

# Hydrological processes governing Groundwater quality in the Sabarmati River Basin, Gujarat

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## INTRODUCTION

Groundwater is an important source of water supply throughout the world. The chemical composition of groundwater is controlled by many factors, which includes mineralogy of the aquifers, climate, topography, dissolution of mineral species, soil/rock–water interactions, composition of precipitation and anthropogenic activities (Stallard and Edmond 1983; Faure 1988; Subba Rao 2002). Intensive agricultural practices and industrial activity are the major anthropogenic activities which are likely to make groundwater vulnerable with respect to its quality.

In one such area is Sabarmati river basin of Gujarat. Situated in the west coast of India, Gujarat is one of the most economically fast growing states, which is dominated by intense growth of agricultural and industrial activities. After green revolution, change in cropping practices has led to different types of fertilizer use and water abstraction especially for cash crops. In 1960-61, total N, P, K fertilizer consumption was 11071 tonnes which increased to 1716983 tonnes in 2008-09 (Fertiliser Association of India, 2009). Rapid increase of industrialization, agriculture and population has induced unplanned abstraction of groundwater. A decline in water table/ piezometric surface at a rate of ~ 3 m/yr is making the area water deficit. High concentrations of fluoride in groundwater have been noticed in North Gujarat (Gupta and Deshpande 1998, 2005, Vasavada 1998, Salve et al, 2008) during the last 3–4 decades. Groundwater salinity and contamination has also increased in many parts. There are very few studies reported on the groundwater quality scenario in Gujarat, one that is dominated by intense agricultural and industrial activity.

In the past, little has been done to describe the groundwater quality scenario of the area. Therefore, the present study attempts to identify the factors controlling the groundwater quality in the study area using hydrochemistry in integration with Geographical Information System (GIS) to suggest groundwater management strategies.

## GEOHYDROLOGY AND CLIMATE OF THE STUDY AREA

The study area (~7221 sq.km; Fig 1) is a part of the Sabarmati River basin (between longitudes 72°15' and 73°49' E and latitudes 22°15' and 24°53' N; total drainage area ~22,000 sq.km). The river originates at an altitude of 782 m in the Aravalli Hills of Rajasthan and it traverses a distance of 416 km up to the Gulf of Cambay in Gujarat state (Jain & Tandon 2003). The basin is bound in the north and northeast by the Aravalli hills; in the east, by a ridge separating it from the Mahi Basin; in the south, by the Gulf of Cambay; and in the west, by a ridge separating it from the basins of minor streams draining into the Rann of Kutch.

Geologically, the basin comprises crystalline rocks of Archean age in the northern and northeastern parts while recent alluvial deposits cover the central and southern parts of the basin (Datta et al. 1980). Large part of the basin is occupied by thick quaternary continental deposits of fluvio-marine origin. Pre-Cambrian hard rocks, semi unconsolidated Mesozoic formations, Tertiary formation and unconsolidated alluvial deposits form aquifers in this area. Quaternary alluvial deposits (~11,300sq.km, occupying 2/3rd of the area) with alternating sand and silt-clay layers constitute the regional aquifer system, having its recharge area in the foothills of Aravalli mountain and discharge area in the Gulf of Cambay. Due to high gradient and undulating topography, the run off is high, which limits the aquifer storage.

Climatic condition in the Sabarmati basin varies from arid to semi arid. The average annual rainfall is about 800mm which is mainly influenced by southwest monsoon which normally sets in the middle of June and continues to be active till mid September. The Sabarmati River has five major tributaries; of these, two tributaries namely Wakal and Sai originate in Rajasthan and the remaining three tributaries namely Harnav, Hathmati and Watrak originate in Gujarat.

## METHODOLOGY

### Sampling and Analytical procedures

Groundwater samples were collected after extensive field survey based on topographic sheets and satellite image. In the satellite image the study area was divided into several grids (5km x 5km). The spectral signature of vegetation and soil with stressed vegetation and high moisture content grid has been taken into consideration, to perceive surface manifestation of groundwater situation and representative groundwater samples were collected. GPS (Garmin) was used to map the location of each sampling site and finally the results were brought in GIS environment for further analysis. Fifty six groundwater samples were collected in post-monsoon in the last week of September 2008, whereas sixty one samples were collected in pre-monsoon in May 2009. The groundwater samples were

collected from the aquifers adjacent to the Sabarmati River in the districts of Ahmedabad, Gandhinagar, Mehsana, Kheda and Anand. Total fourteen water quality parameters have been studied through graphical plot, multivariate statistical analysis and GIS to infer hydrogeochemical processes. Sampling points of the investigated area is shown in the Fig.1.

