ORIGINAL ARTICLE

Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India

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Abstract In the present study, the geochemical characteristics of groundwater and drinking water quality has been studied. 24 groundwater samples were collected and analyzed for pH, electrical conductivity, total dissolved solids, carbonate, bicarbonate, chloride, sulphate, nitrate, calcium, magnesium, sodium, potassium and total hardness. The results were evaluated and compared with WHO and BIS water quality standards. The studied results reveal that the groundwater is fresh to brackish and moderately high to hard in nature. Na and Cl are dominant ions among cations and anions. Chloride, calcium and magnesium ions are within the allowable limit except few samples. According to Gibbs diagram, the predominant samples fall in the rock–water interaction dominance and evaporation dominance field. The piper trilinear diagram shows that groundwater samples are Na–Cl and mixed CaMgCl type. Based on the WQI results majority of the samples are falling under excellent to good category and suitable for drinking water purposes.

Keywords Gibbs and Piper diagram · Groundwater quality · Anna Nagar · Part of Chennai city

Introduction

Ground water contamination in urban environment is a major issue and is complicated by large number of potential source of contamination (Jayaprakash et al. 2008). India has wide spectral variations of meteorological, topographical, geomorphological, hydrological, geological, and hydrogeological conditions. The chemistry of groundwater is an important factor determining its use for domestic, irrigation and industrial purposes. Utilization of land varies from place to place due to rapid urbanization and industrialization, without following the strict environmental norms, causing a lot of variation of quality of groundwater within a short distance, which constrains the developmental activities drastically everywhere (Subba Rao 1997, 2006). The urban aquifers are the only natural resource for drinking water supply, they are often perceived as of lesser relevance for the drinking water supply, leading to crisis in terms of drinking water scarcity, becoming increasingly polluted thereby decreasing their potability (Dixit et al. 2005; Tiwari et al. 2012). Once contamination of groundwater in aquifers occurs by means of industrial activities and urban development, it persists for hundreds of years because of very slow movement of water in them (Jerry 1986) and prompts investigations on their quality. The knowledge of hydrochemistry is important to assess the ground water quality in any area in which the ground water is used for both irrigation and drinking needs (Srinivas et al. 2013). The water quality

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assessment may give clear information about the subsurface geologic environments in which the water presents (Raju et al. 2011). The conventional techniques such as trilinear plots, statistical techniques are widely accepted methods to determine the quality of water. The problems of ground water quality are more acute in areas that are coastal, densely populated and thickly industrialized and have shallow groundwater tube wells (Ballukraya and Ravi 1999; Reddy and Subba Rao 2001; Malini et al. 2003; Krishna kumar et al. 2011; Padmalal et al. 2012; Bagyaraj et al. 2013; Selvam et al. 2013). The present study was carried out for qualitative analysis based on physico-chemical parameters of groundwater.

Study area

Chennai, formerly known as Madras, is the capital of the state of Tamil Nadu and India's fourth largest metropolitan city. The latitude of Chennai city is 13.04°N and longitude 80.17°E. The city covers an area of 174 km². The metropolitan area covers 1,177 km². The city is divided into four major parts like North, Central, South and West regions. The northern localities are devoted for the automobile

industries, other medium- and small-scale industries. The study area has unmatched importance as a commercial and residential area in West Chennai. The study area extends from 13°5′31″ North to 80°11′57″ East (Fig. 1). The population of the Chennai city is 8,917,749 with a density of 26,702/km² (CDSH 2012).

