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GIS-based assessment of groundwater quality and its suitability for drinking and irrigation purpose in a hard rock terrain: a case study in the upper Kodaganar basin, Dindigul district, Tamil Nadu, India

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ABSTRACT

This study emphasizes hydrogeochemistry and quality degradation of groundwater in the upper Kodaganar basin, located in Dindigul district, South India. The Kodaganar basin has a particular significance and requires great attention because groundwater is the only major source for domestic and irrigation consumption. Twenty wells in the basin are randomly identified for sampling groundwater. The standard sampling procedures and laboratory experiments are followed for analyzing each sample. Index representing the suitability of drinking water is estimated based on the recommendations of Canadian Council of Ministry of Environment. The spatial distribution of the suitability was prepared by inverse distance weighted method. The traces of pollution and sources of pollution analyzed through Piper diagram suggested the role of natural and anthropogenic causes. The Gibbs boomerang diagram for both season illustrated around 85% of anions concentration dominated by rock type and also 80% of cation concentration influenced by surface interactions. This survey concludes that the overall drinking suitability of groundwater is fair in 7 wells and good in 13 wells. Only nine wells are found suitable for irrigation and rest of the wells can be used for irrigation only after minor treatment.

Keywords: CCME; WQI; Piper plot; Gibbs chart; USDA

1. Introduction

Water is most essential for the origin, survival and sustenance of life on earth. Every civilization is enriched in the vicinity of water. In arid and semi-arid regions, groundwater is considered as the foremost resource for agricultural, industrial and domestic requirements because of the limited availability of surface water resources [1]. In India recently there has been growth in various fields such as agriculture, industry and urban areas which lead to an increase in the demand of water supplies, and this demand is met mostly from exploitation of subsurface water resources [2]. The overuse of groundwater has deleteriously affected the character and amount of water in the aquifer. The deficiency of understanding about the hydrosphere has contributed to the deterioration of quality of water thus resulting in water pollution. Consequently, water pollution makes the water unfit for future use. Hence, the suitability of water for various purposes needs to be judged based on the recognized standards. Groundwater used for domestic and irrigation

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purposes can change greatly in quality depending upon the character and quantity of dissolved salts. The knowledge of hydrochemistry is important to evaluate the groundwater quality and its suitability for both irrigation and drinking needs [3]. The character of groundwater is controlled by the environment through which it is distributed. The chemical composition of groundwater is directly linked to the lithology of the neighborhood and the residence time the water in contact with the rock materials [4]. The chemistry of subsurface water is not just linked to rock type, but also contemplates the nature of the air, soil and weathering of stones as well as from other pollutant sources [5]. Thus, monitoring of groundwater is essential to assure the sustainability of these valuable resources.

The graphical and numerical analyses and interpretation of water quality were performed based on total ionic distribution and dissolved materials. The chemical facies and mineral formations types are studied using Piper plot and Gibbs plot, respectively. The water quality index (WQI), an indicator of the ambient water quality for drinking is estimated by the recommendations of the Canadian Council of Ministry of Environment (CCME). The role of spatially distributed maps is a general pattern in earth sciences society to evaluate the risk regarding surface water and groundwater quality due to waste disposal from industrial and other sites [6]. Straight off a day's Geographical Information System (GIS) has emerged as an efficient instrument for handling spatial data and these spatial data sets are used for decision-making purposes in several areas including environmental studies. In recent decades, numerous researcher [7–9] used the GIS technique for risk mapping studies, especially researchers, namely Gnanachandrasamy et al. [6], Selvam et al. [2], Srinivas et al. [3], Magesh and Chandrasekar [10], Magesh et al. [11], Srinivasamoorthy et al. [12,13], Guler and Thyne [14] used the GIS technique for their groundwater quality studies with regard to drinking and irrigation uses. Here, the concentration of chemical parameters is aggregated by the recommendations of CCME by using the standards for drinking water suitability [15]. And also United States Department of Agricultural (USDA) salinity diagram and residual sodium carbonate (RSC) plot were used for identifying irrigation suitability. Salinity of groundwater and sodium absorption ratio (SAR) determines its utility for agricultural purposes. Salinity originates in groundwater due to weathering of rocks and leaching from top soil, anthropogenic sources along with modest influence on climate [13]. The USDA diagram was plotted against electrical conductivity (EC) and the SAR to classify the water. In wastes having high concentration of bicarbonate there is a tendency for calcium and magnesium to precipitate as the sodium in the water gets dissolved in the water and forms sodium carbonate rich water that is harmful to plant growth. To quantify the role of this sodium carbonate, a parameter named RSC is used. The results of this analysis enable the planners and decision makers to ensure the drinking and agricultural suitability of groundwater. The prime focus of this current study is to compute the spatial distribution of groundwater quality parameters and to assess its suitability for domestic and irrigation consumptions using GIS technique. The upper Kodaganar basin is the study area that is a division of Dindigul district, Tamil Nadu, India.

2. Materials and methods

The methodology adopted in this study can be divided into four stages: (1) Physicochemical characters of groundwater and its human impact. (2) The ionic distribution and domination are studied through Piper trilinear diagram. The Gibbs boomerang diagram is used to segregate the source that supplies the source of contamination. (3) The overall WQI computed from the CCME is used to conclude the parameters in a simplified form of numerical value called WQI. (4) The suitability of water for irrigation is determined by the USDA salinity diagram. This is carried out by analyzing the salinity diagram and comparing it with the RSC value. The description of the study area and step by step procedure used in the study is as follows.