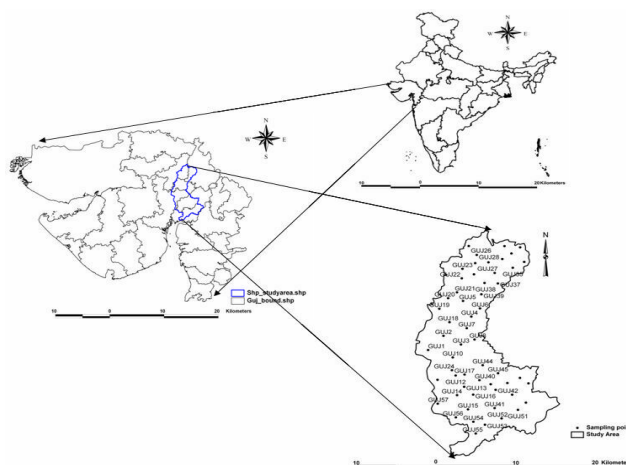


Fig.1. Map showing sampling location of the study area.

Samples were collected from tube wells, bore wells and hand pumps, during sampling, first few strokes of water were discarded to minimize the impact of iron pipes. At each site water samples were collected in two separate clean polypropylene bottles (Tarsons; 250ml and 125ml), rinsed 2-3 times with groundwater to be sampled. One of the bottles (125ml) containing sample was acidified to stabilize trace metals and was used for determination of major cations. Other bottle (250ml) containing un-acidified sample was used for anions analysis. Fourteen physico-chemical parameters were analyzed following the standard procedure (American Public Health Association APHA, 2005). pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured onsite using respective electrodes (Hanna). The samples were stored in ice containing styrofoam boxes and brought to laboratory and stored at 4°C for further analysis. Samples were vacuum filtered with 0.22µ Millipore filter paper. Carbonate and bicarbonate were determined using titration method. Anions (F<sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>) were analyzed using Ion chromatography (ICS-90, Dionex). Major cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>) were analyzed using atomic absorption spectrophotometer (Thermo Fisher). Dissolved silica was analyzed by the molybdo-silicate method (APHA 2005). The analytical precision for the measurement of ions was within ±5%, as calculated by normalized charge balance index.

Spatial variation of the groundwater quality was done using the spatial analyst module of ArcGIS 9.2. The interpolation technique used in the analysis is inverse distance weighted (IDW) algorithm (Mueller et al. 2004; Tomczak 1998; Tabios and Salas 1985) for spatially interpolating, or estimating values between measurements.

## RESULTS AND DISCUSSION

The increase in groundwater pH from an average value of 7.5 in pre-monsoon to 8.4 in post-monsoon (Table. 1) suggest enhanced dissolution of salt in post-monsoon due to higher interaction between soil and rainwater (Subramanian and Saxena, 1983). The variation of EC and TDS during pre-monsoon and post-monsoon is shown in the Table. 1.

The abundance of major anions both in pre-monsoon and post-monsoon was in the following order: Cl<sup>-</sup> > HCO<sub>3</sub><sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > SiO<sub>2</sub><sup>-</sup>, whereas the dominant cations in both pre-monsoon and post-monsoon are in the following order: Na<sup>+</sup> > Ca<sup>2+</sup> > Mg<sup>2+</sup> > K<sup>+</sup>. In pre-monsoon, Na<sup>+</sup>, Mg<sup>2+</sup> and Ca<sup>2+</sup> contributed 99.18 % of total cation whereas Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, and SO<sub>4</sub><sup>2-</sup> contributed about 83.78 % of total anions in the study area. In post-monsoon Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, and SO<sub>4</sub><sup>2-</sup> contributed about 83.15% of total anions where as Na<sup>+</sup>, Mg<sup>2+</sup> and Ca<sup>2+</sup> contributed 99.28% of total cations.

### SPATIO-TEMPORAL VARIATION OF BICARBONATE

HCO<sub>3</sub><sup>-</sup> ion, which represents the major sources of alkalinity as is observed by the values in Table. 1 suggests the contributions from carbonate weathering of carbonate and silicate minerals present in the geological formation, and can be described by the following reaction (Freeze and Cherry, 1979).