The Northeast monsoon during the month of October, November and December chiefly contributes rainfall to the study area. Most of the precipitation occurs in the form of one or two cyclones caused due to depressions in Bay of Bengal. The average annual rainfall of the study area is 1,200 mm. The Chennai district enjoys a tropical climate with a mean annual temperature of 24.3–32.9 °C. The humidity is usually in the range of 6–84 %. Chennai is underlain by various geological formations from ancient Archaean to the Recent Alluvium. The geological formations can be grouped into three units, namely (1) the Archaean crystalline rocks, (2) consolidated Gondwana and Tertiary sediments, and (3) the Recent Alluvium. The study area chiefly consists of unconfined Tertiary sedimentary aquifers. The Archaean crystalline rocks comprise chiefly of Charnockites, gneisses and the associated basic and ultra basic intrusive. The alluvium consists of sand, silt
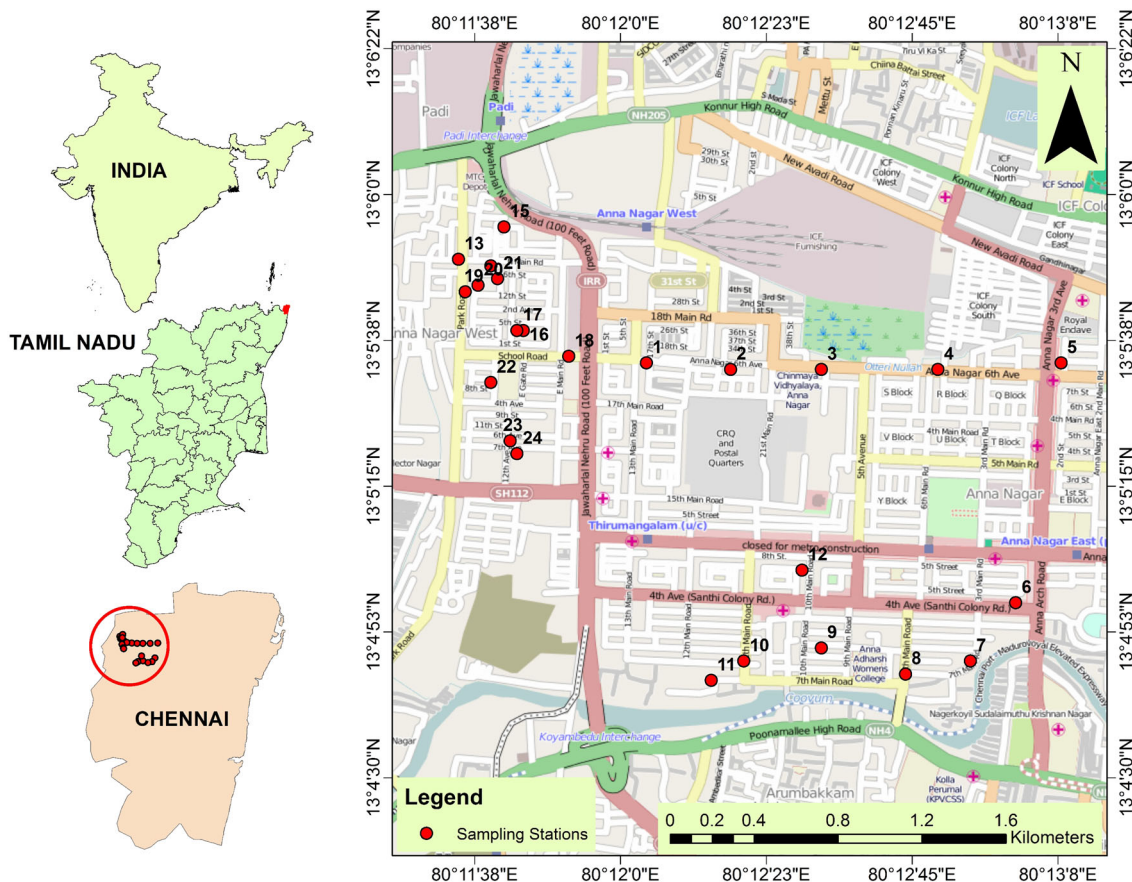

Fig. 1 Sampling location map of the study area

and clays. The thickness of alluvium varies from place to place and a maximum of 28 m is encountered in north Chennai. The computed transmissivity varied between 6.00 and 872 m^2/day and the storativity varied between 2.9×10^{-4} and 4.5×10^{-3} (CGWB Technical Report 2008).

Materials and methods

Representative ground water samples were obtained from 24 bore wells selected on the basis of geographical variation, the depth ranges from 80–150 m. The electrical conductivity, temperature and pH were measured in situ. Field measurements of pH and electrical conductivity (EC) were made using a handheld pH and EC meter (HANNA HI—9828, USA). Bicarbonate analysis was carried out using acid titration method; chloride concentration was measured by AgNO$_3$ titration method; sulphate by BaCl$_3$ turbidity method using a spectrophotometer. Sodium and potassium were analyzed using flame photometer; calcium and magnesium by the titration method. The analytical procedures are as suggested by the American Public Health Association (APHA 1995). The analytical precision and measurement reproducibility was less than 2 %. The ionic balance error for studied ions was within ±5 %. The base map of the study area was prepared using the Survey of India topographic sheets and digitized using Arc GIS 9.3 software. Trimble® Recon GPS was used to find the location of each sampling site and the coordinates were imported to GIS platform for preparation of the base map. The geochemical results are plotted on piper trilinear plot using AquaChem 4.0 software and Gibbs diagram is plotted to assess the quality controlling mechanism and dominated hydro-geochemical facies of the study area. Statistical analysis was performed using SPSS software package (SPSS, 2001). The physico-chemical parameters of the analytical results of groundwater were compared with standard guideline values recommended by the WHO.

