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Water quality assessment of groundwater in area along Nandesari effluent channel, India

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ABSTRACT

This study examines groundwater quality along the Nandesari common effluent channel (Vadodara, Gujarat, India) designed for disposal of treated industrial effluents from the Nandesari industrial area. Groundwater samples have been collected from various available groundwater sources like hand pumps, wells, bore wells, lakes, etc. along the channel in both post-monsoon and pre-monsoon seasons and were subjected to analysis for determining physicochemical parameters like pH, Na, K, Ca, Mg, Cu, Zn, Cd, chloride, fluoride, sulfate, phosphate, electrical conductance, chemical oxygen demand, DO, etc. The chemical composition of groundwater of the study area was found to be strongly influenced by effective weathering and leaching action along with anthropogenic activities. The hydrochemical facies infer groundwater samples irrespective of seasons to be of Ca–Mg–SO_4–Cl type. Furthermore, salinity, sodium adsorption ratio, percentage of sodium Na (%), residual sodium carbonate, piper trilinear diagrams, and Gibbs ratio suggest that 56.25% of samples were found to be unfit for irrigation.

Keywords: Groundwater assessment; Nandesari; Common effluent channel; Gibb's diagram; Piper diagram; SAR; RSC

1. Introduction

Groundwater is used for domestic and industrial water supply and irrigation globally. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, and inland surface water and on sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic, and human factors may cause periodic changes in groundwater quality [1–3]. The hydrochemical study reveals quality of water that is suitable for drinking, domestic, agricultural, and industrial purpose [4,5]. Further, it is possible to understand the change in groundwater quality due to the use of industrial effluent for irrigation and other purposes [6–8]. The aim of this study was to assess the hydrogeochemical parameters of groundwater resources based on the analysis of groundwater

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samples near the Nandesari common effluent channel area, Vadodara, Gujarat.

Vadodara city and surrounding area constitute one of the most developed agro-industrial regions of the Gujarat state and falls within "the Golden Corridor," the most developed industrial belt of the state situated between Mehsana and Mumbai.

The proposed study area constitutes a part of Vadodara City and adjoining semi-urban and rural segments of Padra town. The study area is geographically bounded between latitudes N 21° and 23° and longitudes E 73° and 74° 10′ and sprawls over an area of 714 km^2. This area meets its water demand from varied sources which after requisite treatment is distributed by appropriate administrative bodies at users' end. The agriculture sector by and large subsist its requirement through groundwater exploitation. Over the period, the groundwater resources have been severely affected by the industrial pollutants and the over exploitation of the resources has further deteriorated its quality through sea water encroachment.

The objective of this study was to assess the levels of some physicochemical water quality parameters in groundwater sources located in the residential areas in the vicinity of the common effluent channel, evaluate the effects of seasonal variation on the concentrations of the parameters, and classify the water using piper and Gibbs diagram in terms of water quality and suitability for drinking and irrigation purposes.

2. Materials and methods

2.1. Study area

Padra town located 15 km from Vadodara city which has varied activities that have prompted the present study of assessing the groundwater quality. Padra is a center for vegetable farming and the yield reaches to major cities like Vadodara, Ahmedabad, Mumbai, and Delhi. This original green belt area is now an industrial center. The 56 km long common effluent channel designed for the disposal of treated industrial effluent from the Nandesari Industrial Area into the Mahi estuary also passes through this green belt. Assuming fitness for use, this water from the effluent channel is regularly used for irrigation purpose with excessive use of agrochemicals, resulting in soil and groundwater pollution. The map of the study area is presented in Fig. 1. The effluent channel is presented by gridded portion. Sampling has been carried out from the grid area.

2.2. Sample collection

Groundwater samples have been collected from 16 stations in both post-monsoon(October–December 2009) and pre-monsoon seasons(April–June 2010) from available sources like hand pumps, wells, bore wells, lakes, etc. on either side of the effluent channel that runs from Nandesari region till Jambusar, and were subjected to physicochemical analysis [9,10] by determining parameters like pH, Na, K, Ca, Mg, Cu, Zn, Cd, chloride, fluoride, sulfate, phosphate, effective conductance, chemical oxygen demand (COD), DO, etc. The values are reported as an average of three months for both pre-monsoon and post-monsoon seasons. The list of the villages from where the sampling has been carried out for the pre-monsoon and post-monsoon period is shown in Table 1.

The samples were collected in clean polythene bottles without any air bubbles. The bottles were rinsed before sampling and tightly sealed after collection and labeled. The samples were kept in a refrigerator maintained at 4°C.

2.3. Methods

The samples were analyzed both for physical and chemical water quality parameters [11]. The analysis was carried out for the major ions using the standard procedures [12]. The pH was determined using pH meter (Model Lab India). Electrical conductivity was measured using Digital conductivity meter. Sulfate was analyzed by Digital turbidity meter (Model 331 E), Zn, Cd, and Cu were determined using AAS (Model Aanalyst 200); Na and K by flame photometer (Model Medi 382 E); chloride content by argentimetric method, total hardness (TH) by EDTA titrimetric method, and COD by open reflux method.

Calibration of the instruments had been carried out according to their standard manual before the analysis.

The correlation co-efficient "r" was calculated using the equation.

$$r = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \tag{1}$$

where $x = X - \bar{X}$ and $y = Y - \bar{Y}$, X and Y represent two different parameters $\bar{X}$ = Mean value of X; $\bar{Y}$ = mean value of Y.