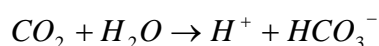
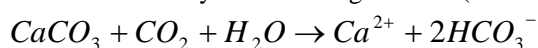


Table.1 Statistical summary of physico-chemical parameters of groundwater the study area

Parameter	Premonsoon		Postmonsoon	
	Mean±SD	Range	Mean±SD	Range
pH	7.49 ± 0.39	7.1-9.1	8.43 ± 0.40	7.1-9.3
TDS (mg/L)	884.75 ± 458.19	160-1850	528.39 ± 316.16	80-1330
EC (µS/cm)	1258.2 ± 725.31	210--2890	1307.68 ± 607.81	240-2350
CO <sub>3</sub> (mg/L)	22.16 ± 10.01	6.0 -54.00	42.20 ± 19.95	0-108.00
HCO <sub>3</sub> (mg/L)	169.22 ± 76.2	73.2-439.2	202.72 ± 150.93	36.60-1000.40
SiO <sub>2</sub> (mg/L)	68.15 ± 19.11	26.30-126.84	43.86 ± 13.84	9.66-68.48
F (mg/L)	1.00 ± 0.53	0.39-2.54	1.07 ± 1.00	0.29-5.55
Cl (mg/L)	432.37± 377.13	58.44-1993.16	282.80 ± 210.40	36.58-850.15
NO <sub>3</sub> (mg/L)	50.09 ± 87.49	1.59 -630.73	33.28 ± 29.12	2.71-131.67
SO <sub>4</sub> (mg/L)	129.09 ± 130.87	14.98-730.54	85.02 ± 87.45	13.36-496.68
Na (mg/L)	374.76 ± 199.05	90.01-1050.34	321.07± 187.75	63.89-808.36
K (mg/L)	3.38 ± 2.59	0.54-12.41	2.69± 1.91	0.46-10.21
Ca (mg/L)	20.56 ± 12.23	1.87-58.86	27.32±14.66	10.19-80.17
Mg (mg/L)	13.49 ± 18.54	0.87-128.67	22.66 ± 12.75	2.42-62.41

From the pre-monsoon to post-monsoon, a considerable change in the HCO<sub>3</sub><sup>-</sup> ion suggests possible contribution of dissolution of higher amount of CO<sub>2</sub> released from industrial activity during monsoon rainfall. Spatial variation of HCO<sub>3</sub><sup>-</sup> in both pre and post-monsoon is shown in the Fig. 2 (a) & (b) respectively.

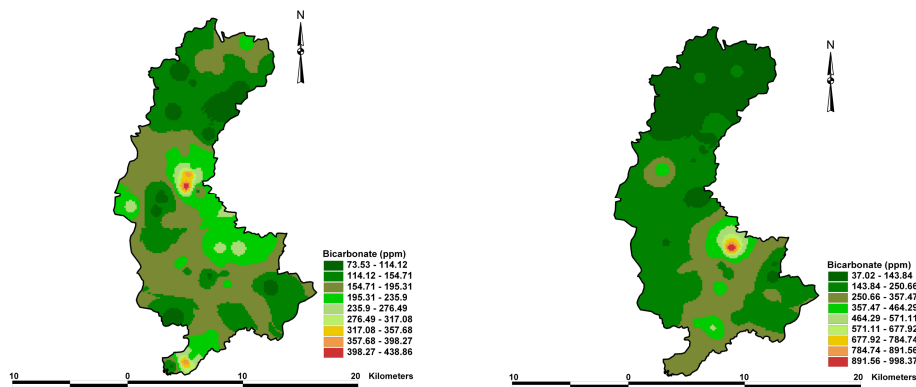


Fig. 2 Spatial variation of HCO<sub>3</sub><sup>-</sup> in (a) pre-monsoon (b) post-monsoon

#### SPATIO-TEMPORAL VARIATION OF CHLORIDE

The high concentration of chloride in the study area (Table. 1) may be due to both anthropogenic activities and leaching of halite and related sedimentary bedrock minerals, during percolation or recharge.

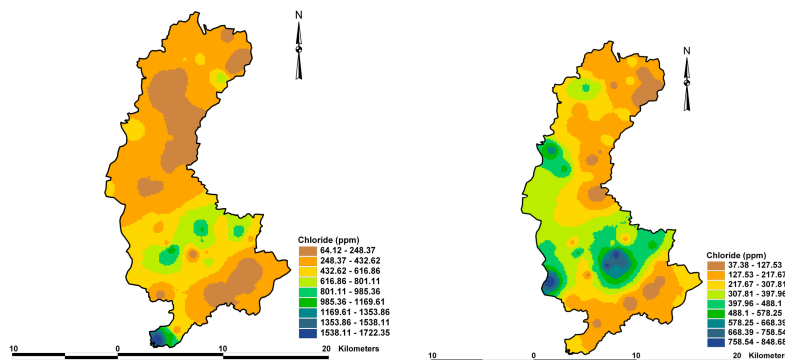


Fig.3. Spatial variation of Cl<sup>-</sup> in (a) pre-monsoon (b) post-monsoon

Spatial variation of chloride concentration in both pre-monsoon and post-monsoon is given in Fig.3 (a) & (b) the northern part of the investigated area under intensive agriculture showed low chloride concentration, whereas the central and southern parts under industrialized and urbanized regime has higher concentration. During post-monsoon leaching of agrochemicals, untreated industrial waste and