Water quality index calculation

The water quality index (WQI) was calculated for evaluating influence of natural and anthropogenic activities based on several key parameters of groundwater chemistry. To calculate the WQI, the weight has been assigned for the physico-chemical parameters according to the parameters relative importance in the overall quality of water for drinking water purposes. The assigned weight ranges from 1 to 5. The maximum weight of 5 has been assigned for nitrate and TDS, 4 for pH, EC, SO$_4$, 3 for HCO$_3$, Cl, 2 for Ca, Na, K and weight 1 assigned for magnesium (Vasanthavigar et al. 2010). The relative weight is computed from the following equation.

$$Wi = wi / \sum_{i=1}^{n} wi, \tag{1}$$

where

Wi is the relative weight

wi is the weight of each parameter

n is the number of parameters.

The quality rating scale for each parameter is calculated by dividing its concentration in each water sample by its respective standards (World Health Organization 2011) and multiplied the results by 100.

$$qi = (Ci/Si) \times 100, \tag{2}$$

where

qi is the quality rating

Ci is the concentration of each chemical parameter in each sample in milligrams per liter

Si is the World Health Organization standard for each chemical parameter in milligrams per liter according to the guidelines of the (WHO 2011)

For computing the final stage of WQI, the SI is first determined for each parameter. The sum of SI values gives the water quality index for each sample.

$$SIi = Wi \times qi \tag{3}$$

$$WQI = \sum SIi, \tag{4}$$

where

SIi is the sub-index of ith parameter

qi is the rating based on concentration of ith parameter

n is the number of parameters

Results and discussion

The statistical parameters like minimum, maximum and mean concentration of physico-chemical parameters, major ion concentrations are tabulated in Table 1.

Temperature and pH

The temperature variation ranges from 26 to 27 °C with a mean value of 26.67 °C. The pH indicates the strength of the water to react with the acidic or alkaline material present in the water. It controls by carbon dioxide, carbonate and bicarbonate equilibrium (Hem 1985). The combination of CO$_2$ with water forms carbonic acid, which affects the pH of the water. The permissible limit of pH is 6.5–8.5. The pH in the groundwater is varied from 6.0 to 8.2. This may be attributed to the anthropogenic activities like sewage disposal and improper irrigation process and weathering process in the study area.

Table 1 Statistics of physico-chemical parameters, major ions ($n = 24$), World Health Organization (World Health Organization 2011) and Bureau of Indian Standards (BIS, 1991) for drinking waters of study area

Parameters	Minimum	Maximum	Mean	WHO standard (2011)	BIS standard (1991)
Temp (°C)	26 °C	27 °C	26.67 °C	–	–
pH (on scale)	6	8.2	7.03	6.5–8.5	6.5–8.5
EC (μS/cm)	580	7,250	1,828	1,500	–
TDS (mg/l)	373.5	4,669	1,177	500	500
HCO$_3$ (mg/l)	18.3	359.9	165.7	500	–
Cl (mg/l)	115.21	2,011.8	383.3	250	250
SO$_4$ (mg/l)	22.2	98.6	53.9	250	200
NO$_3$ (mg/l)	0.1	3.9	1.013	45	45
Ca^{2+} (mg/l)	26	130	53.5	75	75
Mg^{2+} (mg/l)	1.2	141.6	18.8	50	30
Na$^+$ (mg/l)	71	1,200	258.9	200	–
K$^+$ (mg/l)	3	36	9.33	12	–
TH (mg/l)	89.5	814.55	211.58	–	–

Electrical conductivity (EC)

Electrical conductivity is a measure of water capacity to convey the electrical current. The most desirable limit of EC in drinking water is prescribed as 1,500 μS/cm. The value of EC is between 580 and 7,250 μS/cm. EC measures the ability of a material to conduct an electric current such that the higher EC indicates enrichment of salts in the groundwater. Thus, the EC can be classified as type I, if the enrichments of salts are low (EC < 1,500 μS/cm); type II, if the enrichment of salts are medium (EC: 1,500 and 3,000 μS/cm); and type III, if the enrichments of salts are high (EC > 3,000 μS/cm; Sarath Prasanth et al. 2012). According to the classification of EC, 63 % of the total groundwater samples (1, 3–9, 12, 15, 18, 20–23) falling under the type I (low enrichment of salts), 25 % of the samples (13, 14, 16, 17, 19, 24) under the type II (medium enrichment of salts), and 12 % of the samples (2, 10, 11) under the type III (high enrichment of salts).