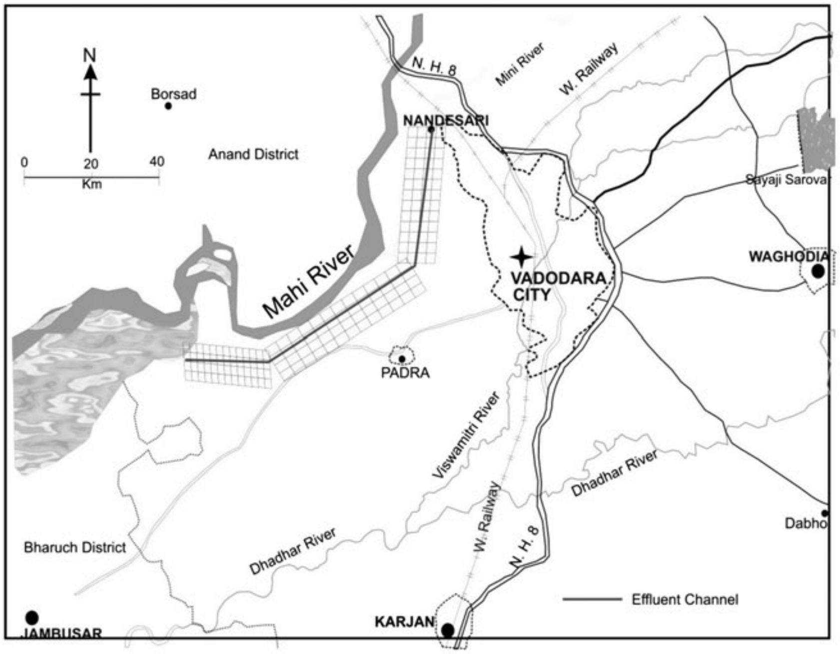

Fig. 1. Map of the study area.

2.4. Irrigation suitability

Salinity, SAR, and percentage of sodium Na (%) were used to evaluate the groundwater for irrigation purposes in this coastal area [2,13].

SAR is given as:

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

where the concentrations are reported in meq/l.

Residual Sodium Carbonate (RSC) is calculated using the following equation.

$$RSC = (HCO_3^{2-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

where all ionic concentrations are expressed in epm.

The percent sodium (% Na) is calculated using the formula given below:

$$\%\,\text{Sodium} = (Na^{+} + K^{+}) \times 100/(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}) \quad (4)$$

where the concentrations are reported in meq/L.

3. Results and discussion

Various physicochemical parameters were analyzed for 16 groundwater samples collected in October–December 2009 (post-monsoon) and April–June 2010 (pre-monsoon). The physical parameters studied are appearance, color, electrical conductivity, and total dissolved solids. The different chemical parameters studied are pH, alkalinity, TH, calcium, magnesium, sodium, potassium, chloride, and sulfates. Out of the total area survey along the effluent channel belt, groundwater samples collected from the villages near the disposal point of the channel were colored showing groundwater contamination due to effluent. Maximum and minimum concentrations found for different parameters analyzed in the groundwater from the study area during both post-monsoon and pre-monsoon seasons are presented in Table 2. Water quality standards recommended for drinking and public health purposes are also given for comparison. The study reveals that there are many samples (Mainly from Villages: Vedach; Piludara, etc.) are having very high concentration of pollutants from that of WHO (2004) permissible limit for the groundwater quality.

The pH values of the groundwater varied between 7.3 and 9.16, indicating slightly alkaline to alkaline nature of groundwater. According to WHO, the range of desirable pH values of water prescribed for drinking purposes is 6.5–9.2 (WHO, 2004). There are no groundwater samples with pH values outside the desirable range. The EC values ranged from 0.73 to 9.78 mS/cm and 0.257 to 8.25 mS/cm during post-monsoon and pre-monsoon, respectively. The groundwater can be classified into (1) fresh (<1,500 μS/cm),

Table 1
List of the name of the villages of sampling

Sr. no.	Name of village	Sr. no.	Name of village
1	Vedach (W)*	9	Chokari (HP)*
2	Vedach (HP)*	10	Dhudhwada (HP)*
3	Vedach (W)*	11	Narsinh Pura (HP)*
4	Vedach (HP)*	12	Narsinh Pura (HP)*
5	Dhudhwada (Bore)*	13	Mujpur (HP)*
6	Suthari pura (HP)*	14	Mujpur (Tube)*
7	Suthari pura (Bore)*	15	Umaraya (Tube)*
8	Suthari pura (Tube)*	16	Umaraya (Bore)*

Notes: *indicates source of groundwater taken. Bore = Bore well; HP = Hand pump; Tube = Tube well; W = Well.

(2) brackish (1,500–3,000 μS/cm), and (3) saline (>3,000 μS/cm) [14]. Based on this pattern of classification, it was observed that 18.75% of the samples were of fresh quality but saline water (81.25% of the samples) was also prevalent in the area.

As seen from Fig. 2, among major cations, sodium represented 50.66% on an average of all the cations. Sodium content was higher during post-monsoon (1,570 mg/L) indicating weathering from plagioclase bearing rocks and also due to over exploitation [15].

Magnesium and Calcium ions were the major cations found next to sodium, representing on an average 30.3 and 19.05% of all cations, respectively. Potassium ion concentration was found to be present within permissible limits.

The heavy metals in the groundwater samples were found to be below permissible limits. In some samples, there were observed heavy metals (samples from Vedach, piludara villages). Only one sample (Handpump, Vedach) was found to contain cadmium

Table 2
Concentration study for pre-monsoon sampling

No	Parameters	Pre-monsoon sampling			Post monsoon sampling			WHO value ground-water
		Max.	Min	Samples out of range In %	Max.	Min	Samples out of range In %	
1	Ph	8.6	7.1	6.3	9.2	7.3	18.7	6.5–9.2
2	DO (ppm)	6.4	1.4	37.5	7.2	1.7	31.2	5.0–6.0
3	EC	8.3	0.3	75.0	9.7	0.7	81.2	1.0
4	TDS (ppm)	9750.0	260.0	68.7	17000.0	680.0	75.0	1200.0
5	Chloride (ppm)	1719.6	3.9	25.0	2516.1	10.0	18.7	600.0
6	TH (ppm)	1324.0	60.0	37.5	2335.0	32.0	50.0	500.0
7	Ca-Hardness (ppm)	412.0	40.0	31.2	700.0	20.0	18.7	200.0
8	Mg-Hardness (ppm)	948.0	10.0	56.2	1650.0	8.0	75.0	200.0
9	TA (ppm)	496.0	72.0	87.5	979.2	132.0	87.5	120.0
10	Nitrate (ppm)	37.0	0.0	OK	ND	ND	OK	45.0
11	Fluoride (ppm)	2.5	0.0	56.2	1.7	0.0	25.0	1.0
12	Sulfate (ppm)	284.7	3.0	OK	1333.8	27.3	OK	250.0
13	Phosphate (ppm)	0.0	0.0	OK	0.3	0.0	OK	–
14	COD (ppm)	720.0	0.0	81.2	3600.0	0.0	50.0	1.0
15	Na (ppm)	199.0	18.0	6.3	1570.0	72.0	37.5	200.0
16	K (ppm)	9.0	0.0	OK	17.0	1.0	6.2	10.0
17	Zn(ppm)	0.6	0.03	OK	0.1	0.0	OK	15.0
18	Cd (ppm)	0.004	0.0003	OK	0.4	0.0	OK	0.01
19	Cu (ppm)	0.4	0.0	OK	0.2	0.0	OK	1.5
20	Hg (ppm)	Not Detected		OK	Not detected		OK	<0.01
21	Pb (ppm)	Not Detected		OK	Not detected		OK	<0.01
22	Cr (ppm)	Not Detected		OK	Not detected		OK	<0.01

