Modeling Earth Systems and Environment (2018) 4:1165–1180
https://doi.org/10.1007/s40808-018-0468-3

ORIGINAL ARTICLE

Appraisal of groundwater quality in upper Manimuktha sub basin, Vellar river, Tamil Nadu, India by using Water Quality Index (WQI) and multivariate statistical techniques

S. Deepa[1] · S. Venkateswaran[1]

Received: 26 December 2017 / Accepted: 23 May 2018 / Published online: 31 May 2018

Abstract
Groundwater is a major natural resource for drinking and irrigation purpose. The overexploited of groundwater is increase year by year and quality of groundwater simultaneously decreases. Groundwater quality is the main issue because water is linked with our metabolism. In order to know the groundwater pollution and controlling factors of groundwater quality in the upper Manimuktha sub basin, Vellar river, Tamil Nadu, India. Forty eight groundwater samples were collected from entire study area on January 2014 and analysed for physicochemical properties. Major ions were as abundance of Na > Ca > Mg > K, and $HCO_3 > Cl > SO_4 > NO_3$ respectively. Multivariate statistical analyses display the good correlation between all the physicochemical parameters except pH and F. The dendrogram reveals cluster 3 (EC and TDS), cluster 2 (alkalinity, TH, HCO_3) and cluster 1 (F, K, NO_3, Ca, Mg, Na, SO_4, Cl). The hydrochemical processes reveal rock-weathering interactions and ion-exchange processes play an important role in groundwater quality of the study area. The WQI indicates 50.03% of the samples fall in excellent to good for drinking in the center of the study area. Remaining samples fall poor to very poor categories, signifying northern and southern side mainly polluted. Maximum of lakes located in the northern side also indicate poor quality, because of the contamination of wastewater at or near the lakes, migrate in the groundwater. This study has shown the great combination of GIS, statistical analysis and WQI in assessing groundwater quality give a clear view for decision makers can plan better for the operation and maintenance of groundwater resources.

Keywords Dendrogram · Groundwater pollution · Ion exchange process · Statistical analyses · WQI

Introduction

Groundwater is the first source of water for human consumption, as well as for agriculture, drinking and industrial uses (Jalali 2009; Mokarram 2016). Groundwater is limited and also overexploited for various purposes. However, river water is insufficient to meet the ever increasing demand of the cities. This scarcity of water has increased the overexploitation of groundwater. Groundwater serves as major and natural source of water for domestic and agricultural purposes in many cities (Mondal et al. 2010; Kumar 2016). In the arid and semi arid regions groundwater is main resources for drinking, irrigation and domestic purposes. The overexploitation leads to decrease of quantity and quality in groundwater. The quality of groundwater is mainly depending on the physicochemical characteristics of the groundwater. In India tremendous variation of the utilization of lands, from place to place and without strict environmental norms, causing a lot of variation in quality of groundwater within a short distance, which constrains the developmental activities drastically everywhere (Kumar et al. 2015). The contamination of the surface also related with increase in population, urbanization and industrialization has those tapping water from shallow unconfined aquifers (Amadi 2011; Oluseyi et al. 2011; Sadat-Noori et al. 2014). The most common source of groundwater pollutions are the discharge of sewage, industrial and agricultural waste, both organic and inorganic, mining, fertilizers and pesticides washed off the land by rain (Nwajei et al. 2012; Boateng et al. 2016). Several researchers have proposed different methods of analyzing water quality data depending on the purpose, samples types and the size of the sampling area (Alobaidy

---

✉ S. Deepa
deepaearthscience@gmail.com

[1] Department of Geology, Periyar University, Salem 636 011, Tamil Nadu, India

et al. 2010; Venkateswaran and Kannan 2015; Arulbalaji and Gurugnanam 2016; Pradeep et al. 2016; Saravanan et al. 2016; Ehteshami et al. 2016; Yazdanpanah 2016). The direct dumping of human wastes into water bodies (Singh et al. 2008) is a major direct effect to contaminate the water with a direct way. Water pollution not only affects water quality but also threats human health, economic development, and social prosperity (Milovanovic 2007). This the main reason to detailed study about groundwater quality of every place and as well as in the study area.

Numerous publications have reported that urban development and agricultural activities directly or indirectly affect the groundwater quality (Fantong et al. 2009; Ramkumar et al. 2011; Kim et al. 2012; Gnanachandrasamy et al. 2012, 2015; Venkateswaran and Deepa 2015; Gopinath et al. 2016; Saravanan et al. 2016). One important study that give appropriate knowledge about quality of groundwater that is water quality index (WQI) for assessing groundwater quality and its suitability for drinking purposes (Vasanthavigar et al. 2010; Gibrilla et al. 2011; Jasmin and Mallikarjuna 2014; Sadat-Noori et al. 2014; Boateng et al. 2016). Another one type studies that various geostatistical concepts are used for the interpretation of complex data sets which give a better perceptive of the water quality (Srinivasamoorthy et al. 2011). The maps gives better view of maximum details of a studies in a work this is possible with GIS environment (Gnanachandrasamy et al. 2012). The Manimuktha sub basin one of the main sub basin at Villupuram district. Surface water sources are normally uneven to get their supply during nonmonsoon seasons in the study area. Therefore in the study area peoples mainly depends on groundwater for their drinking as well as irrigation activities (Prakash and Venkateswaran 2014). So a proper test to need assess the groundwater quality and WQI of a local body is vital to establish a continuing record for possible water remediation.

The aim of this paper was to utilize the WQI model and geostatistical techniques for assessment of water quality. As well as in regulate to purpose of connection among every groundwater aspects used the correlation analysis in study area.

Description of the upper Manimuktha sub basin

Manimuktha sub basin one of the main tributaries of Vellar river originates from Kalrayan hills in Villupuram district, traverses about 111 km (69 mi) and joins Vellar near Srimushnam in Chidambaram taluk of Cuddalore District. It lies between 78°42′ to 78°59′E longitude and 11°42′ to 11°59′N latitude covering the total area of 497.11 km^2 in which hilly area occupies 187.19 km^2. Western side the study area covered by Kalvarayan hills (Fig. 1) which divide the Salem and Villupuram districts are seen to the extreme west of Kallakurichi taluk. The average annual rainfall of the study area is 1115 mm bring the groundwater recharge in the area. The study area chiefly consists of hard crystalline rocks of archean age. The flow of water in the river is reduced during the period from February to June, and as a result, in the region depends on groundwater for their use. A major part of the study area covered in the agricultural activities, where sugarcane, paddy, and groundnut are being cultivated.