Total dissolved solids (TDS)

Total dissolved salts in the groundwater is between 373.52 and 4,669 mg/l. Low TDS (373.52–895.16 mg/l) is observed in the samples 1, 3–9, 15,18 and 23 which indicates the influence of rock–water interaction in relation to recharge water. The high TDS observed in the study area ranges from 959.56 to 4,669 mg/l; the occurrence of high TDS is due to the influence of anthropogenic sources, such as domestic sewage, septic tanks and agricultural activities. According to WHO

specification TDS up to 500 mg/l is the highest desirable and up to 1,500 mg/l is maximum permissible.

Degree of groundwater quality can be classified as fresh, if the TDS is less than 1,000 mg/l; brackish, if the TDS is between 1,000 and 10,000 mg/l; saline, if the TDS is varied from 10,000 to 1,000,000 mg/l; and brine, if the TDS is more than 1,000,000 mg/l (Todd 1980). Accordingly, the quality of groundwater in the present study area is classified as fresh and brackish in 70 and 30 % of the total water samples.

Bicarbonate (HCO$_3$)

The concentration of carbonates in natural waters is a function of dissolved carbon dioxide, temperature, pH, cations and other dissolved salts. Bicarbonate concentration of natural waters generally held within a moderate range by the effects of the carbonate equilibrium. Most surface streams contained less than 200 mg/l of carbonate and bicarbonate, but in ground water somewhat higher. The concentration of bicarbonate is observed from 18.3 to 359.9 mg/l, few samples exceeding the permissible limits of bicarbonate.

Chloride (Cl)

The chloride ion is the most predominant natural form of the element chlorine and is extremely stable in water. The chloride in groundwater may be from diverse sources such as weathering, leaching of sedimentary rocks and soil, domestic and municipal effluents (Sarath Prasanth et al. 2012). The range of chloride is found to vary between 115.21 and 2,011.8 mg/l for water samples. As per (World Health Organization 2011) and Indian standards (BIS, 1991) the desirable limit for chloride is 250 mg/l. For the study area it has been found that in certain locations the chloride concentration exceeds the maximum permissible limit. The chloride ion concentration in groundwater of the study area exceeds the maximum allowable limit of 600 mg/l in two samples (2 and 11). They may be due to the lack of underground drainage system and bad maintenance of environment around the sources.

Sulphate (SO$_4$)

The concentration of sulphate is likely to react with human organs if the concentration exceeds the maximum allowable limit of 400 mg/l and causes a laxative effect on human system with the excess magnesium in groundwater. The content of SO$_4^-$ is observed from 22.2 to 98.6 mg/l. However, the sulphate concentration in groundwater of the study area is within the maximum allowable limit in the entire sample.
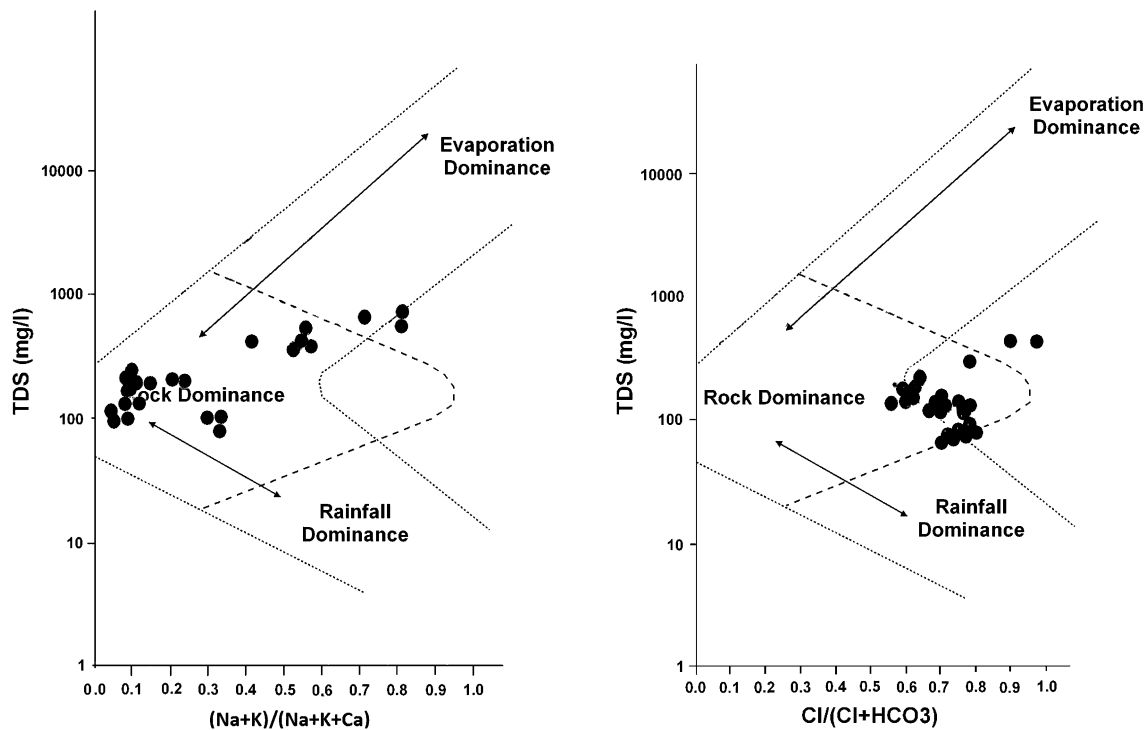
Fig. 2 Gibbs diagram