concentration of ~0.3501 mg L^{-1} which is much higher than the WHO permissible limit (0.01 mg L^{-1}).This could be due to the presence of pigment, dye intermediate industries very near to the source of groundwater. There also have been previous reports stating that the water quality parameters have high values in this region and can also be visually seen (Fig. 3) [16].

However, looking groundwater quality does not necessarily come from the effluent itself, but many a time, the industries pump the effluent directly. This we have shown in the Fig. 4 in which newspaper article demonstrate the level of pollution.

Among the major anions, the order of their abundance is $Cl^{-} > HCO_3^{2-} > SO_4^{2-}$, contributing on an average (mg L^{-1}), 57.52, 30.09, and 12.40% of the total anions, respectively. Sulfate content was higher during post-monsoon (1333.75 ppm), probably due to action of leaching and anthropogenic activities from nearby industries. Nitrate ion concentrations were found to be below WHO limit for groundwater quality (i.e. 45 mg L^{-1}). Fluoride ion concentration in some samples was found to be higher than the WHO limit for groundwater quality (i.e. 1 mg L^{-1}).

There were many samples with very high COD values (65%) suggesting the presence of organic pollutants in the groundwater of the study area.

Total dissolved solids also showed a wide variation from 260 to 9,750 mg/L during pre-monsoon, and from 680 to 17,000 mg/L during post-monsoon. High values were recorded at borewells located close to Umaraya, Vedach, and Sutharipura. According to the salinity classification by [15], groundwaters were classified into non-saline/fresh water (TDS < 1,000 mg/L), slightly saline (TDS = 1,000–3,000 mg/L), moderately saline (TDS = 3,000–10,000 mg/L), and very saline (TDS > 10,000 mg/L) water. It is observed that 15.6% of the groundwater samples under study were of fresh water category, 50% were slightly saline, and 34.4% were moderately saline in both seasons. One sample near Vedach was found having TDS value more than

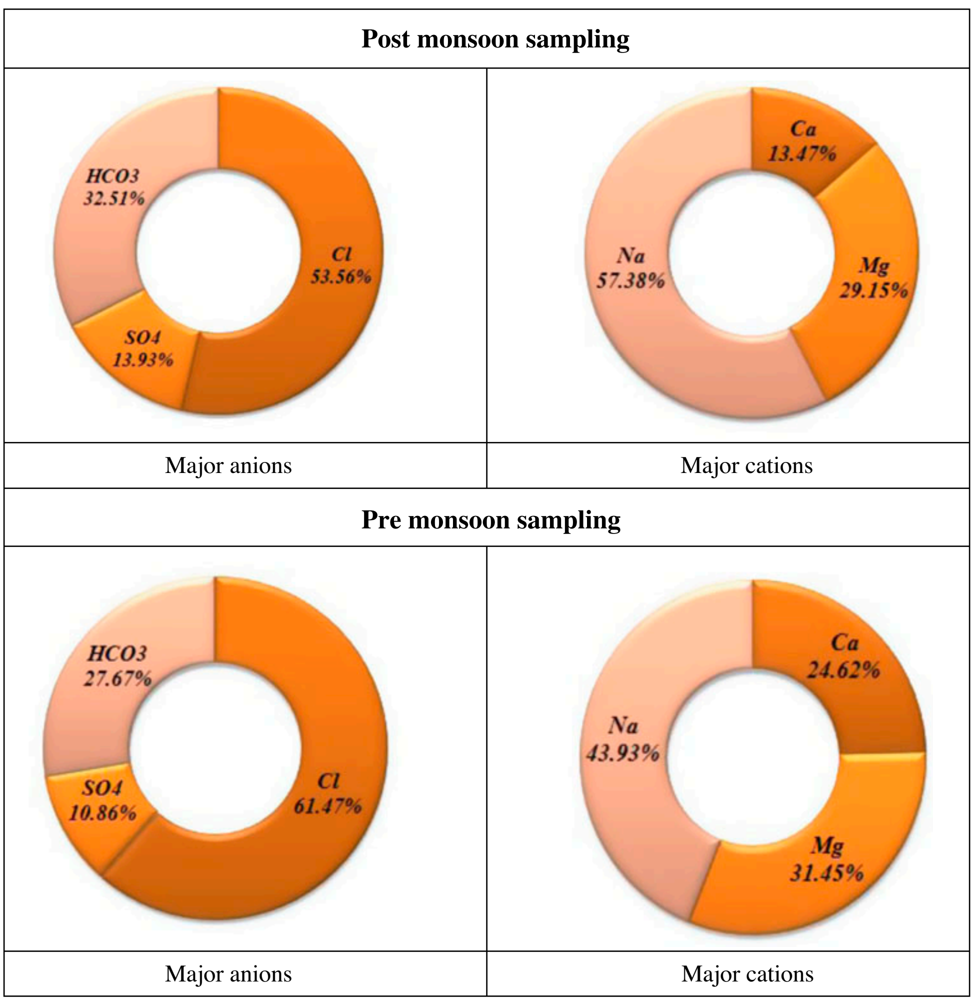

Fig. 2. Major ion contribution study.