2.1. Study area

The study area is upper Kodaganar basin, located in Dindigul district of South India shown in Fig. 1. Geographically the study area lies between the northern latitudes 10°11′01″ to 10°34′26″ and eastern longitudes 77°13′28″ to 77°37′53″. The areal extent of this basin is 1,540 km^2 [16]. The Kodaganar basin is the largest river drainage area in the Dindigul district. The topography of the basin is plain in the central area and surrounded by undulating terrain. The elevation of this basin ranges from 207 to 1,846 m above mean sea level [16]. The wells in the higher elevation zones were dry in the pre-monsoon season. Therefore, the aquifers in the plain were considered for the study. Dindigul is well known for tanneries and vegetable cultivation that consumes large quantities of water and this was met through groundwater. The major soil units available in the basin are red, sandy, clay and black soil [17]. The bigger portion of the watershed is covered with highly folded, fractured and jointed Achaean crystalline metamorphic complex. The general terrain in the catchment area is composed of hard rock terrain, with moderate fractures and weathered to an average depth of 30 m. The major faults are aligned in the NNE–SSW direction of the upper Kodaganar basin [18]. The basin takes the following geological formations, namely anorthosite, charnockite, fissile hornblende biotite gneiss, granite, migmatite gneiss and quartzite [7]. Charnockite being a hard rock and partly weathered is available in the southeast and the southwest portion of the basin. The plains of the basin had more than 70% of the land that are covered by hornblende biotite genesis type of rocks. These were found to be potentially good for groundwater storage because of its relatively poor resistance to weathering. This catchment area consists of five land use/land cover classes, namely agriculture (1,157.16 km^2), built-up (48.97 km^2), waste land (62.10 km^2), water bodies (55.08 km^2) and forest cover (217.42 km^2). The mean annual precipitation of Dindigul district is 934.9 mm [10]. The northeast monsoon and the southwest monsoon are the main source of water supply for groundwater replenishment. The rainy months are October, November and December [19].

2.2. Analysis of physicochemical characteristics

This study utilizes 40 groundwater samples that are collected during January (post-monsoon) and June (pre-monsoon)

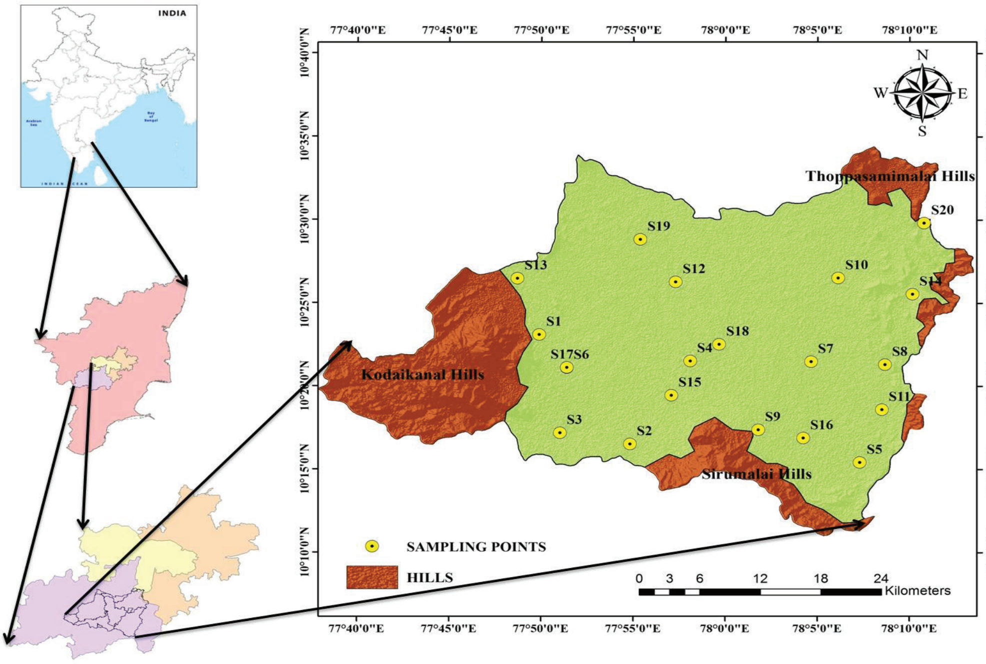

Fig. 1. Location map of the study area.

collected from 20 wells (both dug wells and bore wells) from the upper Kodaganar basin for the year 2012. The details of the sampling wells and their locations are tabulated in Table 1. The positional information about the sampling points is obtained from hand held Global Positioning System (GPS) instrument and is stored as a point vector file in Trimble Juno GPS. Samples are collected in 1 L capacity polyethylene bottles and tested in the laboratory by applying standard methods of analysis [20]. High purity (AR grade) chemicals and double distilled water are used for preparing standard solutions for analysis. Physical quality parameters like pH, EC and total dissolved solids (TDSs) were determined by Systronics pH meter, Systronics EC meter and TDS meter, respectively. Total hardness (TH) is measured by a standard ethylenediaminetetra-acetic acid titration method using Erichrome Black T indicator. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were estimated by titrating with sulfuric acid (H_2SO_4). The chloride ions are determined by titrating the water samples against a standard solution of silver nitrate ($AgNO_3$) using potassium chromate as an indicator. Calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+) are also determined by volumetric titration methods. The sodium (Na^+) ion is determined by flame photometry. The sulfate ions are identified by turbidity method. Nitrates (NO_3^-) and fluorides (F^-) of the water samples are estimated by UV visible physicochemical spectrophotometer. Statistical parameters were calculated from the measured concentration values for both the seasons were compared against the WHO standards and used for analysis [21]. GIS is used in the provision of spatial database and the hydrochemical data are integrated through the join command in the attribute table. The point layer prepared for the location of wells is used to form a continuous surface by an interpolation scheme called inverse distance weighted (IDW) method. This method is based on the distance between the input point and

Table 1
Location details of sample wells

Sample ID	Village	Location of well	
		Longitude	Latitude
S1	Kannivadi	77.8317	10.3847
S2	Chinnalapatti	77.9139	10.275
S3	Sithayankottai	77.8506	10.2861
S4	Dindigul	77.9683	10.3583
S5	Vembarpatti	78.1219	10.2569
S6	Palayakannivadi	77.8567	10.3514
S7	Madurai	78.0778	10.3578
S8	Kambiliampatti	78.1447	10.355
S9	Koovanuthu	78.03	10.2894
S10	Vadamadurai	78.1022	10.4417
S11	Pudupatti	78.1419	10.3097
S12	Thadikombu	77.955	10.4375
S13	Sriramapuram	77.8017	10.4361
S14	Puthur	78.1694	10.4256
S15	Pillayarnattam	77.9514	10.3239
S16	Shanarpatti	78.0708	10.2814
S17	Palayakannivadi	77.8567	10.3517
S18	Balakrishnapuram	77.9944	10.375
S19	Agaram	77.9231	10.48
S20	Ayyalur	78.18	10.4967

the output pixel. This technique is practiced with the limiting distance of 3,000 m to ensure the interest of other neighboring points. The finite difference moving average method in which every picture element in the output image is assigned values computed from the points within the radius of limiting space. This technique assigns larger weights to the points closer to the output pixel.