Geology and Hydrogeology

Upper Manimuktha sub basin comprises the precambrian peninsular gneiss and its retrograded products (Kumar et al. 2009) the area mainly underlain by chornockites, fissile hornblende gneiss, hornblende biotite gneiss, and ultrabasic rocks (Deepa et al. 2016). Drainage mainly consisting of dendritic, sub dendritic and radial in nature. 13 kinds of geomorphological features are noticed in the study area, the catchment area covered by ridge type structural hills in the western side and followed by pediplains, lies along the river course side. Some of area spread by inselberg, pediment canal command, water body masks, linear ridge dykes and upper piedmont slope. Weathering is highly erratic and the depth of abstraction structures is controlled by the intensity of weathering and fracturing. The depth of wells varies from 6.64 to 17 m bgl and water levels in observation wells tapping shallow aquifers varied from 0.74 to 9.7 m bgl during premonsoon (2006–2015) and it varies from 0.7 to 4.45 m bgl during postmonsoon (2006–2015). During premonsoon season, the water levels range of > 2 to 5 m bgl in major part of the district, in the range of > 5–10 m bgl in western and southeastern parts of the district (CGWB 2009).

Materials and methods

Groundwater sample collections and analysis

The base map of the study area was prepared using Survey of India topographic sheets (58E 9 and 13) having a scale of 1:50,000 and digitized using ArcGIS 9.3 software. Forty eight groundwater samples were collected during the January 2014. Figure 1 shows the locations of the groundwater samples.

The collection, preservation and chemical analysis for major ions of water samples were made following the standard methods are given by the American Public Health Association (APHA 1998). The ionic constituents Ca, Mg, Na, K, Cl, HCO_3, NO_3, F and SO_4 and the non-ionic constituents pH, electrical conductivity (EC) and total dissolved solids (TDS) were determined for this groundwater in the study area.The detailed methodology shown in Fig. 2.

Before analyzing the data, the degree of chemical accuracy was identified as ion balance error or reaction error

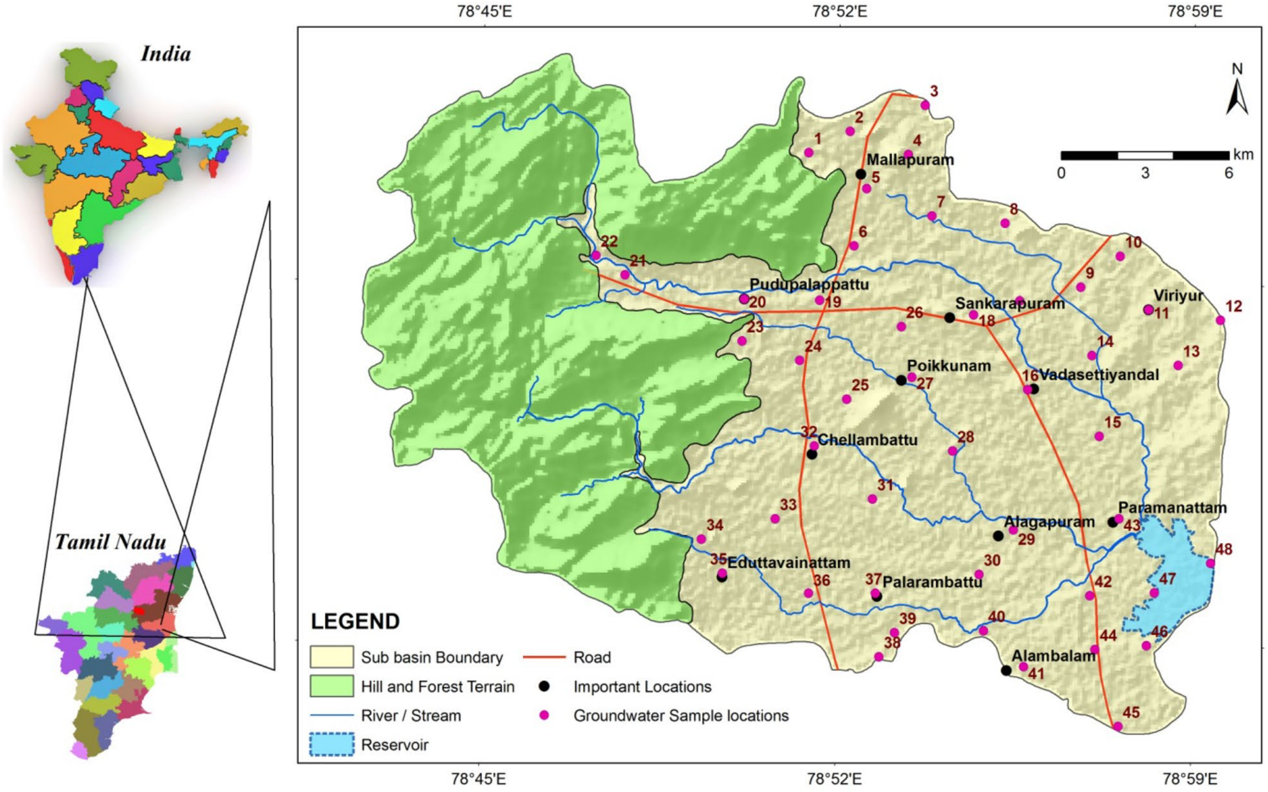
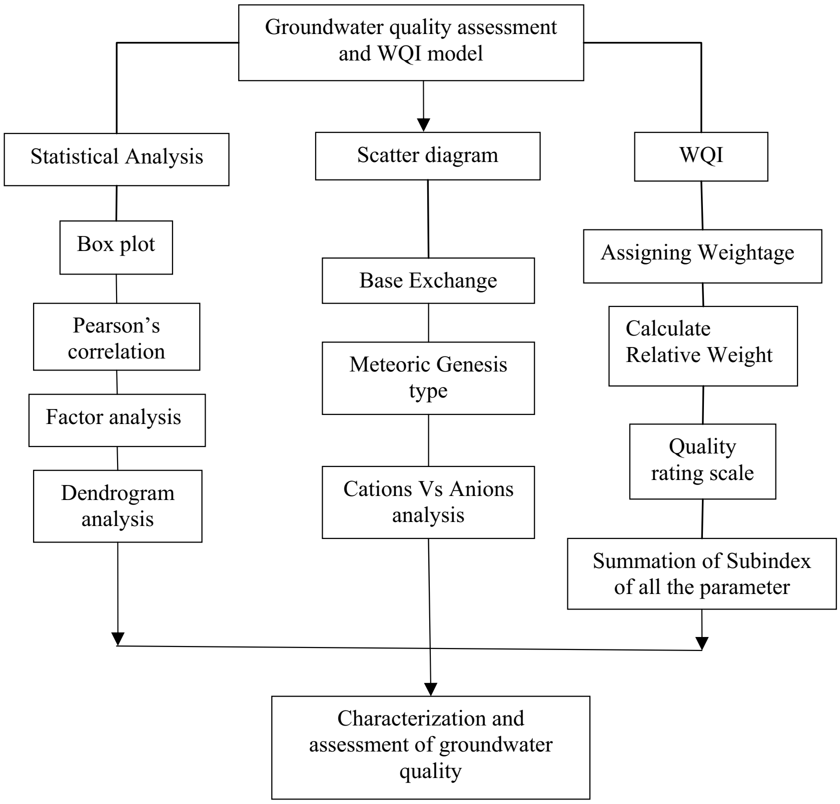