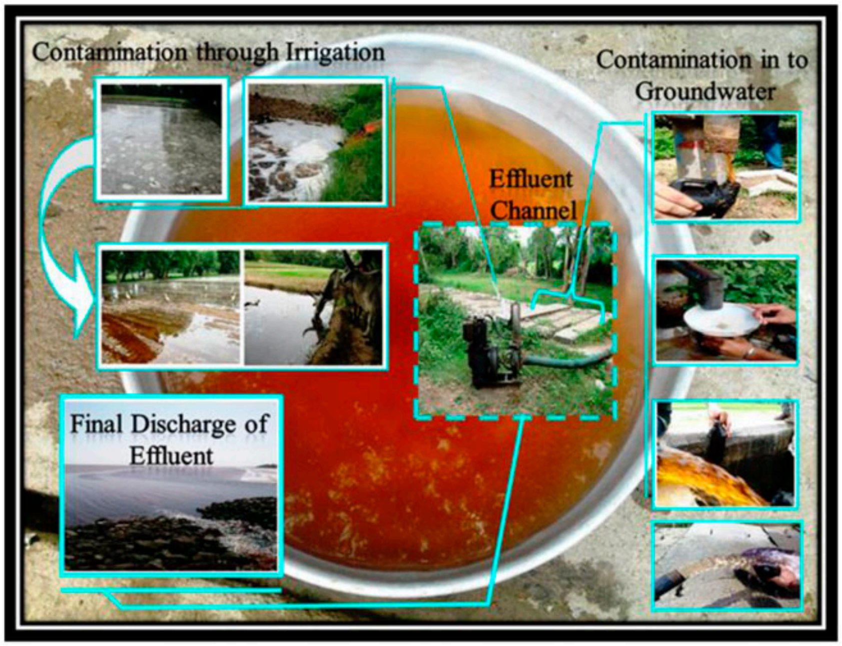

Fig. 3. Pictorial representation of groundwater quality and effect of effluent channel in study area.


GUJARAT

Units dumping toxic effluent in Mahi, says CPCB

CPCB DIRECTIONS

REPORTSPEAK

GUJARAT

Groundwater in Vadodara village scares

CONTAMINATION Villagers in state's 'vegetable basket' say yield has declined; dye unit in dock

Water in and around 55 wells and tubewells in Luna has turned red and yellow.

Fig. 4. Articles of newspaper regarding water quality in study area.

10,000 mg/L. This may indicate the possibility of high rate of incursion/intrusion of saline water [5].

3.1. Correlation studies

Inter-elemental correlation was made (Tables 3a and 3b) for understanding the relationship between different ionic species [17,18].

In post-monsoon, TDS was related to calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), and sulfate (SO_4^{2-}) with a correlation coefficient (*r*) of 0.271, 0.3431, 0.9612, and 0.8398, respectively; and TH was related to these with a correlation coefficient value of 0.339, 0.466, 0.9335, and 0.686, respectively. The interspecies correlation shows correlation of permanent hardness of Ca^{2+}

Table 3a
Correlation matrix for the water quality parameters (post-monsoon)

Correlation coefficient matrix of water quality parameters (post-monsoon)											
		pH	TH ppm	Ca ppm	Mg ppm	Na ppm	TDS ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	COD ppm
pH		1									
TH	ppm	−0.467	1								
Ca	ppm	−0.119	0.339	1							
Mg	ppm	−0.168	0.466	0.5726	1						
Na	ppm	0.0325	0.684	0.1074	0.1874	1					
TDS	ppm	−0.279	0.902	0.2712	0.3431	0.8713	1				
HCO_3	ppm	0.583	−0.764	−0.09	−0.225	−0.3	−0.533	1			
Cl	ppm	−0.322	0.9335	0.2919	0.3575	0.8597	0.9612	−0.663	1		
SO_4	ppm	−0.032	0.686	0.3902	0.3354	0.7374	0.8398	−0.202	0.7419	1	
COD	ppm	0.346	−0.121	−0.296	0.2423	0.039	−0.161	0.231	−0.099	−0.125	1

Table 3b
Correlation matrix for the water quality parameters (pre-monsoon)

		Correlation coefficient matrix of water quality parameters (pre-monsoon)									
		pH	TH ppm	Ca ppm	Mg ppm	Na ppm	TDS ppm	HCO_3 ppm	Cl ppm	SO_4 ppm	COD Ppm
pH		1									
TH	ppm	−0.647	1								
Ca	ppm	−0.642	0.919	1							
Mg	ppm	−0.619	0.9871	0.8442	1						
Na	ppm	0.0409	−0.443	−0.04	−0.441	1					
TDS	ppm	−0.197	−0.467	0.5038	0.4312	0.0231	1				
HCO3	ppm	0.4135	−0.515	−0.464	−0.512	0.4379	0.3098	1			
Cl	ppm	−0.398	0.819	0.8343	0.7753	−0.236	0.811	−0.199	1		
SO4	ppm	−0.228	0.489	0.3583	0.5206	−0.019	0.8024	0.1332	0.6404	1	
COD	ppm	−0.417	0.2635	0.4875	0.1603	−0.023	0.516	0.1914	0.4643	0.1418	1

Table 4a
Alkalinity hazard based on TDS value

TDS	Nature of water	Pre-monsoon	Post-monsoon
<1,000	Fresh water	18.75%	12.5%
1,000–10,000	Brackish water	81.25%	87.5%
10,000–1,00,000	Saline water	NIL	NIL
>1,00,000	Brine water	NIL	NIL

Table 4b
Suitability of groundwater for irrigation based on sodium alkalinity hazard

SAR	Water class	Post-monsoon	Pre-monsoon
<10	Excellent	NIL	31.25%
10–18	Good	43.75%	25%
18–26	Doubtful	18.75%	25%
>26	Unsuitable	37.5%	18.75%

Table 4c
Suitability of groundwater for irrigation based on percent sodium

Percent sodium	Nature of water	Post-monsoon	Pre-monsoon
<20	Excellent	NIL	6.25%
20–40	Good	12.5%	25%
40–60	Permissible	37.5%	37.5%
60–80	Doubtful	31.25%	31.25%
>80	Unsuitable	18.75%	NIL

and Mg^{2+} with Cl^- with a correlation coefficient value of 0.8343 and 0.7753, respectively.

