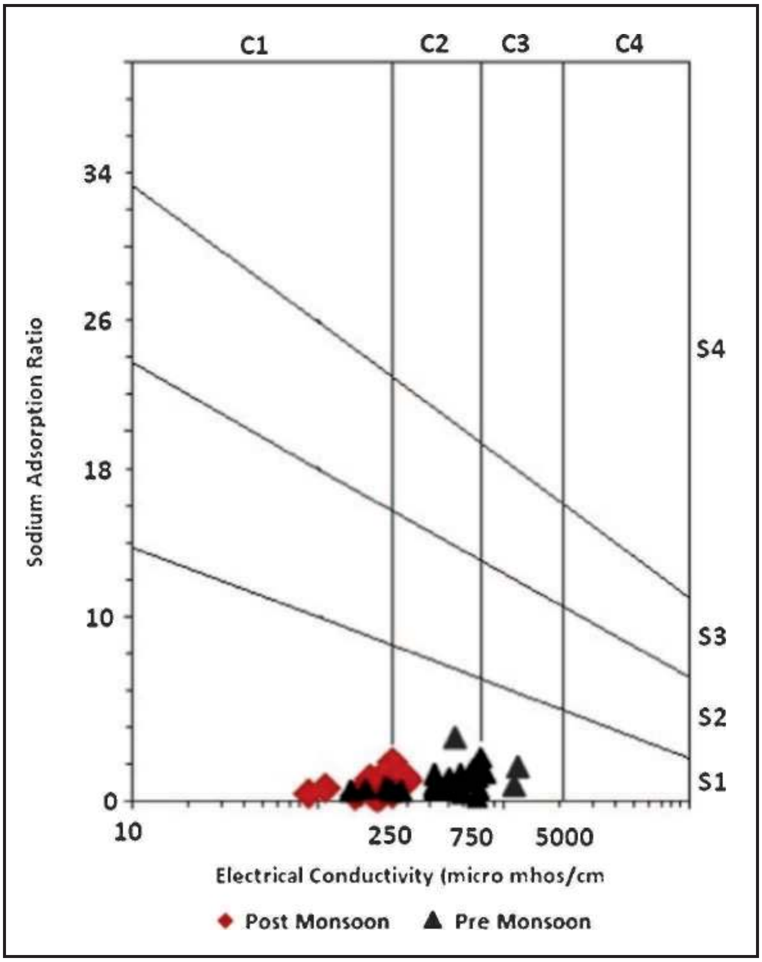


Figure 13. US salinity diagram (post- and pre-monsoon).

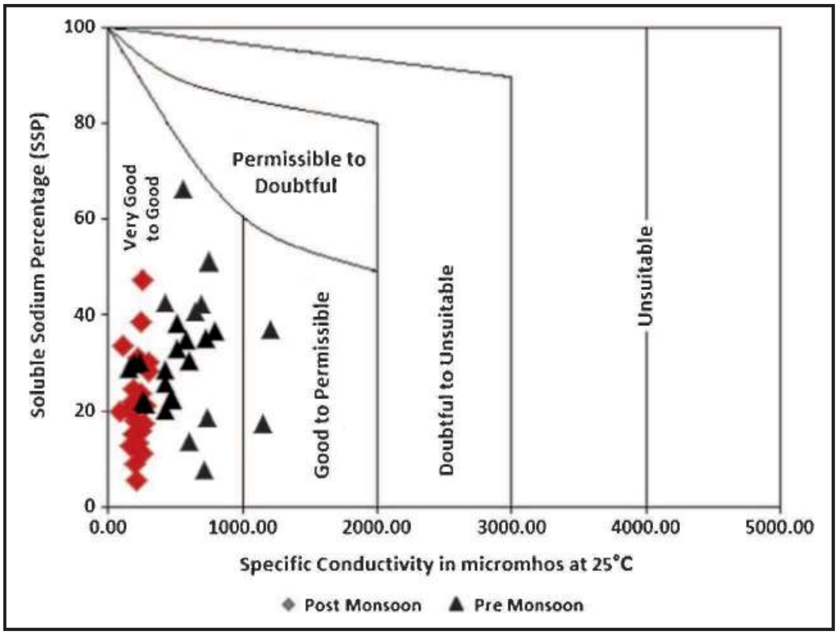


Figure 14. Wilcox diagram (post- and pre-monsoon).