Fig. 1 Base map of the Upper Manimuktha sub basin

Fig. 2 Methodology



(RE). The analytical precision for ions was determined by the ionic balances calculated as Eq. 1.

$$\mathrm{RE} = \frac{\sum Cations - \sum Anions}{\sum (Cations + Anions)} \times 100\,. \tag{1}$$

RE value greater than 5% would indicate that the accuracy of data is questionable (Metcalf and Eddy 2003; Freeze and Cherry 1979). If RE is in permissive extent, Shapiro–Wilk test should be used to check the normality of data distribution (Shapiro and Wilk 1965). Figure 3 shows graph of the total sum of cations vs the total sum of anions. The quality of the analysis was documentation by standardization using blank, spike, and duplicate samples. Statistical measures such as minimum, maximum, average, and standard deviation are given in Table 1.

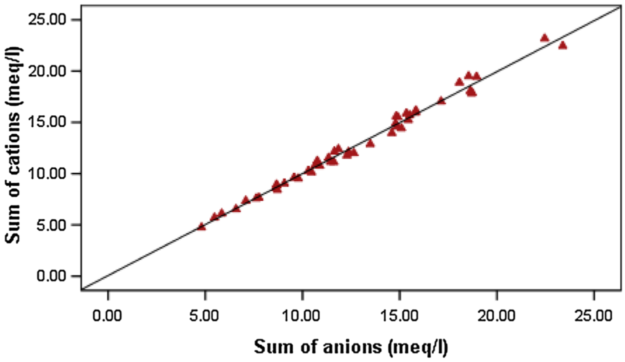


Fig. 3 Correlation coefficient between TCC and TCA

GIS analysis

Spatial Analyst extension (an extended module of ArcGIS 9.3) was used to interpolate the spatial distribution of the WQI map. Inverse distance weighted (IDW) interpolation technique was used to create different thematic layers. IDW is an algorithm used to interpolate data spatially or estimate values between measurements. Weights are computed by taking the inverse of the distance from observations location to the location of the point being estimated (Burrough and Donnell 1998).

WQI model

WQI is a technique that provides the combination of every individual water quality parameters on the overall quality of water. This study focuses on the development of WQI for human consumption. The calculations are made based on the standards suggested by (WHO 1996 and; BIS 1991). For computing WQI three steps are followed (Vasanthavigar et al. 2010; Sadat-Noori et al. 2014). In the first step, each of the 12 parameters (pH, EC, TDS, Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3 and F) has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 2). The maximum weight of 5 has been assigned to nitrate due to its major importance in water quality assessment (Srinivasamoorthy et al. 2008). The maximum and minimum weightages was given based on their importance in the water quality and their weight given in Table 2 depending on their importance in water quality determination. In the second step, the relative weight (Wi) is computed from the Eq. 2:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \tag{2}$$

Table 1 Statistical measures such as maximum, minimum, average and standard deviation

Parameter	Unit	Minimum	Maximum	Mean	Std. deviation
EC	µS/cm	475.0	4080.0	1392.2	632.6
TDS	mg/l	351.0	1572.8	889.1	292.4
pH	–	6.9	8.1	7.5	0.4
Alkalinity	mg/l	152.0	608.0	351.3	100.6
TH	mg/l	136.0	748.0	409.2	134.2
Ca	mg/l	34.0	184.0	86.0	32.4
Mg	mg/l	13.0	73.0	37.5	13.8
Na	mg/l	43.0	192.0	111.9	41.2
K	mg/l	4.0	54.0	17.6	9.4
NO_3	mg/l	4.0	64.0	25.2	13.5
Cl	mg/l	44.0	412.0	191.9	86.7
F	mg/l	0.2	3.6	1.3	0.8
SO_4	mg/l	8.0	150.0	56.6	29.0
HCO_3	mg/l	164.8	555.2	346.1	95.4

Table 2 Relative weight of chemical parameters

Parameters	WHO	Weight (wi)	Relative weight (Wi)
TDS	500	4	0.108
pH	6.5–8.5	4	0.108
TH	–	2	0.054
Ca	75	2	0.054
Mg	30	2	0.054
Na	200	2	0.054
K	12	2	0.054
Cl	250	3	0.081
F	1	4	0.108
NO_3	45	5	0.135
HCO_3	500	3	0.081
SO_4	200	4	0.108
		$\sum wi = 37$	$\sum Wi = 1.000$

where Wi is the relative weight, w_i is the weight of each parameter, n is the number of parameters.

In the third step, a quality rating scale (qi) for each parameter is consigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS 10500 (1991) and the result is multiplied by 100:

$$q_i = (C_i/S_i) \times 100, \tag{3}$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in milligrams per liter. Si is the Indian drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of the BIS 10500 (1991).

For computing the WQI, the SI is first determined for each chemical parameter based on the Eq. 4, which is then used to determine the WQI as per the Eq. 5.

$$SI_i = W_i \times q_i, \tag{4}$$

$$\mathrm{WQI} = \sum SI_i\ , \tag{5}$$

where SI_i is the Sub-Index of ith parameter, q_i is the rating based on concentration of ith parameter, n is the number of parameters.

The calculation method of WQI is expressed in detail by many authors (Saeedi et al. 2010; Vasanthavigar et al. 2010; Yidana and Yidana 2010; Jasmin and Mallikarjuna 2014; Sadat-Noori et al. 2014; Selvam et al. 2016; Boateng et al. 2016; Sakizadeh 2016). WQI values are usually classified into five categories (Table 3) such as excellent, good, poor, very poor, and unsuitable for human consumption (Sahu and Sikdar 2008).