Similarly, in pre-monsoon season, TDS was related to calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), and sulfate (SO_4^{2-}) with a correlation coefficient (r) of

Table 4d
Suitability of groundwater for irrigation based on residual carbonate

RSC (epm)	Remark on quality	Post-monsoon	Pre-monsoon
<1.25	Good	62.5%	50%
1.25–2.5	Doubtful	6.25%	6.25%
>2.5	Unsuitable	31.25%	43.75%

Table 5
Classification based on Piper diagram

Legend	Type
A	Calcium type
B	No dominant TYPE
C	Magnesium type
D	Sodium and potassium type
E	Bicarbonate type
F	Sulfate type
G	Chloride type

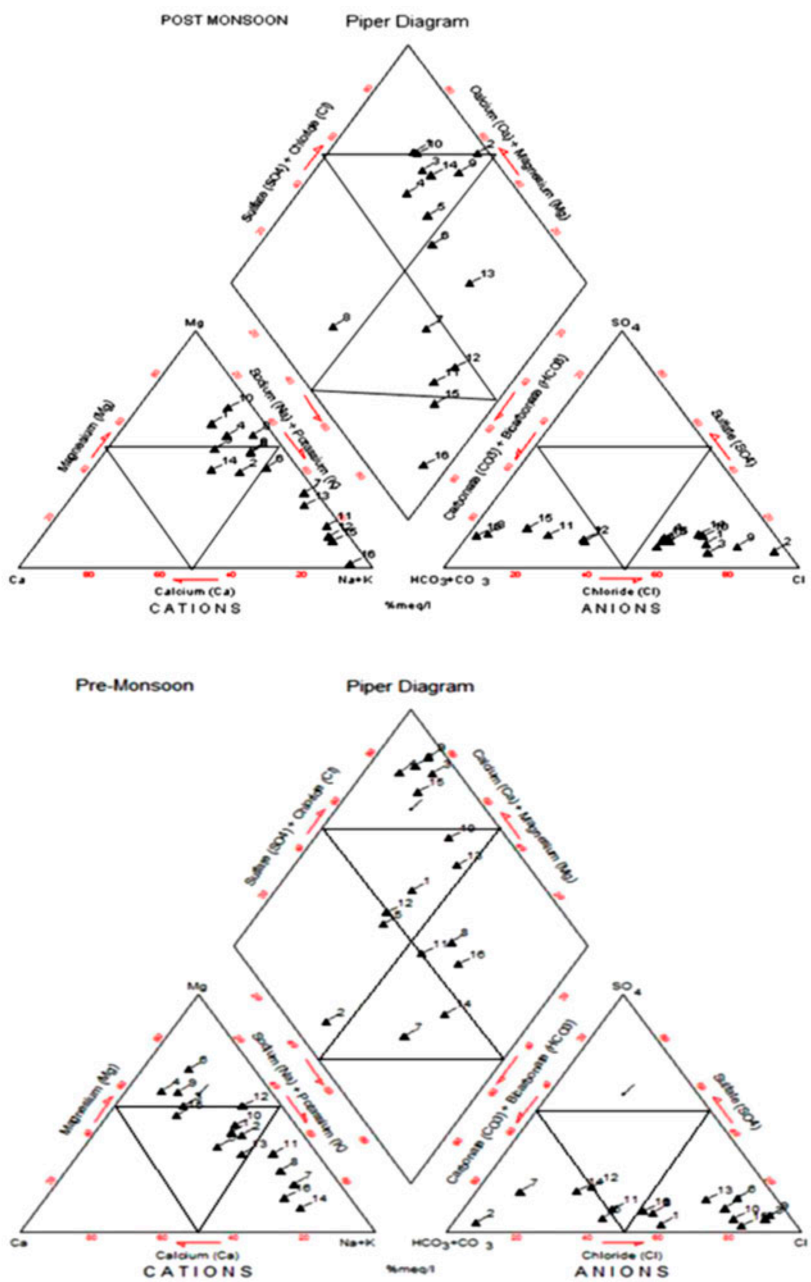

Fig. 5. Groundwater sample plotted in piper trilinear diagram.

0.5038, 0.4312, 0.811, and 0.8024, respectively; and TH was related to these with a correlation coefficient value of 0.919, 0.9871, 0.819, and 0.489, respectively.

3.2. Water quality for irrigation purposes

The suitability of the groundwater samples in the study area, for irrigation was next investigated [14,19]. Parameters such as EC, percent sodium, SAR, RSC, and piper trilinear as well as Gibbs diagram were used to assess the suitability of water for irrigation purposes. Based on EC values, 78% samples were found to be saline. Excess salt results in a drought like condition due to increase in the osmotic pressure.

3.3. Alkalinity hazards

Factors like TDS, SAR, percentage of sodium, and RSC are important tools for determining the alkalinity hazards [5,14] and the suitability of groundwater for the irrigation purpose. According to salinity classification based on TDS by Rabinove (1958), 34% of the samples were found to be highly saline suggesting intrusion of saline water (Table 4a).

3.4. Sodium adsorption ratio (SAR)

It is an important parameter for determining the suitability [2,20,21] of groundwater for irrigation purposes 37.5% of samples during post-monsoon and 18.75% of samples during pre-monsoon had an SAR value >26 and hence were unsuitable for irrigation. There were no samples falling in the excellent range of SAR in post-monsoon samples while 31.25% of samples were falling in the excellent range of SAR in pre-monsoon season (Table 4b).

Percent Na^+ is another widely used parameter for evaluating the suitability of water quality for irrigation [22]. From Table 4c it is evident that the percent sodium was high (>80%) in 18.75% of analyzed post-monsoon samples suggesting that the groundwater was not suitable for irrigation in those regions.

When the range of sodium is high, it will be absorbed by the clay particles, displacing Mg^{2+} and Ca^{2+} ions. The exchange process of Na + in water for Mg^{2+} and Ca^{2+} ions in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry.

In waters having high concentration of bicarbonate [20,22,23], there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate (RSC).