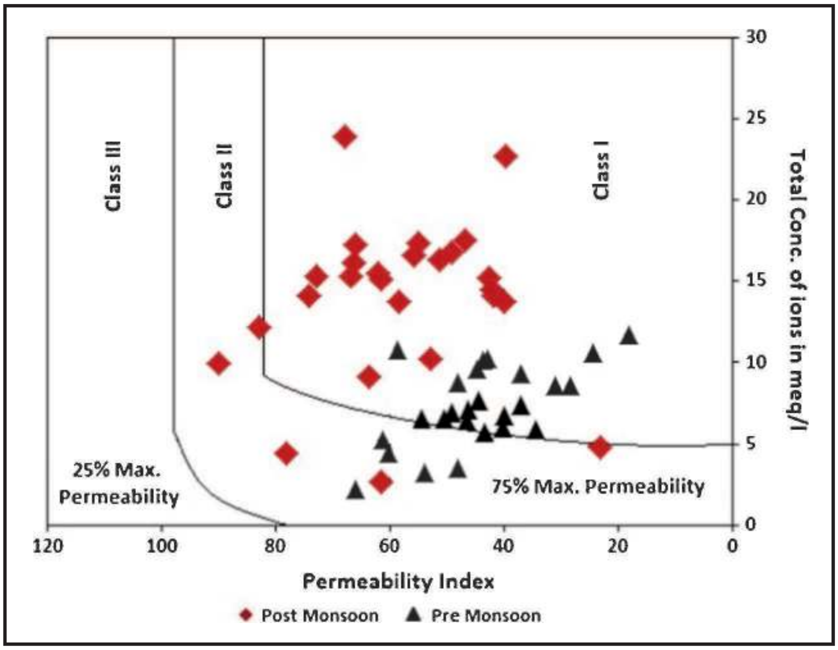


Figure 15. Doneen's chart (post- and pre-monsoon).

as mostly calcium and magnesium maintain equilibrium in water (Hem 1985; Giggenbach 1988).

$$\mathrm{MAR} = \left(\mathrm{Mg}^{2+} * 100\right) / \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right) \qquad (5)$$

where concentrations of all ions have been expressed in meq/L.

MAR categorizes water into two broad classes – water having MAR <50 is considered suitable for irrigation whereas water with MAR >50 is considered unsuitable, based on which it can be concluded that almost two-thirds of the water samples are suitable for irrigation in post-monsoon. During pre-monsoon MAR values change rendering about half of the samples suitable for irrigation (figure 17a and b).

4.9 *Kelly's ratio (KR)*

Classification of groundwater quality for irrigation is also done based on Kelly's (1963) ratio. Kelly's ratio (defined by equation 6) is measured considering sodium ion concentration against calcium and magnesium ion concentrations. Kelly's ratio of more than 1 indicates an excess level of Na^+ in water. Water with a value of KR <1 is considered suitable for irrigation, while those with a ratio more than 3 is considered as unsuitable for irrigation (Ramesh and Elango 2012). It is defined as:

$$\mathrm{KR} = \mathrm{Na}^{2+} / \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right) \qquad (6)$$

where concentrations of all ions have been expressed in meq/L.

During post-monsoon, KR values vary between 0.05 and 0.87 and during pre-monsoon, the values vary between 0.08 and 1.95. According to Kelly's ratio water analyzed is suitable for irrigation during both periods barring two locations in pre-monsoon.