evaporite dissolution has increased the chloride concentration in the area. In the whole area chloride could be a remnant of the seawater also, because the area has thick quaternary fluvio-marine deposits (Merh and Chamyal, 1993), formed due to progressive withdrawal of a high sea.

#### SPATIO-TEMPORAL VARIATION OF SULPHATE

As shown in Table.1 contribution for the abundance of Sulphate in the groundwater results from the dominance of intense agricultural and industrial activity, besides dissolution of gypsum and anhydrite minerals, higher sulphates indicates breaking of organic substances from top soil/water, leachable sulphates present in fertilizer and other human influences (Miller, 1979; Craig and Anderson, 1979). Spatial variation of  $\text{SO}_4^{2-}$  concentration in both pre-monsoon and post-monsoon is shown in Fig.4 (a) & (b). Sulphate concentration is higher in central and southern part of the study area as compared to northern part. This suggests contribution from agrochemical pollutants and other anthropogenic sources such as industrial discharge. Relict sulphide- and sulphate-rich marine clay and silt deposits could also be possible source of elevated  $\text{SO}_4^{2-}$  in the area.

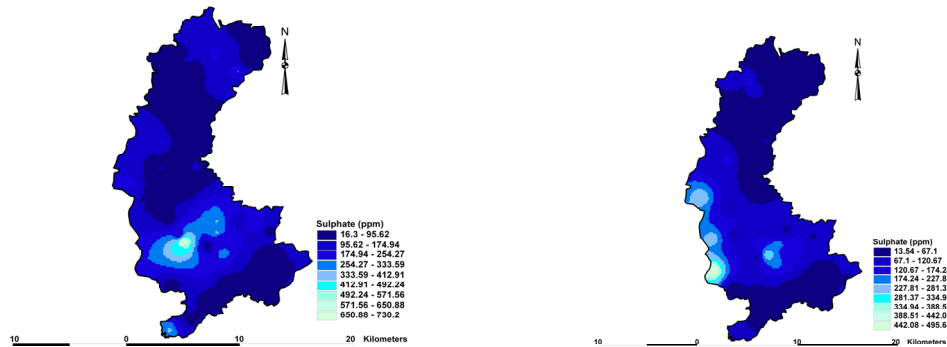


Fig. 4. Spatial variation of  $\text{SO}_4^{2-}$  in (a) pre-monsoon (b) post-monsoon

#### SPATIO-TEMPORAL VARIATION OF NITRATE

Nitrate concentration in groundwater in the pre-monsoon and post monsoon is shown in Table.1. In the northern parts of the area except for few places in pre-monsoon nitrate concentration was higher than the recommended limit of 45 mg/L for drinking water by BIS (1991) and World Health Organization (1993).

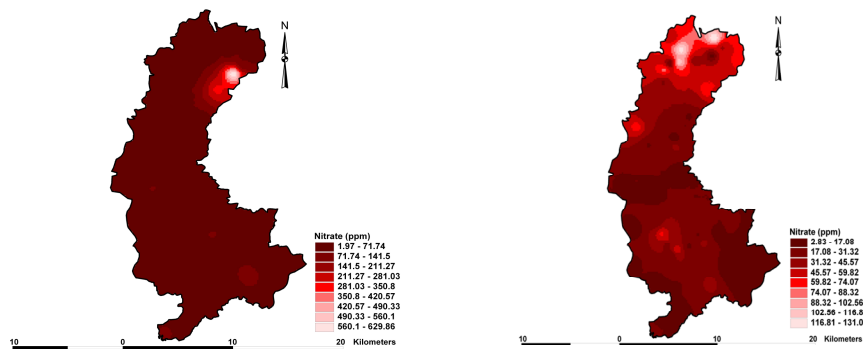


Fig. 5. Spatial variation of  $\text{NO}_3^-$  in (a) pre-monsoon (b) post-monsoon

Spatial variation of nitrate is shown in Fig. 5 (a) & (b). Very wide variation on concentration of  $\text{NO}_3^-$  suggests both point and non-point sources. In the upper part of the study area which is part of Mehsana district, highest nitrate concentration shows the impact of agricultural activity. Lower part of the study area which is part of Kheda and Anand district also shows the impact of agricultural activity. Besides fertilizers other sources of nitrate can be attributed to animal waste, crop residue, septic tanks and effluents from different food processing units present in the area. Decreased nitrate content in the post-monsoon season is due to dilution by addition of rain or irrigation water to aquifer. In pre-monsoon, evapo-transpiration leads to accumulation of agrochemical salts in groundwater and non-availability of sufficient recharge water could be another reason for higher nitrate content in the groundwater.