Nitrate (NO$_3$)

Nitrogen compounds are the most widespread contaminants in subsurface environments, mainly originating from non-point and multi-point agricultural sources (Pang et al. 2013). Epidemiological evidence suggests that nitrate-nitrogen exposure is strongly associated with several diseases, such as methemoglobinemia (blue baby syndrome), gastric cancer, thyroid disease and diabetes (Krishna Kumar et al., 2011). Hence, increasing nitrogen contamination seriously threatens public drinking water supply and human health. The value of NO$_3^-$ in the groundwater is observed between 0.1 and 3.9 mg/l with an average value of 1.01 mg/l. All samples are not exceeding the permissible limit of 45 mg/l as per WHO standard.

Calcium and magnesium (Ca and Mg)

The calcium and magnesium in waters are generally used to classify the suitability of water. Calcium and magnesium are directly related to hardness of the water and these ions are the most abundant elements in the surface and groundwater and exist mainly as bicarbonates and to a lesser degree in the form of sulphate and chloride. The concentration of Ca^{2+} is between 26 and 130 mg/l, and concentration of Mg^{2+} is varied from 1.2 to 141.6 mg/l. The maximum concentration of calcium ions can cause

abdominal ailments and is undesirable for domestic purposes as it causes encrustation and scaling. The higher concentration of Mg^{2+} (66 and 141.6 mg/l) is observed in the groundwater sample nos. 10 and 2. The rest of the groundwater samples show Mg^{2+} from 1.2 to 48 mg/l. The contribution of Ca^{2+} and Mg^{2+} to the total cations is approximately 7 to 19 % and 13 to 29 %, respectively.

Sodium and potassium (Na and K)