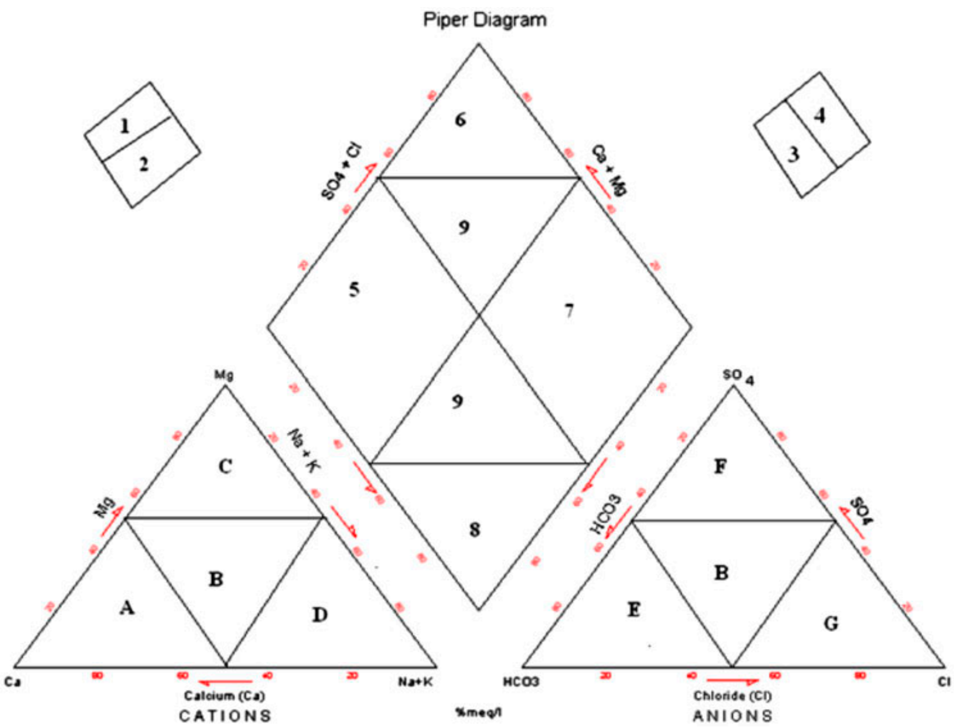

Fig. 6. Classification diagram for anion and cation in the form of major-ion percentage.

Table 6
Characterization of groundwater of the study area on the basis of piper trilinear diagram

Subdivision of the diamond	Characteristics of corresponding subdivisions of diamond-shaped fields	Percentage of samples in this category	
		Pre-monsoon (%)	Post-monsoon (%)
1	Alkaline earth (Ca+Mg) Exceed alkalies (Na+K)	68.75	56.25
2	Alkalies exceeds alkaline earths	31.25	43.75
3	Weak acids (CO_3+HCO_3) exceed Strong acids (SO_4+Cl)	37.5	37.5
4	Strong acids exceeds weak acids	62.5	62.5
5	Magnesium bicarbonate type	18.75	6.25
6	Calcium-chloride type	31.25	18.75
7	Sodium-chloride type	12.5	12.5
8	Sodium-Bicarbonate type	0	6.25
9	Mixed type (No cation-anion exceed 50%)	37.5	56.25

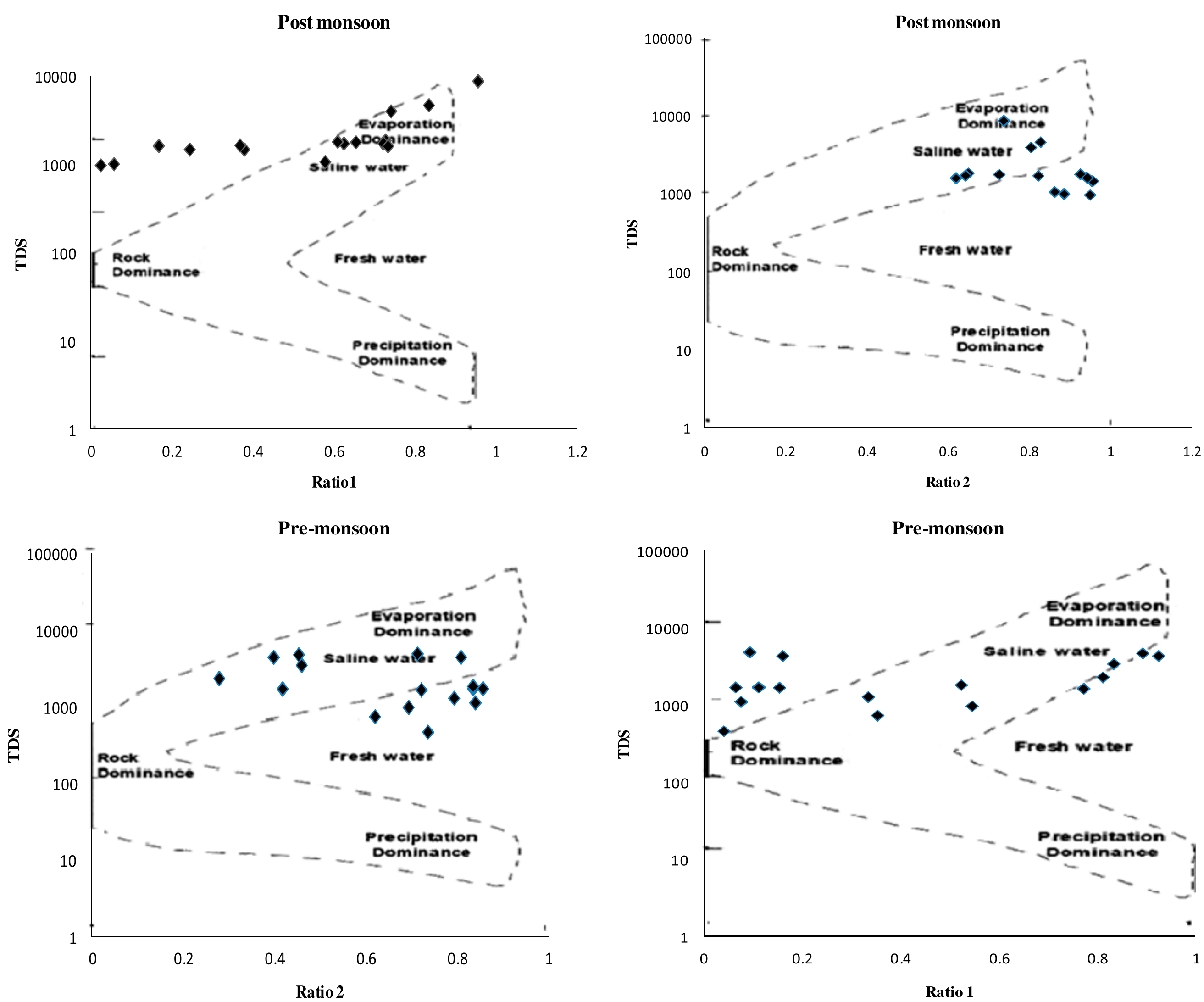

Fig. 7. Gibb's diagram for the groundwater study.