Table 3 Categorization of groundwater quality according to WQI

Range	Type of water
< 50	Excellent water
50–100.1	Good water
100–200.1	Poor water
200–300.1	Very poor water
> 300	Water unsuitable for drinking purposes

Statistical techniques

The analytical results of the chemical analysis and the statistical parameters such as minimum, maximum, average and standard deviation are presented in Table 1. Multivariate statistical analysis was performed by major ions and EC, pH and TDSs. Multivariate statistical analysis was used to reduce and organize large hydrochemical datasets into groups with similar characteristics (Srinivasamoorthy et al. 2011; Selvam et al. 2016). The basic purpose of this analysis was to interpret the relationship of variables. The correlation coefficient (r) commonly used to examine the degree of correlation between the different chemical parameters, which influence the quality of groundwater. It is a simple assess to reveal how well one variable predicts the other (Kurumbein and Graybill 1965).

Analytical data was processed using SPSS version 16.0 software. Factor analysis was performed by varimax rotation (Howitt and Cramer 2005), which minimized the number of variables with a high loading on each component, thus facilitating the interpretation of PCA results. The main advantage of principal component analysis (PCA) is that it identifying patterns by compressing the data by reducing the numbers of dimensions without much loss of information (Irawan et al. 2009; Kazi et al. 2009; Srinivasamoorthy et al. 2011; Selvam et al. 2016; Boateng et al. 2016). The spatial variability of groundwater was determined by the Cluster Analysis (Shanmugasundharam et al. 2015). Two different methods can be applied to identify clusters, including R- or Q-modes. R mode is usually applied to water quality variables to reveal the interactions between them, while Q-mode reveals the interactions between the studied samples.

For this study R mode was used for Fourteen hydrochemical measured variables (EC, TDS, pH, Alkalinity, Total Hardness (TH), Ca, Mg, Na, K, NO_3, Cl, F, SO_4 and HCO_3) were utilized in this analysis. As there is no test to determine the optimum number of groups in the dataset (Guler et al. 2002), the visual inspection is the only criteria to select the groups in the dendrogram.

Result and discussion

pH, EC and TDS

pH of the groundwater samples in the study area ranges from 6.9 to 8.1 the average pH was found to be 7.5. The electrical conductivity (EC) of the groundwater ranges from 475 to 4080 µS/cm, the average EC was found to be 1392.2 µS/cm indicates the groundwater had slightly salinity nature. TDS values are considered as important values in determining the usage of water. The concentration of total dissolved solids (TDS) ranges from 351 to 1572.8 mg/l, the average TDS was found to be 974.56 mg/l indicating well for drinking purpose but few samples fall in the not potable limit.

Major anions

The bicarbonate measured in the groundwater ranges from 164.8 to 555.2 mg/l, the average was found to be 346.1 mg/l it does not exceed above the desirable level

(Table 1). The sulfate concentration of study area ranges from 8 to 150 mg/l, the average was found to be 56.6 mg/l and it is under the permissible limit.

The concentration of nitrate in groundwater varies from 4 to 64 mg/l, the average of the nitrates 25.2 mg/l does not exceed above the potable limit only three groundwater samples fall in the not potable limit. Nitrate is also an indicator of pollution. A large amount of Fertilizers usage in the agricultural land leads to the nitrate content in groundwater is increasing all over the world. Nitrate and nitrite are hazardous to human health (USEPA 2002). The chloride concentration of study area ranges from 44 to 412 mg/l, the average was found to be 191.9 mg/l and it does not exceed above desirable limit only one sample fall in the not potable limit. Fluoride is an essential for maintaining normal development of teeth and bones. The concentration of fluoride ranges from 0.2 to 3.6 mg/l, the average of fluoride 1.3 mg/l. Such a higher concentration may be attributed to the percolation of phosphatic fertilizers from the irrigational runoff from the nearby lands. Discharge of domestic waters and the wastes from the surrounding industries can also increase the fluoride values (Singh et al. 2011). The fluoride contaminations in the groundwater indicate the presence of fluoride bearing minerals (Kumar et al. 2011; Ramachandramoorthy et al. 2010).

Major cations

The calcium concentration in the groundwater ranges from 34 to 184 mg/l, the average of calcium 86 mg/l not exceeds the allowable limit and all samples fall in acceptable and allowable limits. The magnesium concentration in the groundwater ranges from 13 to 73 mg/l and average of magnesium 37.5 mg/l not exceed the allowable level and maximum samples fall in the potable, allowable limit. The concentration of Ca and Mg in the groundwater is most probably derived from leaching of carbonate minerals such as calcite and dolomite. The concentration of sodium in the groundwater ranges from 43 to 192 mg/l and average of the sodium is 111.9 mg/l it does not exceed potable limit. Sodium and potassium were the most important elements occurring naturally. Potassium ranges from 4 to 54 mg/l, the average of the potassium 17.6 mg/l, it exceeds above the potable category, maximum sample falls in the not potable limit. The excess amount of potassium present in the water sample may lead nervous and digestive disorder (Tiwary 2001).

Box plot

Box plot one of the easiest plot and gives better illustration about the anions and cations dominance (Taheri and Voudouris 2008; Srinivasamoorthy et al. 2014). Box plots were used to represent temporal concentration and dominance of the major ions (Fig. 4). The upper and lower quartiles of the

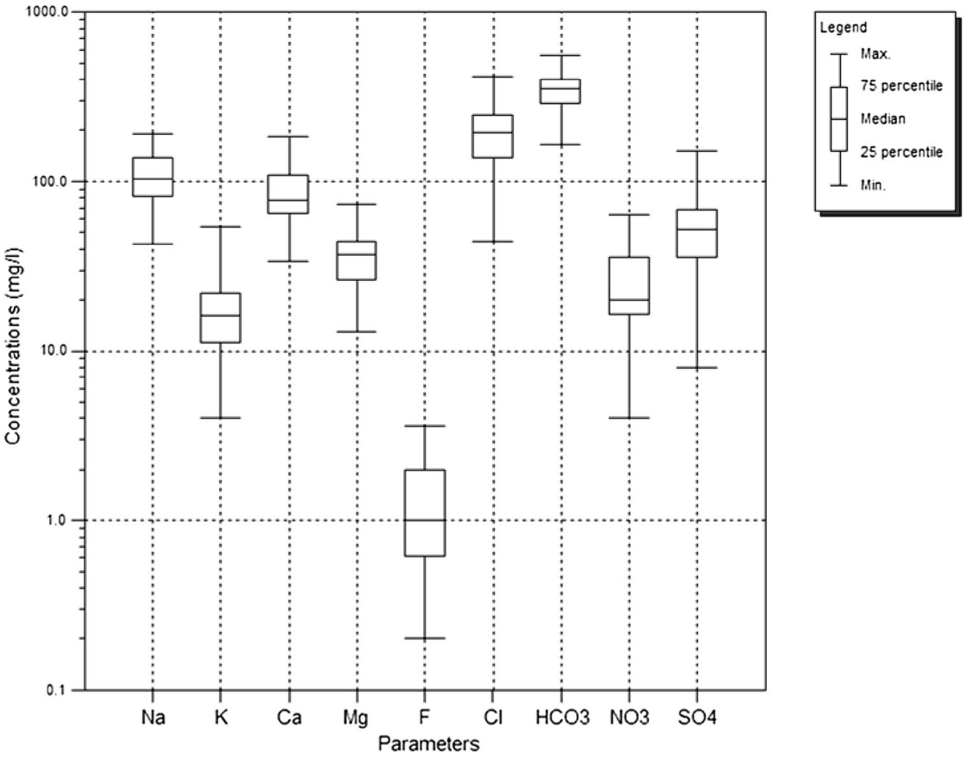


Fig. 4 Box plot for the chemical constituents

data define the top and the bottom of a rectangle box. The line inside the box represents the median value and the size of the box represents the spread of the central value (Srinivamoorthy et al. 2014).