The concentration of Na$^+$ is varied from 71 to 1,200 mg/L. In general case, the Na$^+$ is the dominant ion among the cations and is present in most of the natural waters, which contributing approximately 53 to 69 % of the total cations. This is because of the silicate weathering and/or dissolution of soil salts stored by the influences of evaporation, anthropogenic activities, agricultural activities and poor drainage conditions. The higher contribution of Na$^+$ than that of the contribution of Ca^{2+} to the total cations is expected due to influence of ion exchange. However, the higher concentration of Na$^+$ observed from the groundwater samples contributes approximately 73 % to the total cations. K$^+$ is a naturally occurring element; but its concentration remains quite lower compared with Ca, Mg and Na. The average concentration of potassium is 9.33 mg/l and maximum value of 36 mg/l, which indicate the potassium form complexes in studied conditions.
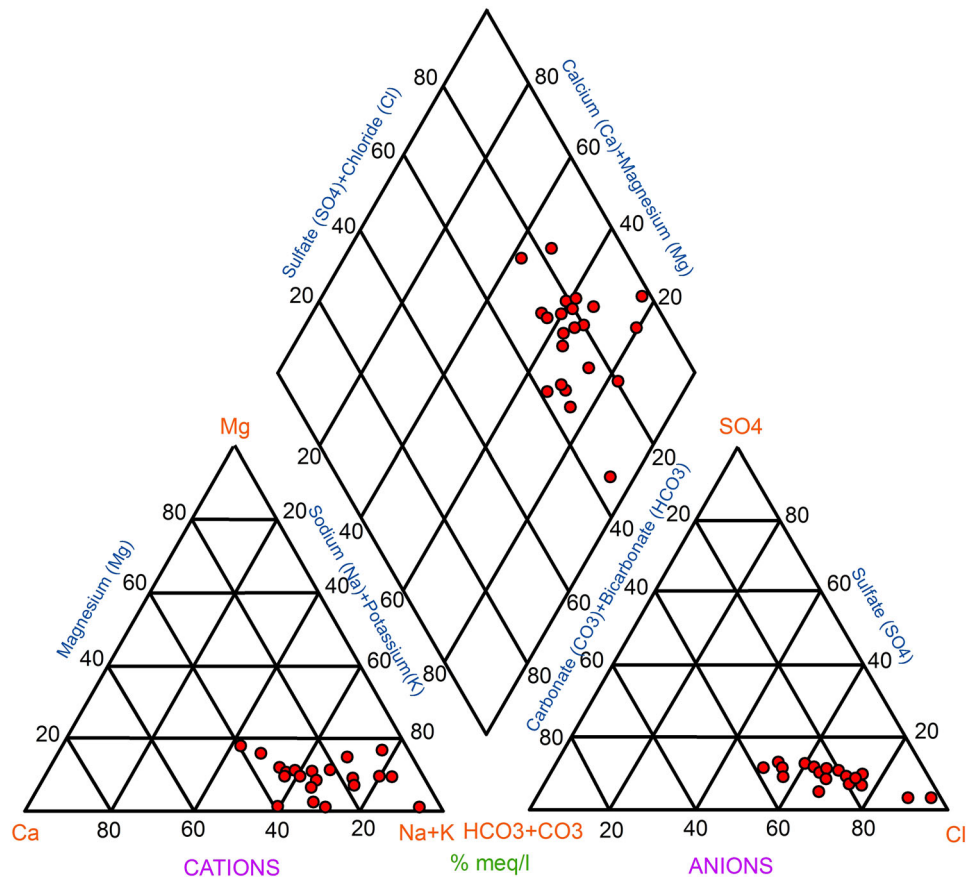
Fig. 3 Piper trilinear diagram

Table 2 Relative weight of chemical of physico-chemical parameters

Chemical parameters	WHO standards (2011)	Weight (wi)	Relative weight $Wi = wi / \sum_{i=1}^{n} wi$
pH (on scale)	6.5–8.5	4	0.114
EC (μS/cm)	500	4	0.114
TDS (mg/l)	500	5	0.142
HCO$_3$ (mg/l)	500	3	0.086
Cl (mg/l)	250	3	0.086
SO$_4$ (mg/l)	250	4	0.114
NO$_3$ (mg/l)	45	5	0.142
Ca (mg/l)	75	2	0.057
Mg (mg/l)	50	1	0.029
Na (mg/l)	200	2	0.057
K (mg/l)	200	2	0.057
		$\sum wi = 35$	$\sum wi = 0.998$

Table 3 Water quality classification ranges and types of water based on WQI values

Range	Type of water
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking purposes

fall in the hard water category. TH of the groundwater was calculated as suggested by Sawyer et al. 2003.

$$TH(\text{as } CaCO_3)\text{mg} = Ca^{2+} + Mg^{2+}\left(\frac{\text{meq}}{\text{l}}\right) \times 50 \qquad (5)$$

The hardness values range from 89.5 to 814.55 mg/l with an average value of 211.59 mg/l. The maximum allowable limit of TH for drinking purpose is 500 mg/l and the most desirable limit is 100 mg/l as per the WHO standard. Groundwater exceeding the limit of 300 mg/l is considered to be very hard. Sample nos. 2 and 11 exceed the maximum allowable limit of 500 mg/l. The hardness of the water is due to the presence of alkaline earths such as calcium and magnesium.