4.10 *Water quality for drinking purposes*

In large and specially semi-urban or rural parts of our country, groundwater sources in the form of dug wells or borewells are the only source of drinking water. In the present study, to ascertain whether or not the water consumed by villagers meet the drinking water standards, the total hardness of samples have been measured and the use of hydrogeochemical facies (Piper diagram) and water quality index have been made.

4.11 *Total hardness*

Water hardness has no known adverse effects; however, some evidence indicates its role in heart disease (WHO 2008). Hard water is unsuitable for domestic use and it is a measure of the Ca^{2+} and Mg^{2+} content expressed in equivalent of calcium carbonate. Hardness of water (temporary and permanent) is by the inhibition of soap action in water due to the precipitation of Ca^{2+} and Mg^{2+} salts like carbonates, sulphates and chlorides. Temporary hardness is mainly due to the presence of calcium carbonate and gets removed when water is

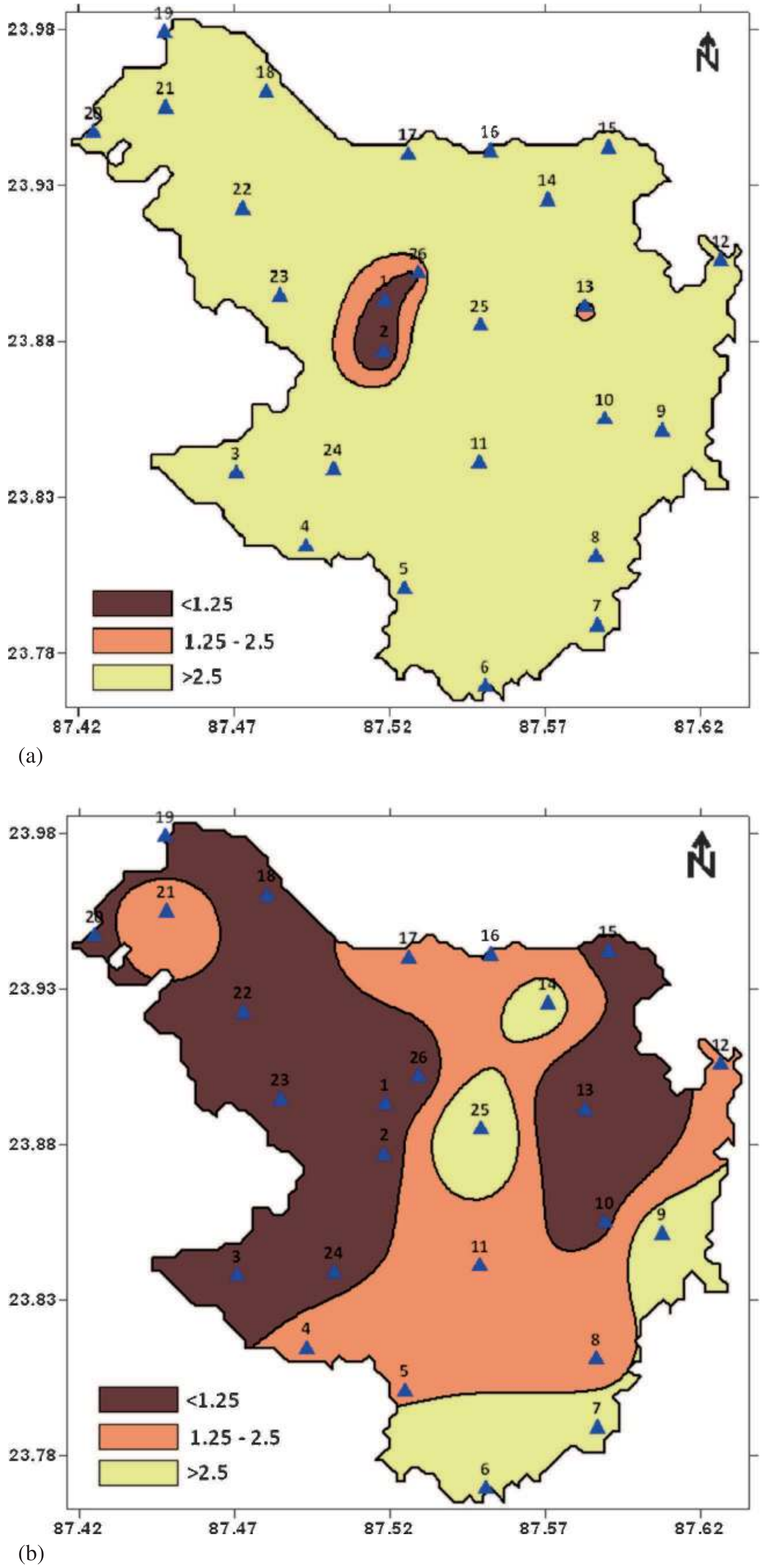
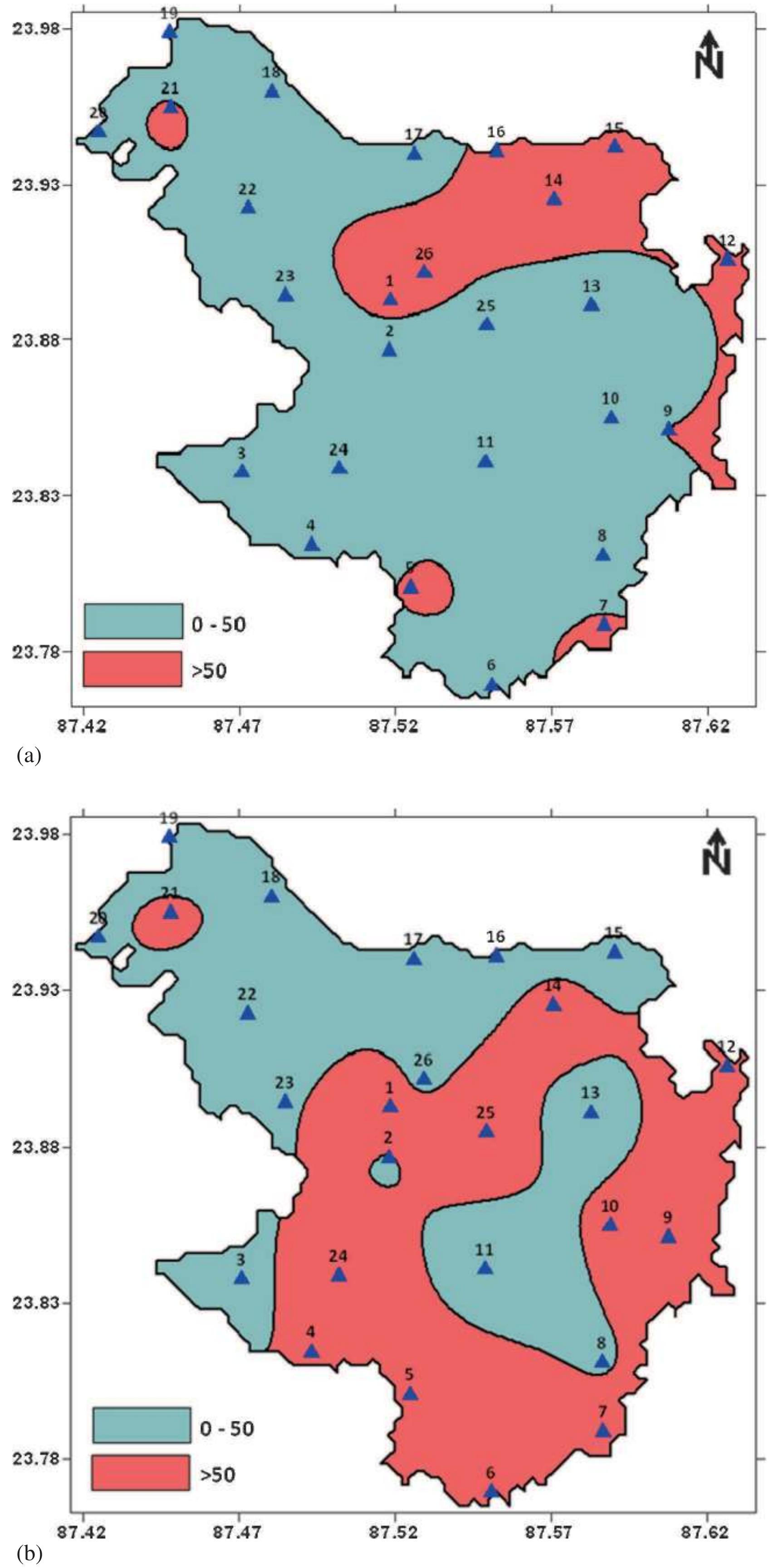