This plot reveals groundwater samples were are dominated by the order of Na > Ca > Mg > K for cations and $HCO_3 > Cl > SO_4 > NO_3$ in anions. The plot shows remarkable variation in mean, median and standard deviation values of hydrochemical parameters indicating study area is wide-ranging of process influenced in the groundwater for various complex contaminant sources.

Base exchange indices

Base Exchange Indices is a process for determine the groundwater type of the study area. It mainly depending the sodium, chloride and sulfate ions. The Base Exchange Indices (Soltan 1999) determined by using the Eq. 6;

$$r1 = Na - Cl/SO_4, \tag{6}$$

where r1 is in milliequivalents per liter.

Table 4 gives details of the groundwater can be grouped as Na-HCO_3 type if r1 > 1 and Na-SO_4 type with r1 < 1. In the study region all the samples fall in Na-HCO_3 type, except one sample fall (Na–SO_4) (Fig. 5).

Meteoric genesis index (r2) is to determine the groundwater sources as shallow or deep meteoric in the groundwater. This index dervied by sodium, potassium, chloride and sulfate ions concentration in the groundwater. Meteoric genesis index is calculated by Soltan (1999) Eq. 7.

$$r2 = ((K + Na) - Cl)/SO_4, \tag{7}$$

where r2 is in milliequivalents per liter.

Figure 6 show maximum of the groundwater samples (79%) were deep meteoric percolation type (Table 4).

Table 4 Classification of groundwater samples by Soltan (1998)

Parameters	Ranges	Type of water	No. of samples
TDS	< 1000 mg/l	Fresh water	28
	> 1000 mg/l	Brackish water	20
Chloride	< 15 meq/l	Normal Chloride type	All samples
	> 15 meq/l		
SO_4	< 6 meq/l	Normal sulfate type	All samples
	> 6 meq/l		
HCO_3	2–7 meq/l	Normal Bicarbonate type	28 samples
	>7 meq/l		20 samples
Base exchange indices			
r1	< 1	Na–HCO_3 type	47 samples
	> 1	Na–SO_4 type	1 samples
r2	< 1	Deep meteoric water	38 samples
	> 1	Shallow meteoric water	10 samples

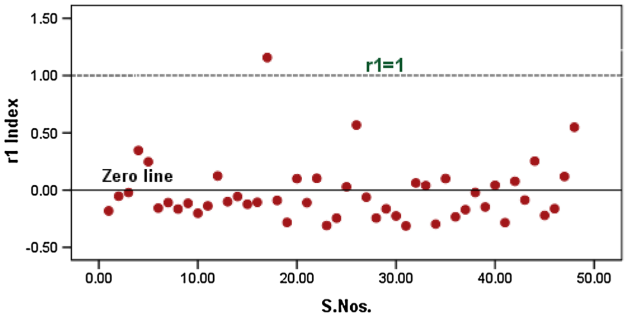


Fig. 5 Base exchange index plot (r1)

Because of high rainfall situation and also the continuous exploitation of groundwater resultant in steep fall in water levels might have led to more of deep meteoric percolation type of water (Rao et al. 2013; Machender et al. 2014).

Hydrochemical processes

The major ion chemistry of groundwater is a powerful tool because of dealing with groundwater evolution as a result of water–rock interaction leading to the dissolution of carbonate minerals, silicate weathering and ion exchange processes (Herczeg et al. 1991; Elliot et al. 1999; Edmunds and Smedley 2000; Kumar et al. 2006). From the resultant average ratio of (Ca + Mg)/total cations varied from 0.4 to 0.66 in the study region.

The Figure 7 shows Ca + Mg vs total cations, that all the points lies above the aquiline signifying the condition of alkalis to the major ions, which resulting from silicate weathering and alkaline earth silicates. This plot also reveals increasing contribution of Na and K with increasing total dissolved solids.

The average ratio of (Na + K)/total cations varied from 0.3 to 0.5. Figure 8 show (Na + K) vs total cations of that samples fall along the aquiline, signifying that the cations in groundwater might have been derived from silicate weathering in the geochemical processes, which contributes mainly

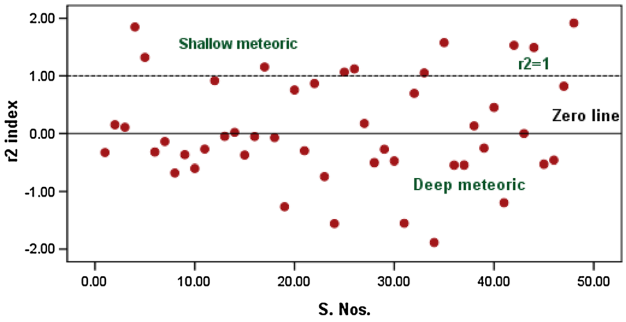


Fig. 6 Meteoric genesis index plot (r2)