2.3. Analysis of hydrochemical facies using Piper trilinear diagram

Piper diagram was produced by Piper [22]. The Piper diagram is extensively used to understand problems concerning the groundwater chemistry and geochemical evolution of groundwater. The diagram consists of three distinct areas, two trilinear triangles (cation in left and anion in right) and a diamond field oriented in the midriff. The milliequivalent value of the cation is cation triangle and that of the anions is plotted in anion triangle. The cation and anion in triangles are projected to the central diamond field and the respective point is plotted along the degree of crossing.

2.4. Analysis of mechanisms controlling groundwater chemistry using Gibb's boomerang diagram

The Gibbs boomerang diagram is the most significant instrument to investigate geochemical processes that are taken in the groundwater chemistry. Gibbs identified three natural mechanisms that check the chemical science of groundwater. The mechanisms are atmospheric precipitation, rock weathering and evaporation–crystallization process. Gibbs' diagram, a boomerang-shaped envelope for cation, is obtained by plotting the weight ratio $Na^+/(Na^+ + Ca^{2+})$ on the *X*-axis against TDS values on the *Y*-axis and the same goes for anions with $Cl^-/(Cl^- + HCO_3^-)$ vs. TDS. When the predominant process is rock weathering, waters produce Ca^{2+} and HCO_3^- as predominant ions, TDS values are moderate and sample data plot lies in the center part of the Gibb's boomerang plot. Saline waters of sodium chloride type are due to the atmospheric precipitation processes and sample data plot lies in the lower right corner of the boomerang. The third mechanism that holds the water chemistry is the evaporation–crystallization process and the sample data plot lies in the upper right corner of the boomerang. This is important in arid areas, where evaporation is higher than haste.

2.5. CCME water quality index

The CCME has forged a valuable instrument for communicating ambient water quality information. The diligence of the CCME WQI requires water quality guidelines (WQGs) or water quality objectives. In this case, WHO and Bureau of Indian Standards (BIS) [23] are accepted as the criterion for objective. The expression of the WQI as described in the Canadian Water Quality Index is based on a combination of three factors: [10].

- Scope (F_1) – the number of variables not meeting water quality targets.
- Frequency (F_2) – the number of times the objectives are not taken on.
- Amplitude (F_3) – the extent to which objectives exceeded.

2.5.1. Scope (F_1)

- Scope assesses the extent of compliance with WQGs over the time period of interest.
- F_1 shows the percentage of parameters, whose guidelines are not met.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \tag{1}$$

2.5.2. Frequency (F_2)

- Assesses the frequency with which guidelines are not met.
- F_2 indicates the fate of individual tests which do not conform to the guidelines (i.e., "Failed tests").

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \tag{2}$$

2.5.3. Amplitude (F_3)

- Amplitude assesses the quantity by which guidelines are not met.
- F_3 shows the amount by which failed test values do not fit their guidelines, and is calculated in the following three steps.
  - The number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the object is termed an "excursion" and is expressed as follows. When the test value must not exceed the target:

$$\text{Excursion}_i = \left(\frac{\text{Failed test value}_i}{\text{Objective}}\right)^{-1} \tag{3}$$

  - The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting the objectives). This variable, referred to as the normalized sum of excursions, or NSE, is counted as:

$$\text{NSE} = \frac{\sum i = 1^n \text{Excursion}_i}{\text{Number of tests}} \tag{4}$$

  - F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (NSE) to generate a range between 0 and 100.

$$F_3 = \frac{\text{NSE}}{0.01(\text{NSE}) + 0.01} \tag{5}$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors. The total of the squares of each element is thus equal to the square of the indicator. This approach handles the index as a three-dimensional space defined by each factor along one axis. With this example, the index changes in direct proportion to changes in all three components.

The CCME water quality index (CCME WQI) is counted as:

$$\text{CCME WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{6}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality.

Water quality is ranked by relating it to one of the following categories:

Excellent: (CCME WQI value 95–100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.

Good: (CCME WQI value 80–94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (CCME WQI value 65–79) – water quality is commonly protected, only occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (CCME WQI value 45–64) – water quality is frequently threatened or impaired; conditions often vary from natural or desirable levels.

Poor: (CCME WQI value 0–44) – water quality is almost always threatened or impaired; conditions usually set forth from natural or desirable levels.

2.6. Suitability analysis for irrigation using the USDA salinity diagram

The USDA salinity diagram is a method of classification of groundwater for irrigation requirements. It is the best method for identifying the groundwater salinity. High salt content in irrigation water does an increase in salt solution and decreases osmotic pressure. The salts affect the development of plants like a shot and also move the ground structure, permeability and aeration of the soil moisture zone. Agricultural production in this basin is primarily dependent on the groundwater sources. Hence, it is necessary to conduct agricultural-based groundwater quality study. The categorization system to assess the suitability of water for irrigation use can be determined by graphically plotting the EC and SAR values on the USDA salinity diagram. Based on Eq. (7) the SAR value will be reckoned.

$$\text{SAR} = \frac{\text{Na}}{\left[\frac{\text{Ca} + \text{Mg}}{2}\right]^{1/2}} \tag{7}$$

2.7. Residual sodium carbonate

RSC has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural use. The amount of hydrogen carbonate and carbonate in excess of alkaline earths (Ca^{2+} + Mg^{2+}) affects the suitability of water for irrigation uses. An excess sodium bicarbonate and carbonate influence the physical attributes of soil by dissolution of organic matter in the soil, which in turn leaves a black tarnish on its surface on drying [24]. RSC has been computed by Eaton [25] which was expressed in Eq. (8):

$$\text{RSC} = [\text{HCO}^{3-} + \text{CO}^{2-}{}_3 - (\text{Mg}^{2+} + \text{Ca}^{2+})] \tag{8}$$

where concentrations are expressed in meq.