#### SPATIO-TEMPORAL VARIATION OF FLUORIDE

Fluoride concentration in groundwater ranged from 0.4 to 2.5 mg/L with average 1.0 mg/L in premonsoon, whereas in post-monsoon, it ranged from 0.3 to 5.5 mg/l with average value of 1.1 mg/L. High concentration of fluoride in drinking water is health hazard, it causes chronic endemic fluorosis. Fluorosis at more severe stage causes bilateral lameness and stiffness of gait (Suttle 1977). As

compared to pre-monsoon, higher fluoride levels in groundwater in post-monsoon may be due to increased pH and  $\text{HCO}_3^-$  content during post-monsoon. Higher alkalinity leads to leaching of fluoride which results in increase in the concentration of fluoride in groundwater. The proterozoic rocks of the Kumbhalgarh group, Ambaji Granites and Gneisses of Delhi super group and Godhra granite are found in this region which are characterized by mineralogical assemblages of quartz, K-feldspar, plagioclase, pegmatites, biotite, amphiboles, fluorite and apatite (Choudhary, 1984).

Weathering of Na–K bearing minerals, cation-exchange processes are responsible for the dominance of  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ , and  $\text{Mg}^{2+}$  in groundwater in region (Kunwar *et al.*, 2005; Srinivasamoorthy *et al.*, 2008; Singh *et al.*, 2010). High concentration of  $\text{Na}^+$  and  $\text{Mg}^{2+}$  also seems to have contributed due to industrial and/or agricultural input (Guo and Wang, 2004). Concentration of  $\text{Na}^+$  in pre-monsoon ranged from 90.0-1050.3 mg/L with average value of 374.8 mg/L whereas in post-monsoon it ranged from 63.9-808.4 mg/L, with average value of 321.1 mg/L. As compared to northern part sodium concentration is high in central and southern part of the investigated area. Monsoonal rainfall has increased leaching of salt from agrochemicals and industrial waste. High sodium concentration in pre-monsoon may be due to evaporation because of semi arid climate. Concentration of calcium in pre-monsoon ranged from 1.9-58.9 mg/L with average value of 20.6 mg/L whereas in post-monsoon it ranged from 10.2-80.2 mg/L, with average value of 27.3 mg/L concentration.

### HYDROCHEMICAL FACIES

Piper (1944) proposed trilinear diagram to understand hydrochemical processes operating in the groundwater system.

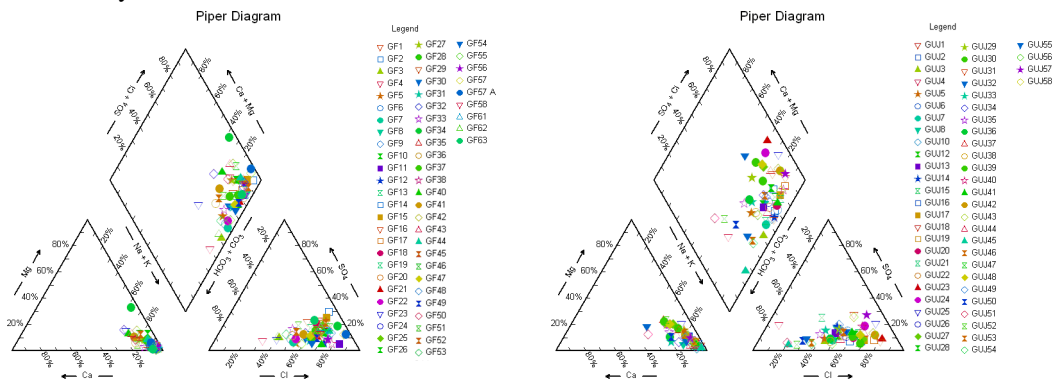


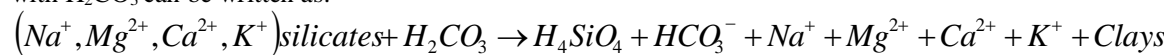
Fig.6. Piper plot for (a) pre-monsoon (b) post-monsoon