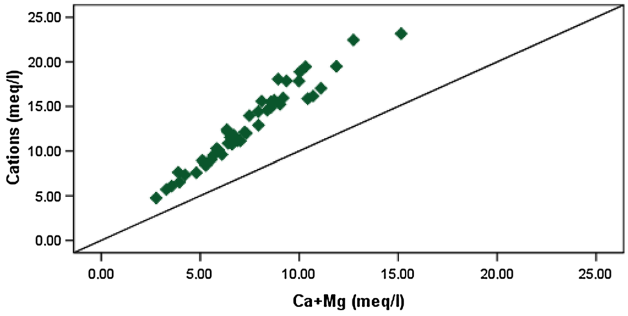


Fig. 7 Ca + Mg versus total cation plot

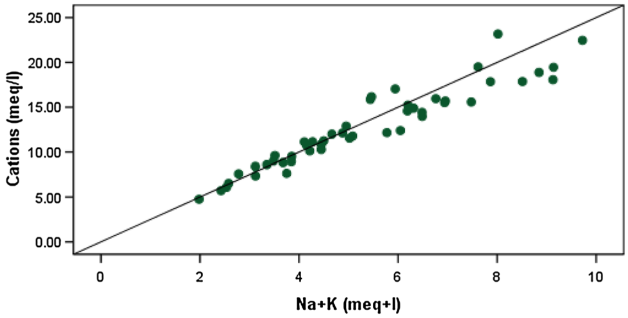


Fig. 8 Na + K versus total cation plot

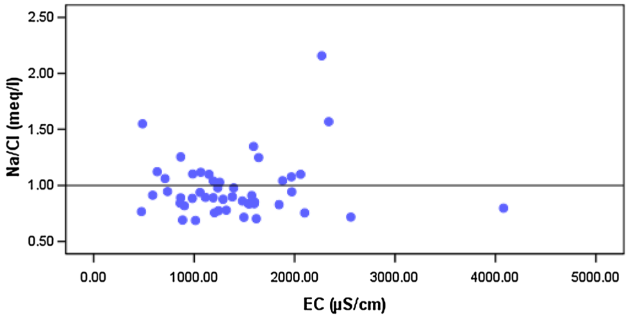


Fig. 9 Na/Cl ration versus EC plot

sodium and potassium ions to the groundwater (Stallard and Edmond 1983).

The Na-Cl relationship is mostly used to identify mechanisms related to salinity in semi-arid regions (Ganyaglo et al. 2011; Nematollahi et al. 2016). Figure 9 shows the Na/Cl ratio decreasing trend with increasing EC, indicating Na released from silicate weathering process. In the plot (Fig. 8) shows 32 samples have Na/Cl ratio below one and 16 groundwater samples above the one in the study area, indicating that maximum of halite dissolution and some places controlled by silicate weathering processes respectively.

The Na vs Cl (Fig. 10) plot indicates the increasing trend of Na with Cl and also most of the samples lie above the aquiline representing the excess of Na is attributed to silicate

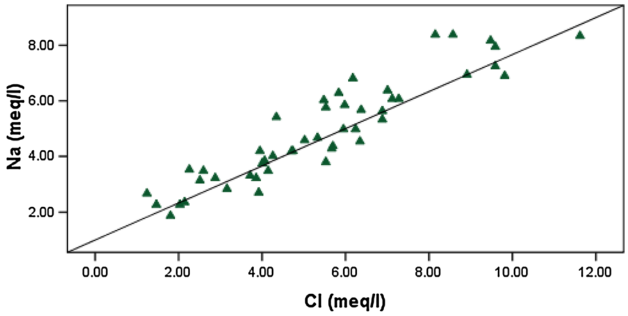


Fig. 10 Na versus Cl plot

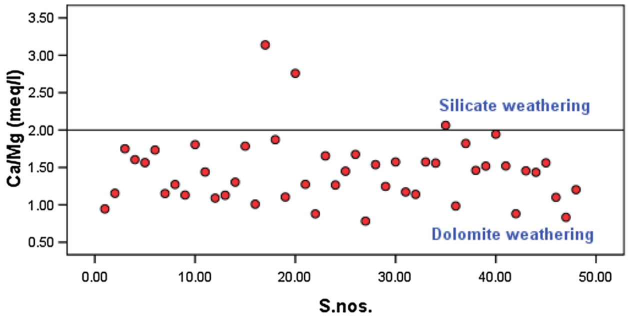


Fig. 11 Ca/Mg versus sample nos. plot

weathering (Stallard and Edmond 1983) whereas some samples lay below it, indicating that the addition of Cl may be due to water level rise which causes more salt dissolution from the soil (Rao et al. 2013).

The Ca/Mg ratio of 1 specify dissolution of dolomite and of > 2 revealed an effect of silicate minerals on the groundwater chemistry; it also suggested dolomite dissolution for Ca-Mg concentration in groundwater (May and Loucks 1995). Ca/Mg ratio of 93.7% samples ranges from 0.78 to 1.94 indicates dolomite dissolution responsible for Ca–Mg contribution (Fig. 11).

The sources of the dissolved constituents in ground water can also be evaluated from the relative abundance of individual ions and inter-elemental correlation (Singh et al. 2011). The plot of (Ca + Mg) vs ($\mathrm{HCO_3 + SO_4}$) will be close to 1:1 line in case of dissolution of calcite, dolomite and gypsum. Ion exchange tends to shift the plotted points towards right due to a large excess of ($\mathrm{HCO_3 + SO_4}$) and towards the left in case of reverse ion exchange and dominance of (Ca + Mg) over ($\mathrm{HCO_3 + SO_4}$) (Cerling et al. 1989; Fisher and Mulican 1997). (Ca + Mg) vs ($\mathrm{SO_4 + HCO_3}$) for groundwater samples indicate in Fig. 12 that majority of the groundwater samples falls near and along the aquiline, it reveals both ion exchange and reverse ion exchange were responsible for hydrochemical process in the study area. If bicarbonate and sulfate are dominating than calcium and magnesium, it reflects that silicate weathering and ion exchange process were dominating

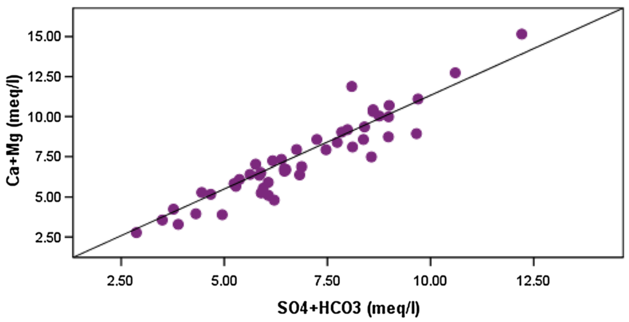


Fig. 12 Ca/Mg versus SO_4+HCO_3 plot

to responsible for the increase in the concentration of HCO_3 in groundwater.