Figure 16. Spatial distribution of RSC (**a**) post-monsoon and (**b**) pre-monsoon.



(a)

(b)

Figure 17. Spatial distribution of MAR (**a**) post-monsoon and (**b**) pre-monsoon.

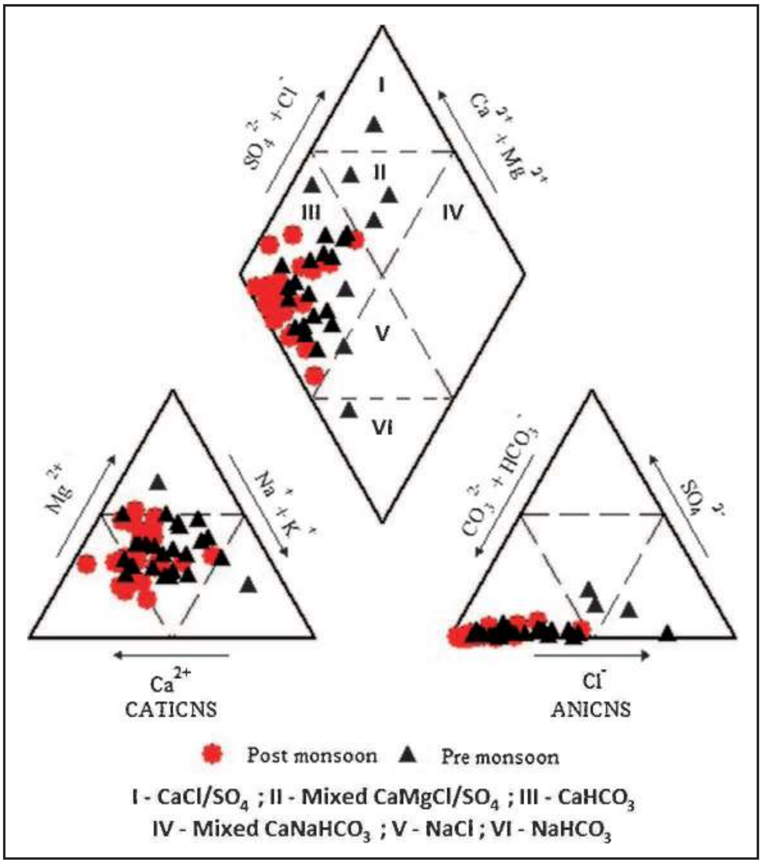


Figure 18. Piper trilinear diagram (post- and pre-monsoon).

boiled. Permanent hardness is caused by the presence of Ca^{2+} and Mg^{2+} which gets removed by ion exchange processes. Hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes, may cause health problems to humans, such as kidney failure (WHO 2008). The total hardness in mg/L is determined by the following equation (Todd 1980).

$$\mathrm{TH}\,(\mathrm{mg/L}) = 2:497\mathrm{Ca}^{2+} + 4:115\mathrm{Mg}^{2+}$$

During post-monsoon, total hardness (TH) ranges between 55.0 and 365.0 mg/L with an average of 206.9 mg/L, and during pre-monsoon, it ranges between 48.0 and 384.0 mg/L with an average of 148.3 mg/L. Covering the two sampling sessions, most of the water samples were found to be moderately hard in nature with exceptions of a few hard to very hard types as well.