3. Results and discussion

3.1. Physicochemical characters and its health hazards

The general geochemical standards for drinking water are shown in Table 2. If the concentrations of physicochemical constituents in groundwater are exceeding this prescribed standard, it may induce serious health impacts to the consumers. Here, the geochemistry of groundwater samples is compared with the drinking water standards for mapping the health hazard zones in the upper Kodaganar basin. pH in this region varies from 7.8 to 8.7 in pre-monsoon, and in post-monsoon it ranges from 7 to 8.8. The alkaline nature of water may cause irritation to eyes, nose, stomach, mouth, etc. The TDS value varies between 204 and 1,956 mg/L in pre-monsoon and in post-monsoon, it varies from 283to 1,628 mg/L. In the Kodaganar basin, most of the samples on both monsoon periods exceed the drinking standards of TDS (500 mg/L) which puts down the taste of the drinking water and causes health impacts like kidney stone, gastrointestinal irritation, etc. The classified spatial variation maps of the TDS in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 2. The TH plays a significant role in demarcating the suitable zones of groundwater for domestic, industrial and other uses. The TH in the pre-monsoon ranges from 140 to 1,157 mg/L and it ranges from 185 to 3,856 mg/L in post-monsoon. In most of the samples TH values are underlined within the permissible limit of 600 mg/L in both seasons. The classified spatial variation maps of the TH in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 3.

The calcium concentration in the collected pre-monsoon samples varied from 12 to 152 mg/L and post-monsoon samples varied from 14 to 156 mg/L which comes under the permissible limit of 200 mg/L. The calcium deficiency leads osteoporosis on the human bone and induces tooth decay with weak and brittle nails. The classified spatial variation maps of the calcium in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 4. The magnesium concentration of pre-monsoon samples is within safe limit of 200 mg/L except sample S1 which was collected from Kannivadi village. The minimum and upper limit values of magnesium are 15 and 190 mg/L,

Table 2
Physicochemical characteristics of groundwater during post-monsoon and pre-monsoon

Parameters	WHO (2004)	BIS (10500:2012)		Post-monsoon				Pre-monsoon			
	Desirable limit	Desirable limit	Permissible limit	Min	Max	Avg	SD	Min	Max	Avg	SD
EC (μS/cm)	300	–	–	430	2,730	1,316	691	321	3,344	1,326	734
TDS (mg/L)	500	500	2,000	283	1,628	863	414	204	1,956	854	441
Na (mg/L)	50	–	–	184	3,856	665	863	140	1,157	413	238
K (mg/L)	–	–	–	5	109	19	23	5	74	17	17
Ca (mg/L)	75	75	200	14	156	59	40	12	152	46	36
Mg (mg/L)	30	30	No relaxation	26	143	63	35	15	190	73	41
F (mg/L)	1	1	1.5	0.1	1.4	0.7	0.4	0.2	1.6	0.8	0.4
Cl (mg/L)	250	250	1,000	21	659	193	191	21	808	206	191
HCO_3 (mg/L)	300	–	–	138	634	355	144	74	708	340	145
CO_3 (mg/L)	–	–	–	0.1	48	12	14	1.1	48	17	14
NO_3 (mg/L)	45	45	45	1	37	11	10	1	42	12	11
SO_4 (mg/L)	200	200	400	6	130	44	28	6	106	42	25
pH	6.5–8.5	6.5–8.5	–	7	8.8	8.2	0.4	7.8	8.7	8.1	0.2
TH	–	200	600	116	14,516	1,067	2,503	130	16,310	1,199	2,774

Min., minimum; Max., maximum; Avg., average; SD, standard deviation.

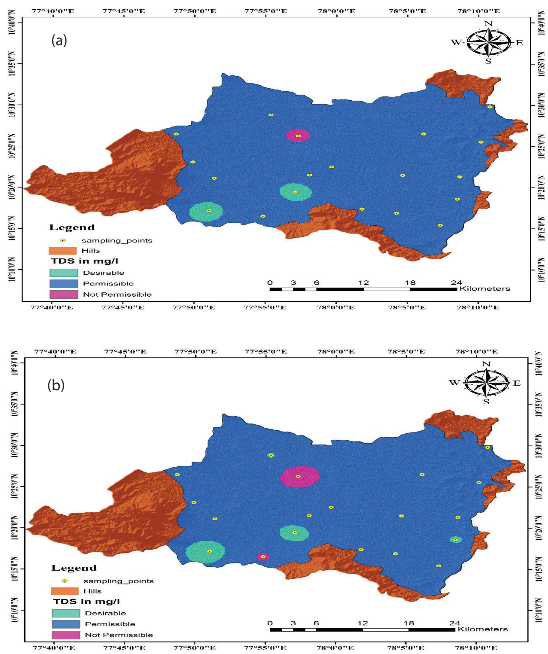

Fig. 2. Spatial distribution map illustrating the classified TDS concentration during (a) post-monsoon and (b) pre-monsoon.

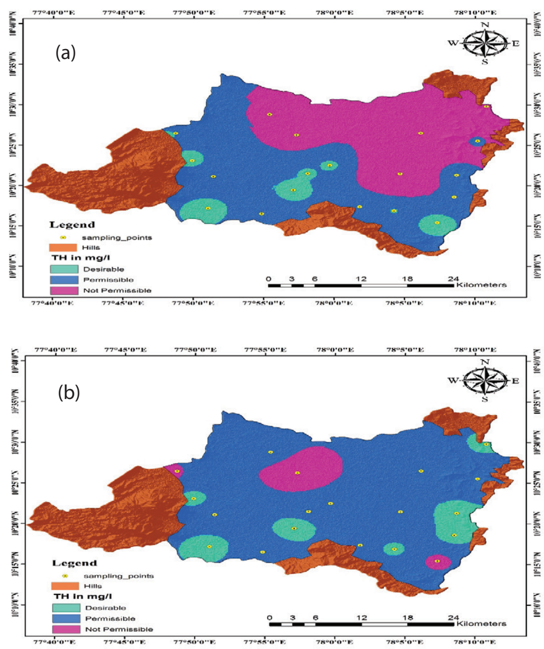

Fig. 3. Spatial distribution map illustrating the classified TH concentration during (a) post-monsoon and (b) pre-monsoon.

during pre-monsoon and in post-monsoon, it runs from 26 to 143 mg/L which are also in safe limit. The presence of magnesium could be due to organic contents of animal base, domestic and industrial waste land. The classified spatial variation maps of the magnesium in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 5. The chloride ion value presented in groundwater samples is between 21 and 808 mg/L in pre-monsoon and