WQI of the Upper Manimuktha sub basin

Water quality types were determined on the basis of WQI. The computed WQI values range from 45.8 to 225.1. According to the WQI values for 2 samples were located in Excellent classification, 22 samples to be found in Good water classification, 23 samples placed in poor water and 1 sample located in the very poor water. Based on the WQI, 50% of the samples not good for drinking purposes. Figure 13 indicates that the central part of the study area covered by good WQI. The groundwater quality decreases in the northern and southern side of the sub basin. This is mainly due to the effects of the hydraulic gradient (Sadat-Noori et al. 2014) and the domestic pollution; anthropogenic activities such as fertilizer usage for agricultural land mainly affect the groundwater of southern and northern side of the

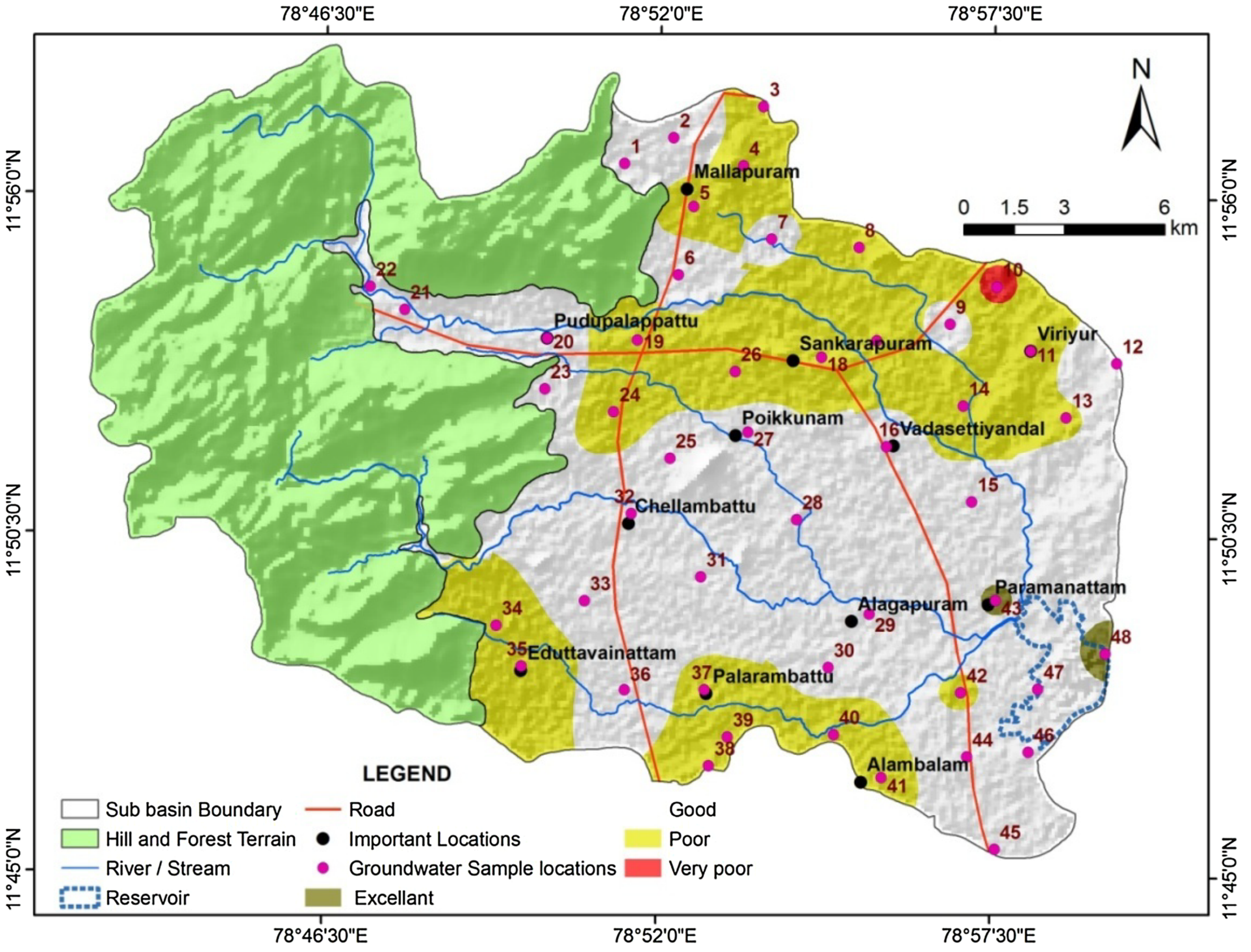


Fig. 13 Spatial distribution of WQI

study area. As well as the area with deep groundwater is also the main reason for poor water quality of the study area (Vasanthavigar et al. 2010).

Calculation of WQI for every sample are represented in Table 5. Groundwater samples represent 4.2% of samples within the “excellent water”, 45.83% indicate “good water”, 47.91% shows “poor water”, and 2.1% shows “very poor water”. This may be due to effective leaching of ions, over-exploitation of groundwater, direct discharge of effluents and agricultural impact (Sahu and Sikdar 2008).

Table 5 Groundwater classification in the study area based on WQI

S. No.	WQI	Classification	S. No.	WQI	Classification
1	75.0	Good water	25	86.5	Good water
2	63.2	Good water	26	152.6	Poor water
3	113.6	Good water	27	84.0	Good water
4	126.3	Poor water	28	100.7	Poor water
5	123.3	Poor water	29	115.0	Poor water
6	66.2	Good water	30	97.4	Good water
7	93.1	Good water	31	82.7	Good water
8	124.3	Poor water	32	66.8	Good water
9	80.9	Good water	33	89.7	Good water
10	225.1	Very poor water	34	125.8	Poor water
11	109.0	Poor water	35	175.4	Poor water
12	56.3	Good water	36	59.3	Good water
13	112.4	Poor water	37	132.7	Poor water
14	138.0	Poor water	38	111.7	Poor water
15	98.0	Good water	39	132.1	Poor water
16	86.5	Good water	40	119.8	Poor water
17	146.1	Poor water	41	124.8	Poor water
18	111.1	Poor water	42	127.7	Poor water
19	166.4	Poor water	43	50.0	Excellent water
20	87.5	Good water	44	70.2	Good water
21	88.2	Good water	45	96.4	Good water
22	82.9	Good water	46	104.7	Poor water
23	72.7	Good water	47	85.9	Good water
24	149.2	Poor water	48	45.8	Excellent water

Multivariate statistical analysis

The Pearson’s correlation matrices (Swan and Sandilands 1995) are used to find the relationships between two or more variables, where the correlation matrices between 13 chemical parameters were computed and presented in Table 6.