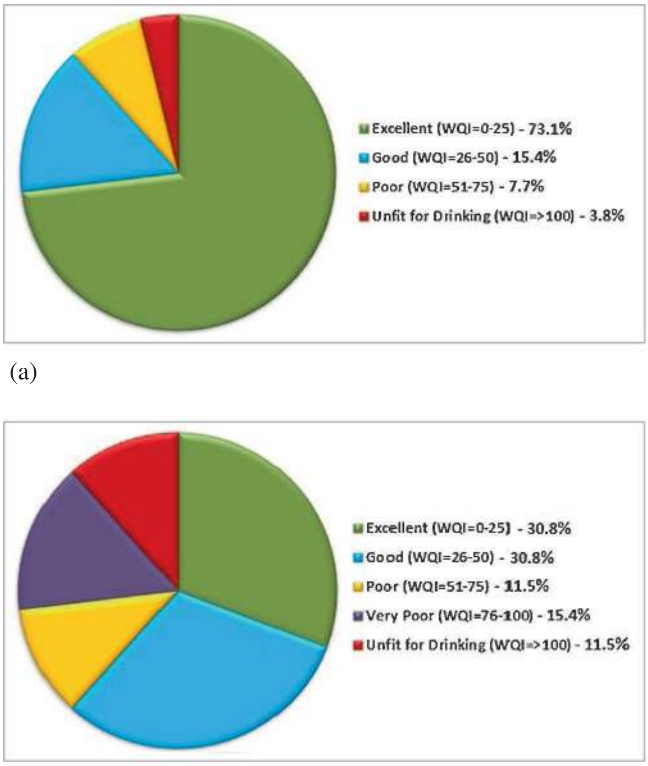
4.12 *Hydrogeochemical facies*

Piper trilinear diagram is a graphical representation classifying water, based on the dominant presence of cations and anions and has widespread use to assess the water type (Back 1966; Apambire *et al.* 1997; Kumar *et al.* 2007). Piper diagram indicates suitability of drinking water based on the 'type' of water sample in accordance with the classification standards. Piper diagram broadly classifies water into four types: Bicarbonate type (fresh), sulfate type (which renders an odour to water) chloride or saline type (which renders a salty taste to water) (figure 18). In figure 18, it can be seen that the water samples fall under $CaMgHCO_3$ or $NaHCO_3$ (the bicarbonate type) during both post-monsoon and pre-monsoon sampling sessions. During pre-monsoon, a couple of samples fall under the $CaMgSO_4$ and $CaMgClSO_4$ (sulfate type) class as well.

4.13 *Water quality index (WQI)*

The contamination status of groundwater and whether or not it is suitable for consumption can be determined with the help of a quality index measure (Tiwari and Mishra 1985). For evaluation of WQI, the analyzed, standard and permissible values of ions present in water have been considered to calculate the quality rating of a water sample (Pradhan *et al.* 2001; Asadi *et al.* 2007).

$$\mathrm{WQI} = \mathrm{Antilog}\,[W_{n=1}^{n}\log_{10} q_n] \quad (7)$$



(a)

(b)

Figure 19. Categorization of groundwater according to WQI (**a**) post-monsoon and (**b**) pre-monsoon.

where W is weightage factor and q is quality rating.