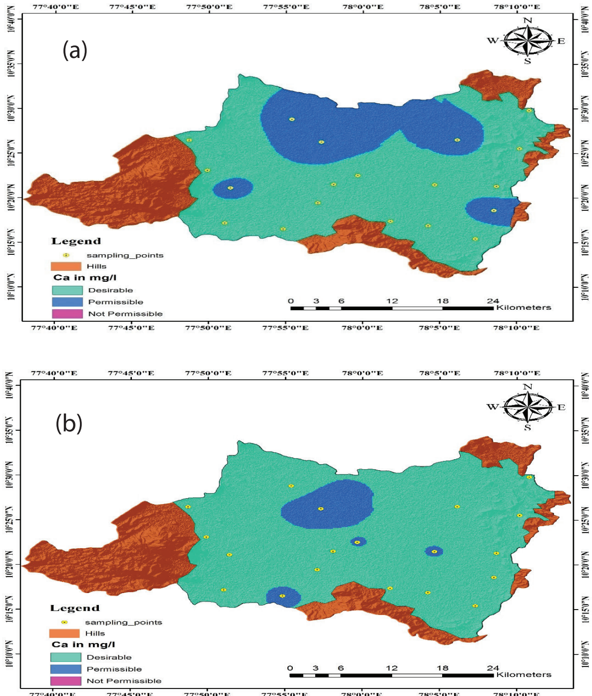

Fig. 4. Spatial distribution map illustrating the classified calcium concentration during (a) post-monsoon and (b) pre-monsoon.

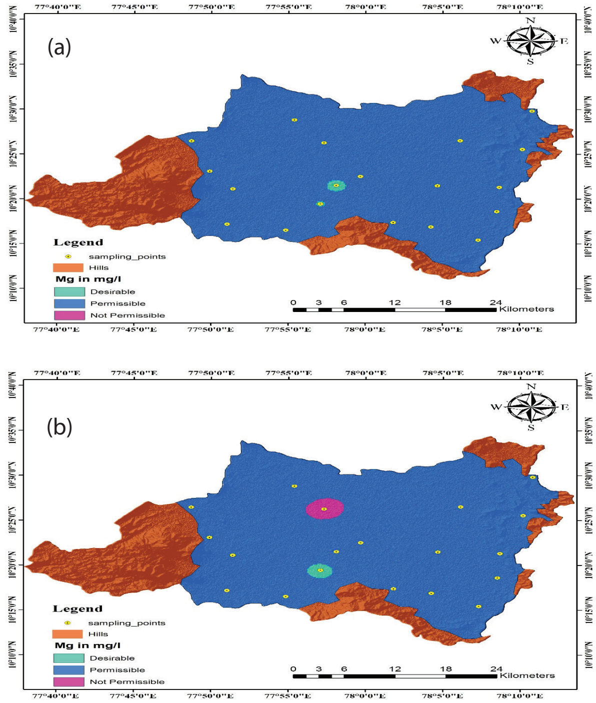

Fig. 5. Spatial distribution map illustrating the classified magnesium concentration during (a) post-monsoon and (b) pre-monsoon.

in post-monsoon, it ranges between 21 and 659 mg/L. Eight samples exceed the desirable limit of chloride, in pre-monsoon and six samples in post-monsoon. The anomalous concentration of chloride was obtained in this area is due to the domestic and fertilizers effluents and other anthropogenic activities. The excess chloride leads to high blood pressure risk, dehydration, diarrhea, diabetic coma, asthma, etc. The classified spatial variation maps of the chloride in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 6. The sulfate ion in this area is within the safe boundary. It runs from 6 to 106 mg/L in pre-monsoon and from 6 to 130 mg/L in the post-monsoon. The low concentration of calcium and sulfate is due to the precipitation resulted from the reaction of calcium and sulfates. The classified spatial variation maps of the sulfate in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 7. The observed range of sodium varied from 13 to 244 mg/L in pre-monsoon and from 13 to 258 mg/L in post-monsoon. The presence of sodium could be due to the influence of domestic and animal waste. The use of lower concentration of sodium will cause fatigue, muscle cramp, vomiting, headache, etc. The classified spatial variation maps of the sodium in the upper Kodaganar basin for both pre-monsoon and post-monsoon seasons are illustrated in Fig. 8. The absorption values of each parameter are separated according to WHO (2004) criteria for drinking water. The EC concentration of post-monsoon samples is between 430 and 2,730 mho/cm and pre-monsoon, it may be between 321 and 3,344 mho/cm. The presence of hydrogen carbonate is found to be exceeding the permissible limit at 60% of the samples. Hydrogen carbonate concentration

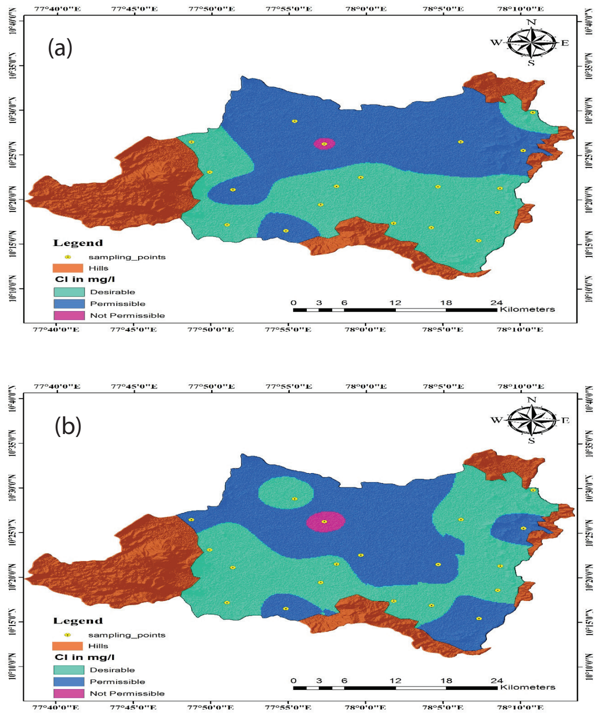

Fig. 6. Spatial distribution map illustrating the classified chloride concentration during (a) post-monsoon and (b) pre-monsoon.