The trilinear plot of major cations and anions in the groundwater of the study suggests that among cation Na, K, and Ca, whereas among anions  $\text{Cl}^-$ ,  $\text{HCO}_3^-$  and  $\text{SO}_4^{2-}$ , dominate in the aquifer both in post-monsoon and pre-monsoon. In most of the area, water facies is of Na-Cl type, except at few places it is Na- $\text{HCO}_3$ . Na-Cl facies confirms highly saline water in the area. Some samples which shows Na- $\text{HCO}_3$  type facies, indicates rock-water interaction. Piper plot of the study area for both pre and post-monsoon season of the study is shown in the Fig. 6. (a) & (b).

### HYDROGEOCHEMICAL PROCESSES OCCURRING IN THE STUDY AREA

In order to identify various hydrogeochemical processes occurring in the study area, the hydrochemical data was subjected to various conventional graphical plots. The scatter diagram of (Ca + Mg) versus ( $\text{HCO}_3^- + \text{SO}_4^{2-}$ ) (Fig. 7) shows that in pre-monsoon most of the samples fall below the equiline (1:1) indicating silicate weathering as the dominant process whereas in post monsoon more samples falls above the equiline due to excess of (Ca + Mg) over ( $\text{SO}_4^{2-} + \text{HCO}_3^-$ ) which indicates that these ions have resulted from carbonate weathering, whereas some samples also falls below the equiline which indicates silicate weathering (Datta *et al.*, 1996; Rajmohan and Elango 2004). It also indicates that in pre-monsoon ion exchange is the dominant process whereas in post-monsoon both ion exchanges as well as reverse ion exchange is taking place in the groundwater.

Carbonic acid ( $\text{H}_2\text{CO}_3$ ) is formed in nature when atmospheric  $\text{CO}_2$  reacts with water ( $\text{H}_2\text{O}$ ). In the flow path of groundwater  $\text{H}_2\text{CO}_3$  dissolves the minerals. A general reaction for weathering of silicate rocks with  $\text{H}_2\text{CO}_3$  can be written as:



Good correlation of Ca and Mg with each other but not with Na shows that besides weathering there may be other sources of these cations. In the plot (Ca+Mg) vs ( $\text{SO}_4 + \text{HCO}_3$ ) the samples which fall below the equiline (1:1) in pre-monsoon, suggests that an excess of ( $\text{SO}_4 + \text{HCO}_3$ ) in the water has been balanced by alkalis ( $\text{Na}^+ + \text{K}^+$ ).

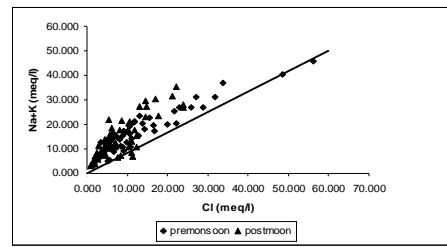
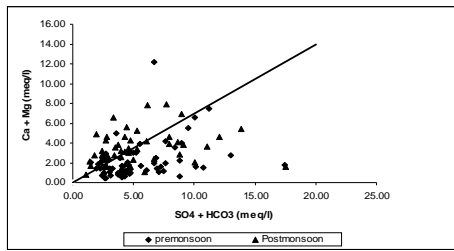


Fig. 7. Scatter plot between  $(Ca + Mg)$  and  $(SO_4 + HCO_3)$  Fig.8. Scatter plot of  $Na + K$  vs.  $Cl$ . Whereas in post-monsoon even when  $SO_4$  and  $HCO_3$  is at low concentration,  $Ca$  and  $Mg$  is present in relatively higher concentration which shows that the excess of  $Ca$  and  $Mg$  might be due to anthropogenic activity .

The plot between  $(Na^+ + K^+)$  and  $Cl$  (Fig.8) shows that in both pre-monsoon and post-monsoon almost all samples lie above the equiline. The excess of cation is either due to silicate weathering or due to salts present in the soil (Stallard and Edmond, 1983). Chloride ion has a tendency to be associated with alkalis and form alkaline chlorides. In Fig.9 ( $Na + K$  vs.  $Cl$ ) plot the data point also shows that abundant alkalis are available to form alkali carbonates or alkali sulphate. Among the alkalis sodium is dominant and concentration of potassium is very low. The excess of  $Na^+$  might be from anthropogenic activity. Semi-arid climate, gentle slope, lack of good drainage conditions also contributes to the groundwater quality. Evaporation greatly increases the concentrations of ions formed by chemical weathering.