$$W_n = K/S_n \tag{8}$$

where the proportionality constant,

$$K = \left[1\Big/\left(\sum_{n=1}^{n} 1/S_i\right)\right] \tag{9}$$

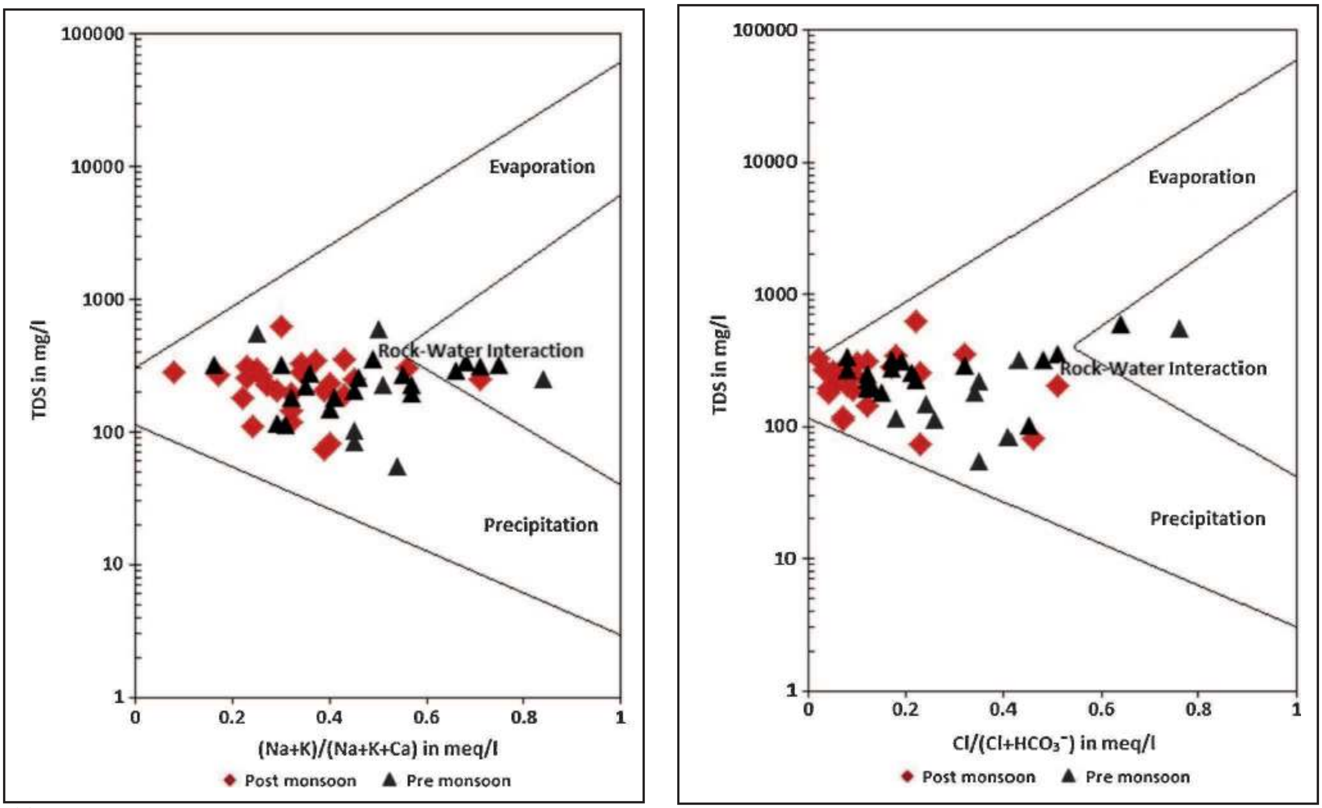
where S_n and S_i are the standard/permissible values of water quality parameters, proposed by WHO or ICMR.

Quality rating,

$$q = \{[(V_{\text{actual}} - V_{\text{ideal}})/(V_{\text{standard}} - V_{\text{ideal}})] * 100\} \tag{10}$$

where V_{actual} = analytical value of ith parameter obtained from laboratory analysis, V_{standard}=WHO/ICMR standard of ith parameter and V_{ideal} = value of ith parameter obtained from standard tables ($V_{\text{ideal}} = 0$ for all parameters except pH for which $V_{\text{ideal}} = 7$).