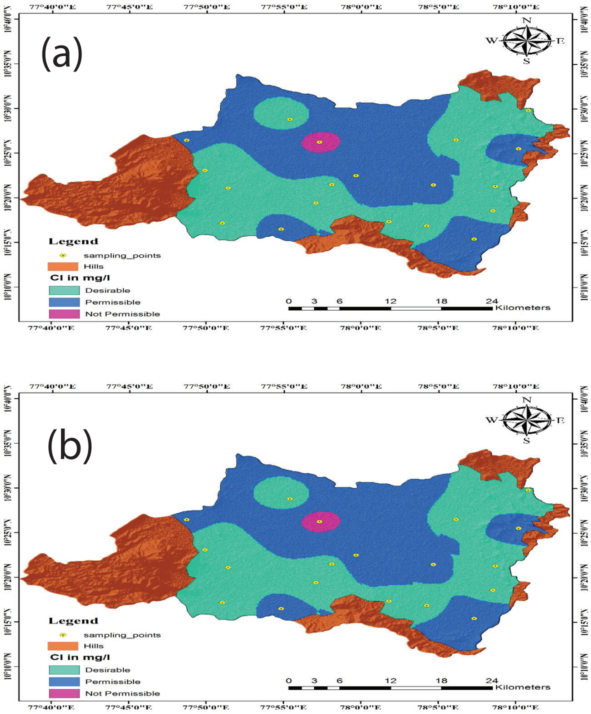

Fig. 7. Spatial distribution map illustrating the classified sulfate concentration during (a) post-monsoon and (b) pre-monsoon.

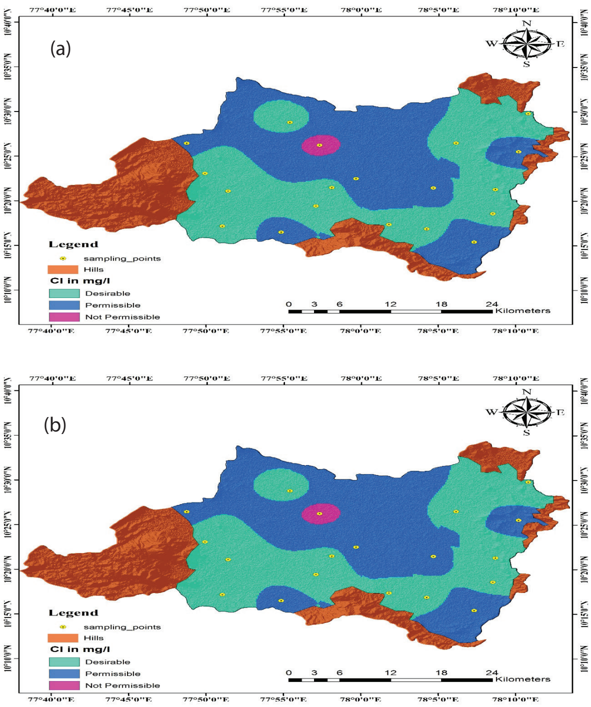

Fig. 8. Spatial distribution map illustrating the classified sodium concentration during (a) post-monsoon and (b) pre-monsoon.

varies between 20 and 756 mg/L in post-monsoon and in pre-monsoon, it varies from 21 to 1,031 mg/L. The increase of calcium and bicarbonate in the post-monsoon season may be due to the biodegradation of organic matter and wastewater derived from domestic, industrial sewage, septic tanks and landfills.

3.2. Piper trilinear diagram

Hydrochemical composition of samples from this basin is represented by plotting the major ions in Piper trilinear diagram for post-monsoon and pre-monsoon in Fig. 9. Temporary hardness induced by hydrogen carbonate along with the presence of calcium and magnesium (alkaline earth) is found in some sample. The presence of salinity is due to the presence of sodium and potassium over the calcium and magnesium is found in three wells in both seasons. Permanent hardness induced by chloride along with alkaline earth is found in some samples. Water collected from wells associated with area 5 is dominated by mixed water type with Ca–Mg–Cl and (Ca^{2+}–HCO_3^-) in post-monsoon and pre-monsoon, respectively. This mixed water type with high salinity is caused by the surface contamination sources such as irrigation return flow, domestic wastewater and septic tank effluents with existing water followed by ion-exchange reaction [2]. The dominant composition of cation and anion in post-monsoon and pre-monsoon samples is arrived from the cation and anion triangles of trilinear diagram. Domination of chloride and sulfate than the carbonate and bicarbonate results in brine water with permanent hardness which will be too salty for drinking. The presence of primary hardness is observed in more than 50% of wells, 13 wells in post-monsoon and 11 wells in pre-monsoon. Combined concentrations of calcium, magnesium and bicarbonate with high total dissolved constituent load resulted in temporary hardness and are frequently found in unconsolidated deposits containing abundant carbonate minerals. In this study, 10 samples in post-monsoon and 7 in pre-monsoon seasons are found to have combined concentrations of sulfate, chloride, magnesium and calcium that resulted in the permanent hardness in some field. The combination of alkali metals with sulfate and chloride is found in some region. Concentrated waters of these hydrochemical aspects are considered brackish or

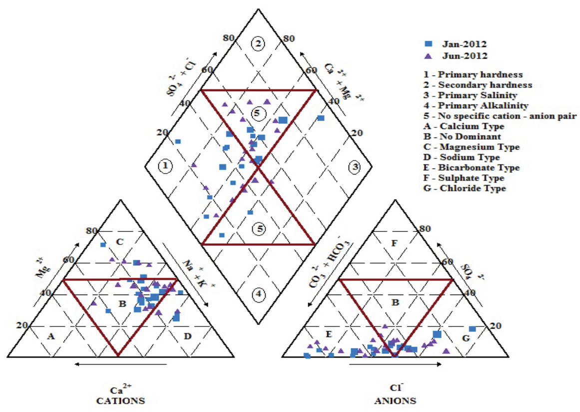

Fig. 9. Ionic distribution illustrated through Piper trilinear diagram.

saline (in extreme cases). The presence of sodium, potassium and bicarbonate in waters generally has low hardness in proportion to their dissolved solids concentration [26]. Only few samples fall in this region and no specific cation–anion pair exceeds 50% of the total dissolved constituent in well. Such waters could result from mineral dissolution or mixing of two chemically distinct groundwater bodies.