#### DATA ANALYSIS USING CORRELATION MATRIX

Correlation coefficient for both season is shown in table (2& 3). Prior to statistical analysis the data was standardized with the criterion presented by Davis (2002). In both pre-monsoon and post-monsoon  $Cl^-$ ,  $Na^+$ ,  $Mg^{2+}$  and  $SO_4^{2-}$  contents exhibit mutual positive correlation and correlate strongly with EC and TDS. Compared to pre-monsoon season chloride, sodium and magnesium are strongly correlated with EC in post-monsoon which is due to more mineralization in post-monsoon season.  $Na^+$  and  $Cl^-$  show high positive correlation in both pre-monsoon and post-monsoon which indicates presence of moderately to highly saline groundwater in the study area. Correlation of  $SO_4^{2-} - Cl^-$ ,  $Mg^{2+} - Cl^-$ ,  $Mg^{2+} - SO_4^{2-}$  indicates the impact of agricultural activity i.e. excessive use of fertilizer which leads to increase in salinity in the study area. Moderate correlation of  $K^+ - NO_3^-$  and  $K^+ - Mg^{2+}$  indicates the impact of agricultural activity in the study area.

#### SODIUM AND SALINITY HAZARD IN THE AREA

In semi arid region agricultural productivity depends on both the availability of water and its quality. However, sodicity and salinity are the main constraints of productivity in semi-arid regions. EC and  $Na^+$  play a vital role in suitability of water for irrigation. Salts causes change in soil structure, permeability and aeration which indirectly affect the plant growth (Todd, 1980; Domenico and Schwartz, 1990). Wilcox (1995) and US salinity Laboratory Staff (1954) proposed a criterion for evaluating the suitability of water for irrigational use. The electrical conductivity and SAR values of groundwater of study area, plotted in the US salinity diagram ((Fig.9a & b) shows that in post-monsoon 17 samples fall in low sodium hazard category. Most of the samples were in C3S2 category which is high salinity and medium sodium category but it is considered tolerable for agricultural use. Eight samples were in C3S3 category (high salinity and high sodium hazard zone) and nine samples were in C3S4 category which is high salinity and very high sodium hazard zone. 4 samples fall in C4S4 zone which is very high salinity and sodium hazard zone and considered as poor water quality for irrigation purposes. As compared to post-monsoon no samples fall in C4S4 category in pre-monsoon but sodium hazard were more in pre-monsoon. High salinity in the area during post-monsoon may be due to increased vertical recharge. The area is highly industrialised and has intensive agricultural practices, leaching of surficial salt and untreated industrial waste have contributed to salinity along with unplanned abstraction of groundwater. From the salinity diagrams different groundwater mixing flow pathways between highly saline with medium and low saline water and fresh water can be visualised. Salinity in groundwater may be a remnant of the seawater (as discussed in the study area section above) (Merh and Chamyal, 1993) and a possible contribution of semi arid climate.

	pH	TDS	EC	CO3	HCO3	SiO2	F	Cl	NO3	SO4	Na	K	Ca	Mg
pH	1													
TDS	0.038	1.000												
EC	-0.050	<b>0.929</b>	1.000											
CO3	0.319	0.207	0.200	1.000										
HCO3	-0.028	0.119	0.198	<b>0.433</b>	1.000									
SiO2	0.079	0.027	-0.034	0.017	0.010	1.000								
F	0.147	-0.045	-0.018	0.393	<b>0.414</b>	-0.095	1.000							
Cl	0.004	<b>0.743</b>	<b>0.805</b>	0.209	0.083	-0.067	0.034	1.000						
NO3	-0.072	0.324	0.340	-0.171	-0.244	-0.108	-0.186	0.218	1.000					
SO4	-0.138	<b>0.571</b>	<b>0.631</b>	0.221	0.064	-0.094	0.152	<b>0.796</b>	0.163	1.000				
Na	0.003	<b>0.738</b>	<b>0.814</b>	0.320	0.239	-0.060	0.202	<b>0.931</b>	0.131	<b>0.762</b>	1.000			
K	-0.038	0.346	0.234	-0.205	-0.226	0.002	-0.224	0.233	<b>0.491</b>	0.184	0.142	1.000		
Ca	-0.005	0.321	0.313	0.011	-0.106	0.125	0.026	<b>0.457</b>	0.157	0.349	0.306	0.221	1.000	
Mg	-0.098	<b>0.536</b>	<b>0.546</b>	-0.050	-0.082	-0.170	-0.071	<b>0.433</b>	<b>0.745</b>	0.400	0.316	<b>0.490</b>	<b>0.543</b>	1.000