Water having more than 2.5 epm of RSC is not suitable for irrigation purposes. The classification of groundwater on the basis of RSC is presented in Table 4d for both pre- and post-monsoon seasons. Based on RSC values, over 62.5% samples during post-monsoon and 50% samples during pre-monsoon were found to have values less than 1.25 and hence are safe for irrigation purposes. Over 31.25% samples during post-monsoon and 43.75% of the samples in the pre-monsoon were found to be unsuitable for irrigation purposes.

3.5. Hydro-geochemical facies

Hydrochemical facies are distinct zones that possess cation and anion concentration categories. The Piper-Hill diagram [24,25] is used to infer hydrogeochemical facies. These plots include two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydrogeochemical facies concept. These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting methods. These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting methods.

Piper trilinear diagrams for pre-and post-monsoon seasons are presented in Fig. 5. Water types are designed according to the domain in which they occur on the diagram segments as shown in Table 5 and also graphical representation is given in Fig. 6. These diagrams reveal small variations in the study area during pre-monsoon and post-monsoon seasons and are listed in Table 6.

Ca-Mg-type of water predominated during pre-monsoon. The percentage of samples falling under Ca-Mg-type was 68% during pre-monsoon season and 56.25% during post-monsoon. Sulfate type of water predominated during pre-monsoon with 62.5% samples during both post-monsoon and pre-monsoon seasons.

3.6. Groundwater quality based on Gibb's ratio

Various factors controlling groundwater chemistry were analyzed by Gibb's diagram [26] as shown in Fig. 7. Three types of distinct fields are recognized in the Gibbs' diagram such as precipitation dominance, evaporation dominance, and rock dominance. Gibbs' ratio $1 = Cl/(Cl+HCO_3)$ for anion and ratio $2 = Na+K/(Na+K+Ca)$ for cation of groundwater samples of the study area were plotted separately against the respective values of total dissolved solids [8]. Gibb's ratio 1 and ratio 2 have been calculated and are represented in Table 7. Ratio 1 ranged from 0.031 to 0.94 with an average of 0.472, while Ratio 2 ranged from 0.461 to 0.906 with an average of 0.740 in the groundwater samples under study.

Table 7
Water quality assessment using statistical analysis

No.	Post-Monsoon						Pre-Monsoon					
	TDS	SAR	Ratio1	Ratio2	%Na	RSC	TDS	SAR	Ratio1	Ratio2	%Na	RSC
1	1870.0	12.0	0.7	0.6	36.9	0.1	990.0	15.0	0.5	0.7	49.7	1.2
2	8800.0	42.4	1.0	0.7	74.9	−2.6	470.0	12.2	0.0	0.7	53.6	0.7
3	1740.0	14.1	0.7	0.6	36.6	3.6	4800.0	8.6	0.9	0.5	27.6	−2.2
4	1790.0	15.4	0.7	0.7	43.3	3.1	2350.0	3.7	0.8	0.3	15.0	−1.5
5	1730.0	20.3	0.6	0.8	45.3	4.7	750.0	12.7	0.4	0.6	47.4	1.4
6	1070.0	21.8	0.6	0.9	50.4	2.5	3500.0	5.9	0.8	0.5	20.5	−2.4
7	1480.0	35.6	0.4	1.0	68.1	−4.4	1740.0	35.0	0.1	0.9	75.6	3.6
8	1010.0	16.4	0.1	0.9	66.9	−2.7	1860.0	21.9	0.5	0.8	70.4	5.0
9	4700.0	27.1	0.8	0.8	73.7	3.3	4450.0	7.1	0.9	0.4	21.9	−4.2
10	4000.0	14.7	0.7	0.8	40.9	4.8	1670.0	18.1	0.8	0.7	49.8	−0.1
11	1480.0	41.5	0.2	1.0	48.0	1.1	1730.0	18.4	0.1	0.8	66.0	4.8
12	1650.0	62.9	0.4	0.9	86.6	−0.4	1300.0	15.5	0.3	0.8	49.3	2.7
13	1810.0	45.4	0.6	0.9	86.8	0.8	4950.0	19.2	0.1	0.7	56.2	3.8
14	1610.0	14.6	0.7	0.6	65.5	0.3	1130.0	35.7	0.1	0.8	79.2	3.2
15	1630.0	48.4	0.2	0.9	44.0	−2.6	1720.0	7.8	0.2	0.4	26.8	−1.6
16	980.0	75.3	0.0	1.0	89.5	−1.9	4450.0	29.1	0.2	0.8	74.1	8.9

Groundwater samples for fresh and saline waters were individually scattered in the rock and evaporation dominance fields in both seasons. Saline waters showed more of evaporation dominance while freshwaters showed rock dominance. The Gibb's study suggests the ingress of salinity into the area [26].

4. Conclusion

The chemical composition of groundwater of the study area was found to be strongly influenced by effective weathering and leaching action along with anthropogenic activities. The groundwater samples irrespective of seasons belonged to Ca–Mg–SO_4–Cl type. EC, TDS, TH, TA, and sodium content were higher during post-monsoon due to effective leaching and anthropogenic activities. On the other hand, COD was found to be higher during pre-monsoon as compared to post-monsoon. From Gibbs study, it was observed that saline waters were showing more of evaporation dominance while the few freshwater samples which were present were showing rock dominance suggesting ingress of salinity in the study area. From the piper diagram, we can conclude that alkaline earths (Ca^{2+}+Mg^{2+}) exceeded over alkaline (Na^{+}+K^{+}) where in strong acid anions (SO_4^{2-}+Cl^{-}) predominated. The SAR values and RSC values indicated that 31–38% post-monsoon samples and 19–44% pre-monsoon samples were unsuitable for irrigation.