3.3. Gibb's boomerang diagram

The concentration of groundwater sample points of the area is plotted in Gibbs's diagram [27]. The samples during post-monsoon and pre-monsoon for cation and anions are plotted and shown in Fig. 10. The resolution of the plot indicates that all the samples in the study area belong to surface influences and rock water interaction. The effect of (Na + K)/(Na + K + Ca) shows the surface influence due to the agricultural practices (use of fertilizers) followed in pre-monsoon and post-monsoon, respectively. The results of $Cl^-/(Cl^- + HCO_3^-)$ demonstrate that the rock water interaction as the main origin of water quality change. Table 3 shows the Gibbs boomerang interpretation result in post-monsoon and pre-monsoon periods, respectively. The Gibbs diagram illustrated that the earth's surface influence for cation and rock water interaction influence the anions and controls the mechanisms of the groundwater chemistry for both the monsoon periods. On comparisons with the chemical characteristics, the presence of

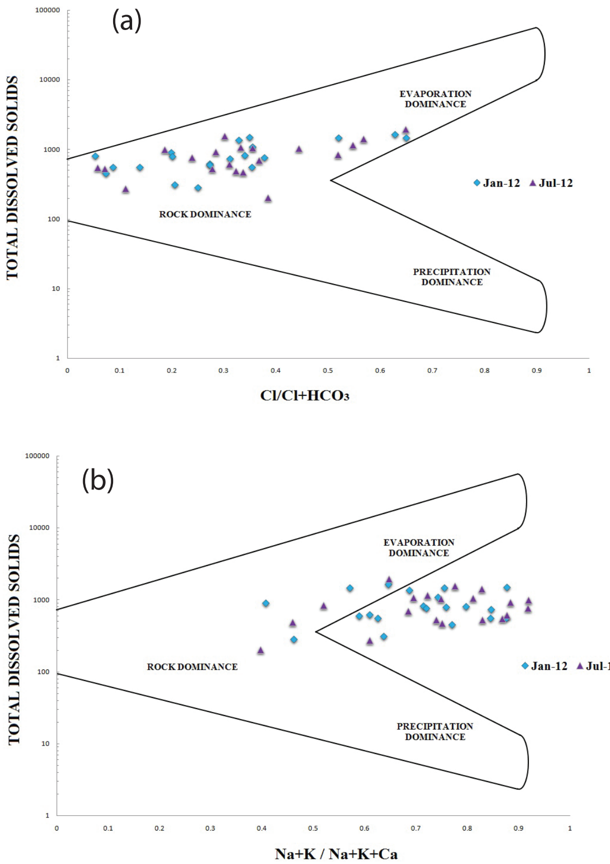

Fig. 10. (a) Anion ratio and (b) cation ratio illustrated through Gibbs' boomerang plot.

carbonate and bicarbonate could be due to the calcite weathering and carbonations. The presence of magnesium in the groundwater is due to the dissolution of magnesium bearing minerals. Dissolution of *k*-feldspars and clay minerals from the aquifer matrix has resulted in potassium ions in groundwater. The presence of potassium in groundwater results in lower geochemical mobility [13]. The presence of sodium and chloride rich minerals is an indication of halite dissolution that is observed in the wells namely S2, S6, S12 and S14. The high concentration of chloride in some samples may also influenced by domestic and agricultural effluents [2]. The presence of sodium, calcium, potassium and chloride in groundwater confirms the plagioclase weathering. Generally, in this region the ionic concentration was influenced by the weathered lithological units of this neighborhood.

3.4. CCME water quality index

The statistics on the physicochemical characteristics of the groundwater samples and the effects on human due to this degradation are indicated in Table 4. The most common contaminants that are setup in most of the samples are bicarbonate and potassium. Though the undesirable result of taking in this contaminant in the groundwater is not so serious, the condition of exceeding the allowable limit should not be ignored. The WQI calculated from the CCME method was classified based on the range value which was prescribed in Table 5. The classification scheme suggests that the WQI exceeding 45 is found to be marginal to excellent for human consumption, whereas the wells that fail to meet 45 is unsuitable for consumption. The WQI map prepared by the interpolation of point data through IDW method is shown in Fig. 11. The watershed receives a reasonable quality of water with considerable regions having good tone of water. The samples S3, S9, S11 and S15 are fall under the right category which means groundwater here are safe for drinking, agriculture with a small degree of threat and the Thadikombu village (S12) has a middling rank in the index and this indicates that quality of groundwater is moderate with less degree of menace. The remainders of the samples lie between good and fair ranking of the indicator. The map illustrates that the northern and northeast portion of the basin comes under four categories. It clearly shows the degradation of groundwater quality has started in the northern plains.

Table 3
Mechanism controlling groundwater chemistry (Gibb's diagram)

Mechanism controlling groundwater chemistry	No. of pre-monsoon samples		No. of post-monsoon samples	
	Anions	Cations	Anions	Cations
Rock dominance	17	3	17	2
Evaporation dominance	3	1	3	2
Precipitation dominance	0	0	0	0
Earth's surface influence	0	16	0	16

Table 4
Groundwater samples of Kodaganar basin exceeding the permissible limits prescribed by WHO for drinking purposes

Parameters	Units	WHO (2004) drinking water quality standards		Exceeding allowable limits				Undesirable effects
		Most desirable limits	Maximum allowable limits	Post-monsoon		Pre-monsoon		
				In no's	In %	In no's	In %	
pH	–	6.5	8.5	4	20	1	5	Taste
TDS	mg/L	500	1,500	1	5	2	10	Gastrointestinal irritation
Na^+	mg/L	–	200	3	15	4	20	–
K^+	mg/L	–	10	11	55	9	45	Bitter taste
Ca^{2+}	mg/L	75	200	Nil	0	Nil	0	Scale formation
Mg^{2+}	mg/L	30	150	Nil	0	1	5	–
Cl^-	mg/L	200	600	1	5	1	5	Salty taste
HCO_3^-	mg/L	–	300	12	60	12	60	–
SO_4^{2-}	mg/L	200	400	Nil	0	Nil	0	Laxative effective

Table 5
Classification of CCME water quality index (Source Magesh and Chandrasekar [10])

Category	CCME–WQI ranges
Excellent	95–100
Good	80–94
Fair	60–79
Marginal	45–59
Poor	0–44

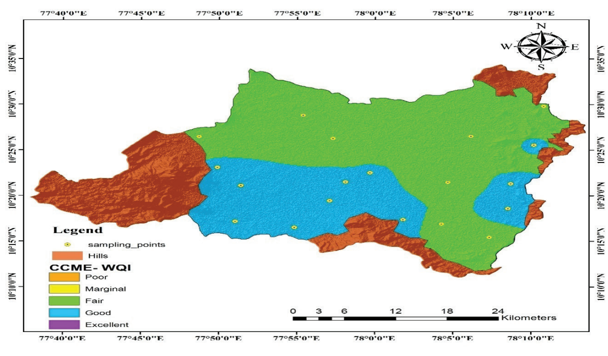

Fig. 11. Water quality index map prepared through CCME standards.