Table.2 Correlation matrix of various parameters analysed in pre-monsoon season

	pH	TDS	EC	CO3	HCO3	SiO2	F	Cl	NO3	SO4	Na	K	Ca	Mg
pH	1													
TDS	0.030	1.000												
EC	0.112	<b>0.944</b>	1.000											
CO3	<b>0.578</b>	0.314	0.354	1.000										
HCO3	0.402	0.396	0.448	0.328	1.000									
SiO2	0.018	0.027	0.035	0.043	-0.117	1.000								
F	0.215	0.013	0.083	0.278	0.191	-0.168	1.000							
Cl	-0.021	<b>0.913</b>	<b>0.840</b>	0.191	0.203	0.095	-0.068	1.000						
NO3	-0.416	-0.068	0.024	-0.292	-0.270	0.209	-0.093	-0.023	1.000					
SO4	-0.056	<b>0.678</b>	<b>0.533</b>	0.114	0.142	0.011	-0.053	<b>0.766</b>	-0.236	1.000				
Na	0.214	<b>0.901</b>	<b>0.855</b>	0.461	<b>0.529</b>	0.052	0.165	<b>0.832</b>	-0.130	<b>0.620</b>	1.000			
K	-0.323	0.130	0.086	-0.162	-0.201	-0.244	-0.166	0.166	0.164	0.139	-0.045	1.000		
Ca	-0.165	0.294	0.248	-0.071	-0.080	0.262	-0.215	0.398	0.103	0.303	0.169	0.358	1.000	
Mg	-0.149	<b>0.627</b>	<b>0.589</b>	-0.015	0.069	0.102	-0.246	<b>0.731</b>	0.059	<b>0.534</b>	0.439	0.287	<b>0.713</b>	1.000

Table.3 Correlation matrix of various parameters analysed in post-monsoon season

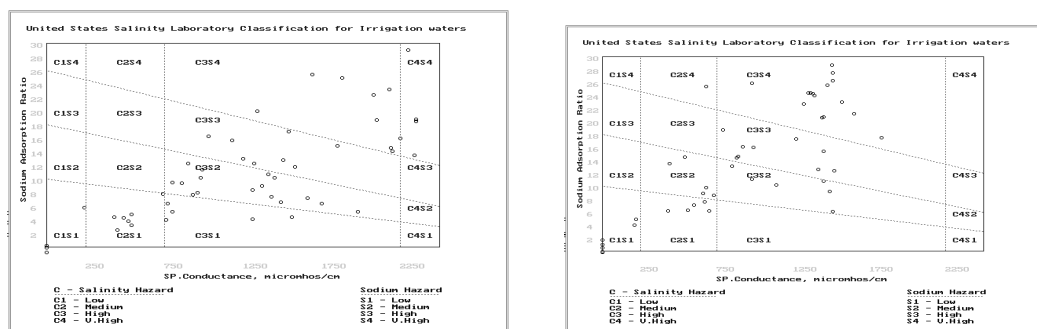


Fig. 9 US salinity diagram for (a) pre-monsoon (b) post-monsoon

## CONCLUSION

The integration of hydrochemistry with GIS has been very helpful to understand the factors governing the groundwater quality in the studied parts of the Sabarmati basin.

GIS gives a clear understanding of spatiotemporal behavior of the groundwater quality and better management strategy in the area. With the help of various conventional graph and hydrochemistry it was found that besides natural factors such as silicate and carbonate weathering; ion exchange, and reverse ion exchange it is mainly anthropogenic activities which are governing groundwater quality in the area. Majority of the samples showed that Na-Cl type of hydrochemical species which indicates presence of highly saline water in the area. High nitrate concentration in groundwater shows the impact caused by leaching of agrichemicals from intensive agricultural activity in the area. At most of places fluoride concentration is higher than above permissible limit. Except for few places groundwater is unsuitable for irrigation purposes. As compared to pre-monsoon salinity hazard is more in post-monsoon. Vertical recharge during monsoon has increased leaching of surficial salt from agrichemical and industrial activity and from evaporite dissolution. From USSL diagram it is also clear that highly saline water is getting mixed with medium and low saline water and fresh water. From USSL diagram it is also clear that as compared to post-monsoon sodium hazard is more in pre-monsoon, it may be due to arid climate during pre-monsoon. To protect the good quality water from further depletion and pollution, appropriate measures need to be taken to control indiscriminate and unplanned exploitation of groundwater, application of fertilizers and disposal of industrial wastes in the affected areas.

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