Total hardness (TH)

The classification of groundwater based on total hardness (TH) shows that a majority of the ground water samples

Table 4 Water quality index (WQI) classification for individual samples

S No.	WQI values	Water quality classification type
1	53.69	Good water
2	428.53	Water unsuitable for drinking purposes
3	81.71	Good water
4	48.63	Excellent water
5	49.41	Excellent water
6	44.28	Excellent water
7	80.87	Good water
8	80.47	Good water
9	80.14	Good water
10	226.75	Very poor water
11	399.18	Water unsuitable for drinking purposes
12	47.89	Excellent water
13	92.18	Good water
14	110.77	Poor water
15	92.93	Good water
16	101.30	Poor water
17	135.88	Poor water
18	48.54	Excellent water
19	162.39	Poor water
20	55.95	Good water
21	50.54	Good water
22	78.61	Good water
23	84.25	Good water
24	115.66	Poor water

Gibbs diagram

Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics. Three distinct fields such as precipitation dominance, evaporation dominance and rock–water interaction dominance areas are shown in the Gibbs diagram (Gibbs, 1970). The predominant samples fall in the rock–water interaction dominance and evaporation dominance field of the Gibbs diagram (Fig. 2). The rock–water interaction dominance field indicates the interaction between rock chemistry and the chemistry of the percolated waters under the subsurface.

$$\text{Gibbs ratio I (for anion)} = \frac{Cl^-}{(Cl^- + HCO_3^-)} \tag{6}$$

$$\text{Gibbs ratio II (for cation)} = \frac{Na^+ + K^+}{(Na^+ + K^+ + Ca^{2+})}, \tag{7}$$

whereas all the ionic concentration is expressed in meq/l.

Piper trilinear diagram

Piper diagram is extensively used to understand problems concerning the geochemical evolution of groundwater.

This diagram consists of three distinct fields including two triangular fields and a diamond-shaped field. The cations expressed as percentage of total cations in meq/l as a single point on the left triangle while anions plot in the right triangle (Piper 1944). Each point is then projected into the upper field along a line parallel to the upper margin of the field and the point where the extension intersects indicates the character of the water as represented by the relationship among $Na^+ + K^+$, $Ca^{2+} + Mg^{2+}$, $CO_3^- + HCO_3^-$ and Cl^-, SO_4^{2-} ions. Similarities and differences among groundwater samples can be revealed from the trilinear diagram because water of similar qualities will tend to plot together as groups. Aquachem 4.0 scientific software is used for the plotting of piper trilinear diagram. The piper diagram is dominated by NaCl followed by mixed CaMgCl type facies (Fig. 3). This process indicates that alkalis ($Na^+ + K^+$) and strong acids ($Cl^- + SO_4^{2-}$) dominated over the alkaline earth ($Ca^{2+} + Mg^{2+}$) and weak acids. The elevated Na^+ concentrations coupled to low Ca^{2+} suggesting that Ca^{2+} and Na^+ ion exchange process is an important geochemical process for the Na–Cl type of groundwater.

Water quality index calculation (WQI)

The chemistry of groundwater is often used as a tool for discriminating the drinking and irrigation water quality (Subba Rao 2006; Vasanthavigar et al. 2010). Water quality index (WQI) is an important parameter for identifying the water quality and its sustainability for drinking purposes (Subba Rao, 1997; Magesh et al. 2013). WQI is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall water quality (Mitra and ASABE Member 1998). (World Health Organization 2011) standards for drinking water quality have been used to calculate the WQI. The relative weight (wi) was assigned for water quality parameters based on their relative importance on water quality for drinking purposes (Table 2). The water quality classification based on WQI values is shown in Table 3. The calculation of WQI for groundwater samples is shown in Table 4. A total of 24 samples were analyzed for WQI. Among these, 20.83 % of the samples showed excellent water, 45.83 % of the samples fell under good water category, 20.83 % of the samples showed poor water category, 4.16 and 8.33 % of the samples fell under very poor water quality and water unsuitable for drinking purposes, respectively. This may be due to effective leaching and dissolution process of rock salt and gypsum-bearing rock formations. High concentration of EC, chloride, sodium followed by calcium clearly suggests that rock–water interaction process is the main source for degrading the water quality in the study area.