3.5. USDA salinity diagram

Fig. 12 displays the salinity and sodium interpretation in the USDA salinity chart for both post-monsoon and pre-monsoon seasons. It records the seasonal interpretation result of well water with respect to USDA classes. C2S1 (medium salinity – low sodium water) zone had 15% of the collected water samples that are suited for irrigation in both the monsoon seasons. This grade of water could be applied if a moderate amount of leaching occurs with little risk of building up harmful levels of sodium. C3S1 (high salt – low sodium water) zone had 70% of the water samples in both office and pre-monsoon. This class of irrigation water cannot be applied on soils with restricted drainage otherwise harmful level of sodium may develop. C4S1 (very high salinity – low sodium water) zone had 15% of the collected water samples in both seasons and are not suited for irrigation under ordinary conditions, but it may be used occasionally under very limited circumstances (practically these classes of water would cause the intrusion of solid deposits of Na^+). There is no substantial deviation in the attitude of the polluted wells in both the seasons. The USDA salinity diagram shows 3 wells in C2S1 (medium salinity – low sodium water), 14 wells in C3S1 (high salt – low sodium water) and 3 wells in C4S1 (very high salinity – low sodium water) zones. The three wells in the C4S1 are in severe shape when compared with other and these wells cannot be applied for irrigation with normal condition. This presence of high sodium could be due to the over exploitation of groundwater.

3.6. RSC graph of USDA

The classification of irrigation water according to the RSC values is shown in the graph is displayed in Fig. 13. Granting to the USDA, water having more than 2.5 epm of the RSC is not suited for irrigation purposes while those having 1.25–2.5 epm are marginally suitable and those with less than 1.25 epm are safe for irrigation. The outcome demonstrates that most of the wells are good for irrigation in both the seasons. Some wells are suitable with restricted drainage condition in post-monsoon. In pre-monsoon, it is unsuitable for irrigation purpose because of solid deposition of sodium. This is used to demarcate periodical change in concentration of groundwater. The resulting graphs show that the RSC values are fluctuating with increase in pre-monsoon due to the influence of drying up and decrease in post-monsoon periods due to the influence of recharge from rainfall. Due to the ion-exchange reaction during infiltration, the groundwater changes its form from mixed water type to Ca^{2+}–HCO_3^- type [28] during its travel at vadose zone and this water type enables the carbonate precipitation. The RSC values suggest that the S2 well is unsuitable for irrigation.

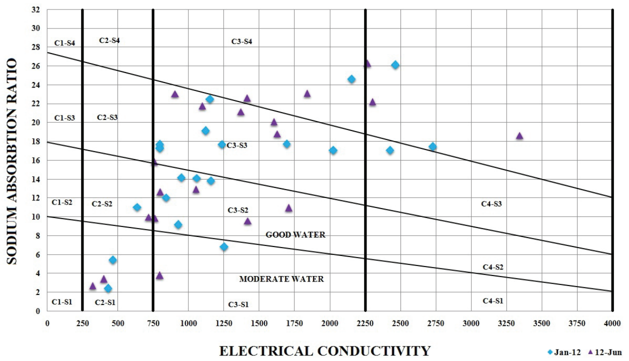

Fig. 12. USDA salinity diagram illustrating the post-monsoon and pre-monsoon characteristics of groundwater.

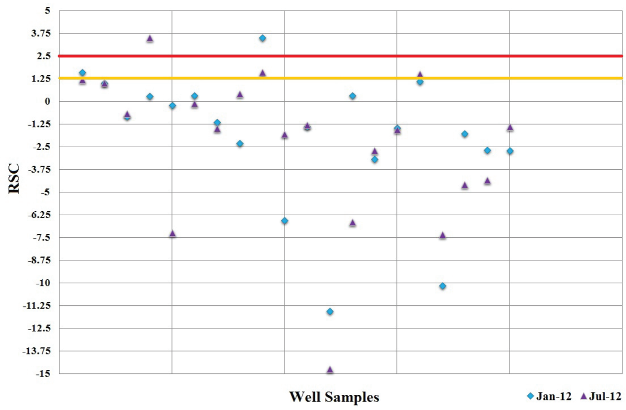

Fig. 13. RSC plot illustrating the post-monsoon and pre-monsoon characteristics of groundwater.

4. Conclusion

The groundwater in the upper Kodaganar basin is alkaline in nature which is dominated by HCO_3^-, Cl^-, Mg^{2+} and mostly mixed type in both the seasons. $Mg^{2+} > Na^+ > Ca^{2+} > K^+$:$HCO_3^- > Cl^- > SO_4^- > NO_3^-$ is the order of dominance of hydrochemical characteristics in the basin. The quality of groundwater is naturally controlled by the impact of calcite and plagioclase weathering, carbonation and dissolution of *k*-feldspar and rock salt. Other controlling processes such as ion-exchange controlled by evaporation are also observed in some samples. The contamination due to the anthropogenic activities is found in samples such as S2, S10, S12, S14 and S17. These areas were experiencing high chloride concentration and in contrary low bicarbonate concentration. The CCME WQI shows that most of the samples fall under the safe and mediocre quality. Hence, water quality of few wells is good for drinking purpose with minimal threat of contamination. As per the classification of water for irrigation purposes, water is deemed to be fit with few exceptional wells irrespective of the seasons. However, the chemical variation of ions in both the seasons did not significantly alter the utility for irrigation application. The determination of concentration of chemical parameters in groundwater is helpful in estimating the utility of groundwater for various applications. Incorporation of the relationship between infiltration and runoff will enable the groundwater utilization studies for agricultural purposes. The dependency of groundwater for irrigation is observed throughout the region. The harmful effect of over exploitation is also witnessed in some region. Irrespective of the seasons, the citizenry in this area depends on the groundwater as the main source of consumption. The study suggests that apart from monitoring there is a pressing need to preserve the water against contamination.

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