Thus, some of the groundwater sources of the study area are unfit for domestic and drinking purpose and needs treatment to minimize the alkalinity, acidity, and COD before the water is further put to use. Some colored samples and high COD values suggest groundwater contamination due to effluents. However, there was no contamination of groundwater with metals. The present study provides the basic data on the groundwater quality. Further, analysis of the presence of organics in the groundwater has to be done.

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References

[1] M. Vasanthavigar, K. Srinivasamoorthy, K. Vijayaragavan, R. Rajiv Ganthi, S. Chidambaram, P. Anandhan, R. Manivannan, S. Vasudevan, Application of water quality index for groundwater quality assessment, Thirumanimuttar sub-basin, Tamilnadu, India, Environ. Monit. Assess. 171 (2010) 595–609.

[2] L. Khodapanah, W.N.A. Sulaiman, N. Khodapanah, Groundwater quality assessment for different purposes in Eshtehard district, Tehran, Iran, Eur. J. Sci. Res. 36(4) (2009) 543–553.

[3] A.A. Zorpas, C. Coumi, M. Drtil, I. Voukalli, Municipal sewage sludge characteristics and waste water treatment plant effectiveness under warm climate conditions, Desalin. Water Treat. 36 (2011) 319–333.

[4] J.K. Chawala, S.D. Khepar, S.K. Sondhi, A.K. Yadav, Assessment of long-term groundwater behaviour in Punjab, India, Water Int. 35(1) (2010) 63–77.

[5] N.C. Mondal, V.S. Singh, V.K. Saxena, V.P. Singh, Assessment of seawater impact using major hydrochemical ions: A case study from Sadras, Tamilnadu, India, Environ. Monit. Assess. 177 (2011) 315–335.

[6] J.R. Fianko, D. Adomako, S. Osae, S. Ganyaglo, B.K. Kortatsi, C.K. Tay, E.T. Glover, The hydrochemistry of groundwater in the Densu river basin, Ghana, Environ. Monit. Assess. 167(1–4) (2010) 663–674.

[7] V.N. Bulut, A. Bayram, A. Gundogdu, M. Soylak, M. Tufekci, Assessment of water quality parameters in the stream Galyan, Trabzon, Turkey, Environ. Monit. Assess. 165 (2010) 1–13.

[8] T. Rajaram, A. Das, Water pollution by industrial effluents in India: Discharge scenarios and case for participatory ecosystem specific local regulation, Futures 40 (2008) 56–69.

[9] M. Adekunle1, M.T. Adetunji, A.M. Gbadebo1, O.B. Banjoko1, Assessment of groundwater quality in a typical rural settlement in southwest Nigeria, Int. J. Environ. Res. Public Health. 4(4) (2007) 307–318.

[10] N. Rajkumar, T. Subramani, L. Elango, Groundwater Contamination due to municipal solid waste disposal – A GIS based study in Erode city, Int. J. Environ. Sci. 1(1) (2010) 39–55.

[11] F. Hamzaoui-Azaza, M. Ketata, R. Bouhlila, M. Gueddari, L. Riberio, Hydro-geochemical characteristics and assessment of drinking water quality in Zeuss–Koutine aquifer southeastern Tunisia, Environ. Monit. Assess. 174 (2011) 283–298.

[12] L.S. Clesceri, A.E. Greenberg, A.D. Eaton, Standard Methods for Examination of Water and Wastewater, twentieth ed., American Public Health Association (APHA), Washington, DC, 1998.

[13] D. Gupta, R. Jayakrishnan and P.R. Onta, Assessment of Groundwater Quality for the Bangkok Aquifer System. Models for Assessing and Monitoring Groundwater Quality, Oxfordshire OX10 8BB, Wallingford, 1995, pp. 3–10.

[14] N.J. Raju, U.K. Shukla, P. Ram, Hydrogeochemistry for the assessment of groundwater quality in Varanasi: A fast-urbanizing center in Uttar Pradesh, India, Environ. Monit. Assess. 173 (2011) 279–300.

[15] L. Rabinove, R.H. Longford, J.W. Brookhart, Saline Water Resources of North Dakota, US Geographical Survey Water Supply, Washington, DC, 1958 Paper 1418.

[16] CPCB Report, February 2010, Available from: http://www.indiaenvironmentportal.org.in/files/Final%20Report.doc

[17] J.K. Pathak, M. Alam, S. Sharma, Interpretation of groundwater quality using multivariate statistical technique in Moradabad city, Western Uttar Pradesh state, India, E-J. Chem. 5(3) (2008) 607–619.

[18] C.R. Ramakrishnaiah, C. Sadashiviah, G. Ranganna, Assessment of water quality index for the groundwater in Tumkur taluk, Karnataka state, India, E-J. Chem. 6(2) (2009) 523–530.

[19] R. Shyamala, M. Shanthi, P. Lalitha, Physicochemical analysis of borewell water samples of Telungupalayam area in Coimbatore district, Tamilnadu, India, E-J. Chem. 5(4) (2008) 924–929.

[20] V.K. Saxena, V.S. Singh, N.C. Mondal, S.C. Jain, Use of hydrochemical parameters for the identification of fresh groundwater resources, Potharlanka island, India, Environ. Geol. 44 (5) (2003) 516–521.

[21] J.D. Hem, Study and Interpretation of Chemical Characteristics of Natural Water, US Geological Survey Water Supply, Alexandria, VA, 1985 Paper No 2254.

[22] L.V. Wilcox, Classification and Use of Irrigation Waters, U.S. Dept. Agri. Circular, Washington, DC, 1955, p. 19.

[23] D.K. Tank, C.P.S. Chandel, Analysis of the major ion constituents in groundwater of Jaipur city, Nat. Sci. 8(10) (2010) 1–7.
[24] C. Sadashivaiah, C.R. Ramakrishnaiah, G. Ranganna, Hydrochemical analysis and evaluation of groundwater quality in Tumkur taluk, Karnataka state, India, Int. J. Environ. Res. Publ. Health 5(3) (2008) 158–164.
[25] M. Piper, A Graphic Procedure I the Geo-Chemical Interpretation of Water Analysis, USGS Groundwater, Washington, DC, Note no 12 ,1953.
[26] R.J. Gibbs, Mechanisms controlling world water chemistry, Science 170 (1970) 1088–1090.