Table 5 Correlation matrix (r_2) of studied physico-chemical parameters and major ions (N = 24) of groundwater

| Parameters	Temp	pH	EC	TDS	CO$_3$	HCO$_3$	Cl	SO$_4$	NO$_3$	Ca	Mg	Na	K
Temp	1.000												
pH	0.244	1.000											
EC	−0.118	0.285	1.000										
TDS	−0.118	0.285	1.000	1.000									
CO$_3$	0.213	0.376	0.549	0.549	1.000								
HCO$_3$	0.013	0.605	0.255	0.255	0.076	1.000							
Cl	−0.125	0.158	0.952	0.952	0.471	0.114	1.000						
SO$_4$	0.131	0.536	0.777	0.777	0.454	0.601	0.638	1.000					
NO$_3$	0.227	0.362	0.297	0.297	−0.019	0.216	0.331	0.439	1.000				
Ca	−0.240	0.179	0.727	0.727	0.134	0.215	0.767	0.454	0.296	1.000			
Mg	−0.053	0.087	0.894	0.894	0.545	−0.107	0.872	0.565	0.231	0.621	1.000		
Na	−0.117	0.311	0.964	0.964	0.663	0.256	0.892	0.759	0.170	0.636	0.838	1.000	
K	−0.117	0.190	0.966	0.966	0.604	0.090	0.924	0.687	0.255	0.639	0.903	0.960	1.000

Correlation matrix

Statistical analysis was performed on the physico-chemical parameters and major ion concentration to detect the relationship and differences between the groundwater samples. In order to discuss the data, the values grouped with respect to the geochemical parameters. The average value of all the variables (temperature, pH, EC, TDS, CO$_3^-$, HCO$_3^-$, Cl$^-$, SO$_4^{2-}$, NO$_3$, Ca^{2+}, Mg^{2+}, Na$^+$, K$^+$) determined and tabulated as matrix (13 × 24) in Table 5. This matrix was analyzed with cluster analysis (hierarchical tree clustering, rescaled distance cluster combine analysis) using SPSS software (SPSS, 2001). The hierarchical cluster analysis was used to group water samples into significant clusters. The dendrogram analysis was performed using Ward method and the results of parameters are shown three groups in Fig. 4. Most of the samples were classified in group I and II with good correlation between SO$_4$, Ca, HCO$_3$, Cl and Na with EC and TDS. The group III with one sub-group constructed with EC and TDS. The possible salt combinations (CaSO$_4$, NaCl, and mixed CaNaHCO$_3$) are probably derived from weathering of rock salts, gypsum-bearing aquifers and irrigation return flow. The concentration of nitrate is probably derived from anthropogenic activities. The water quality management can be implemented by proper removal/recycling of waste water and installation of sewage treatment plants.

Conclusions

The study area is always under stress due to increasing population and more demand for water resources. The hydrogeochemical analysis of the study reveals that the groundwater is fresh to brackish and moderately high to hard. The
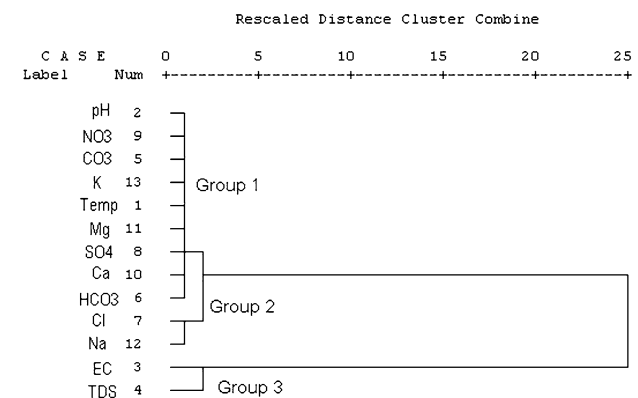
Fig. 4 Dendrogram for the groundwater grouping with respect to their physico-geochemical parameters

order of the abundance of the major cation and anion is as follows: Na$^+$ > Ca^{2+} > Mg^{2+} > K$^+$ = Cl$^-$ > HCO$_3^-$ > SO$_4^{2-}$ > CO$_3^{2-}$ > NO$_3^{2-}$. Na and Cl are dominant ions among the studied cations and anions. The concentration of potassium ion is within the permissible limit for drinking purpose except few locations. 20 % of the groundwater samples have exceeded the permissible limit of sodium. Nitrate and sulphate ion concentrations are within the allowable limit for drinking purpose. Chloride, calcium and magnesium are within the allowable limit except few samples. According to Gibbs diagram, the predominant samples fall in the rock–water interaction dominance and evaporation dominance field. The piper trilinear diagram shows that groundwater in the study area is Na–Cl and mixed CaMgCl type. Based on the WQI classification majority of the samples are falling under excellent to good water category and suitable for drinking water purposes. To improve the quality of water, the Government and non-government

organization should provide the moral support to design the rain water harvesting structures and artificial recharge methods for young generation especially budding civil engineers.

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