In table 3, the classification ranges with respect to water quality index values of the water samples analyzed have been presented. Based on the standard, permissible and actual concentrations of each chemical parameter were tested and we reached the WQI value. Lower the WQI values,



(a) (b)

Figure 20. Gibbs' diagrams for post- and pre-monsoon.

greater is the suitability of water with respect to drinking purpose. Similarly, higher values of WQI indicate poorer quality of water in terms of drinking. It is self-explanatory that water quality depends upon water quality index. Figure 19(a and b) shows pie diagrams which present the distribution of water samples for the post-monsoon and pre-monsoon sessions respectively with respect to the classification standards of water quality index study. Percentage of samples falling in each class of WQI study has been presented as individual sections of the pie diagram.

4.14 *Factors controlling hydrogeochemistry*

Gibbs' diagrams. The hydrogeochemistry of a particular region is usually determined by a number of factors like climate (average temperature of the region), geology (composition of the underlying bed rocks lining the aquifer systems in the region), rainfall, etc. Plotting of values of specific water quality parameters over the Gibbs' diagram (Gibbs 1970) gives us an insight as to which particular factor – evaporation, precipitation or rock–water interaction, plays the dominant role in controlling the hydrogeochemistry of an area. Gibbs' diagram is prepared using TDS, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), chloride (Cl^-) and bicarbonate (HCO_3^-) concentrations in groundwater. In figure 20(a and b), the Gibbs' diagrams for post-monsoon and pre-monsoon sessions have been presented. From these diagrams it can be interpreted that during both sampling sessions rock–water interaction processes significantly control the levels of all chemical constituents in groundwater of the study area. Dissolution and displacement reactions in rocks lining the aquifers are the primary reasons behind changing concentrations of major ions in solution.

5. Conclusion

The groundwater quality of Suri I and II blocks of Birbhum district, West Bengal has been assessed for its irrigational and domestic suitability purposes. The quantitative chemical analysis results reflect that the dominant cations in the study area are calcium and sodium and the dominant anions are bicarbonate and chloride. Hydrochemical facies analysis as well as the pH of water, both indicates that groundwater in the area is of alkaline nature. The electrical conductivity values and total dissolved solids values of water samples are all found to be within acceptable limits during both sampling sessions. Most of the water samples were found to be moderately hard in nature with exceptions of a few hard to very hard types as well.

Based on the water quality parameters analyzed like SAR, SSP, MAR, PI and KR, the suitability of groundwater samples for irrigation is good to medium in almost all cases, indicating low sodic waters, but may pose prominent alkaline hazard to soil reflected by the Residual Sodium Carbonate (RSC) values during post-monsoon. The groundwater will thus, neither cause salinity hazards nor have an adverse effect on the soil properties and is largely suitable for irrigational purposes. Piper diagram results show majority of samples belong to 'fresh water' type during both post- and pre-monsoon sessions. The water quality index results show that close to 90% of water samples are suitable for consumption during the post- monsoon session. 73.1% samples fall under the 'excellent' category and 15.4% samples fall under 'good' category during post-monsoon. During the pre-monsoon, a significant variation is noticed as only around 60% of the samples are found to be fit for drinking combining the 'excellent' (30.8%) and 'good' (30.8%) categories. Thus it can be concluded that overall quality of water with respect to drinking standards is better during the post-monsoon session in comparison with pre-monsoon.

Results from the water analysis were used as a tool to identify the process and mechanisms affecting the chemistry of groundwater from the study area. The data points of the area are plotted on the Gibbs' (1970) diagram. The plot is used to determine the mechanism controlling the water chemistry (figure 20a, b). The samples fall in rock–water interaction dominant zone indicating chemical weathering of rock-forming minerals as the prime factor influencing the groundwater quality suggesting dissolution and displacement of minerals constituting the aquifer materials.

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