Based on the Pearson’s correlation, significant and high positive correlation ($r > 0.7$), majority of the parameters were found to tolerate statistically significant correlation with each other representing close association of these parameters with each other except pH and F. Strong significant correlation of TDS between all the elements except pH, F. The pH was negatively correlated with all the physicochemical parameters and also the strong significant correlation of alkalinity with all the elements except pH, F, SO_4. The strong significant correlation of Total hardness with Na, K, NO_3, Cl, SO_4, HCO_3 and moderately correlated with Ca, Mg. Table 6 indicates all the constituents highly correlated with one another except pH and F. This reflects that the groundwater in the area has been contaminated due to application of excess amount of fertilizer, over exploitation, and anthropogenic activities. The variation of these relationships may indicate the complexity of the hydrochemical components of groundwater where natural water always contains dissolved and suspended substances of mineral origin (Elkrail and Obied 2013). Sodium also highly correlated with Cl and then NO_3, HCO_3, K. High positive correlation coefficient between Na and Cl suggests the predominance of chemical weathering and dissolution of chloride salts (mostly halite) in the study area. This means that Base Exchange and dissolution of sodium salts during movement of the groundwater through sediments might lead to high

Table 6 Correlation matrix connecting groundwater quality parameters

	TDS	pH	Alk	TH	Ca	Mg	Na	K	NO_3	Cl	F	SO_4	HCO_3
TDS	1.00												
pH	−0.06	1.00											
Alk	0.81	−0.10	1.00										
TH	0.79	0.05	0.70	1.00									
Ca	0.93	−0.03	0.80	0.67	1.00								
Mg	0.87	−0.14	0.73	0.64	0.76	1.00							
Na	0.94	0.02	0.72	0.80	0.81	0.74	1.00						
K	0.86	−0.19	0.69	0.70	0.71	0.81	0.81	1.00					
NO_3	0.92	−0.04	0.79	0.81	0.79	0.81	0.88	0.89	1.00				
Cl	0.95	−0.01	0.77	0.77	0.87	0.83	0.92	0.87	0.90	1.00			
F	0.18	−0.24	0.08	0.30	0.10	0.18	0.21	0.23	0.15	0.15	1.00		
SO_4	0.70	0.02	0.45	0.45	0.73	0.62	0.62	0.51	0.56	0.63	0.13	1.00	
HCO_3	0.93	−0.13	0.78	0.72	0.85	0.81	0.83	0.77	0.82	0.79	0.16	0.53	1.00

sodium concentration (Nematollahi et al. 2016). The NO_3 ion was strongly correlated with Cl it indicates a possibility of contamination from fertilizers, municipal wastewaters, septic systems, and sometimes the cultivation of grasslands. Weathering processes and anthropogenic inputs are the two main contributors for changing the geochemical composition of the groundwater (Chan 2001). Potassium also first of all highly correlated with NO_3 then only the Cl, it also indicate wherever NO_3 high that mainly correlated with K. The weak correlation of F and pH with others, indicate these not influence of other constituents in the study area.

Negative correlation relation between parameters

The correlation analysis mainly deals with correlation between elements and another one main thing it also indicate a opposite relation with element as pH is negatively correlated with TDS, alkalinity, calcium, magnesium, potassium, nitrate, chloride and fluoride. It indicate that wherever pH ranges going to decreases with also TDS, alkalinity, calcium, magnesium, potassium, nitrate, chloride and fluoride increased. It clearly explains the acidic nature of groundwater mainly rich with anions and cations.

Factor analysis explain observed relation between numerous variables in terms of simpler relations. It is also a way of classifying manifestation of variables (Kumar et al. 2006). The concentration of each compound is separated in two partial contributions, one related to weathering reactions, and the other related to pollution. Factor analysis was applied to distinguish the partial contributions (Rao et al. 2013). An Eigenvalue provides assess of the significance of the factor: the factors with the highest Eigenvalues are the most significant. Eigenvalues of 1.0 or greater are considered significant. Liu et al. (2003) classified the factor loadings as 'strong', 'moderate' and 'weak', resultant to the absolute loading values of > 0.75, 0.50 to 0.75 and 0.30 to 0.50, respectively. The results of the analysis discovered in the Table 7, three factors accounted for 84.14% of the total variance. Based on the distribution of the Eigenvalues, factor 1 alone explained 69.04% of the variance. Figure 14 clearly reveals all the constituents were strongly correlated with factor 1 except pH and F. Factor 1 source mainly attributed to weathering and leaching of host rocks and as well as natural sources. From the factor 1 natural process is the important process in ions concentration in the groundwater. Factor 2 which describes 8.96% of the total variance has high positive loading for F. This factor could be mainly attributed to the gypsum and silicate weathering processes and cation exchange processes at soil–water interfaces. pH was strongly correlated with factor 3. Factor 3, therefore, could be said to reflect the influence of anthropogenic activities. Because the third factor mainly indicate the groundwater acidic and basic nature may be contribute by the anthropogenic activities such high amount of fertilizer usage, the dumping of organic and inorganic waste at or near the lakes.

Table 7 Factor-loading matrix, eigenvalues

Parameters	Factor 1	Factor 2	Factor 3
EC	0.93	0.16	− 0.07
TDS	0.99	0.08	− 0.02
pH	− 0.03	− 0.13	0.97
Alk	0.85	− 0.04	− 0.11
TH	0.80	0.33	0.16
Ca	0.92	− 0.03	0.01
Mg	0.88	0.06	− 0.16
Na	0.92	0.17	0.10
K	0.88	0.17	− 0.18
NO_3	0.94	0.09	0.00
Cl	0.96	0.08	0.03
F	0.09	0.97	− 0.14
SO_4	0.68	0.04	0.11
HCO_3	0.90	0.05	− 0.12
Total	9.66	1.25	0.86
% of Variance	69.04	8.96	6.15
Cumulative %	69.04	77.96	84.14

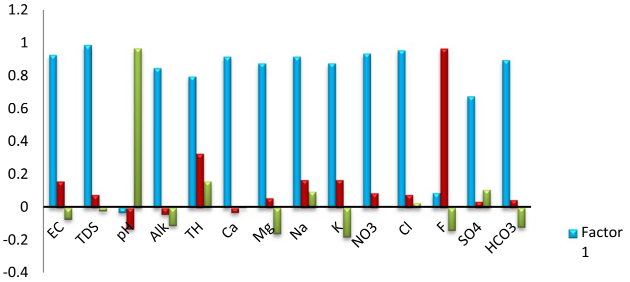


Fig. 14 Factor analysis results

According to Massart and Kaufmann (1983) the multivariate statistical analysis mainly based on the similarity and dissimilarity of variables and cases. Hieratical cluster analysis performed using Ward method. The results of parameters are shown three groups in Fig. 15. Most of the samples were classified in cluster 1 with similarity between major ions (F, K, NO_3, Ca, Mg, Na, SO_4, Cl and pH) which indicated the same source of origin of charnockitic terrain. Because the study area mainly underlain by charnockite. Cluster 2 demonstrate, total hardness (TH), bicarbonate and alkalinity were associated based on their amount of concentration were correlated with one another. The third cluster shows the similarity between EC and TDS also the amount of contribution is more or less same.

Another one way also illustrates quality of groundwater that is case wise classification of dendrogram. From Fig. 16 consists two classes as good water and polluted water of the

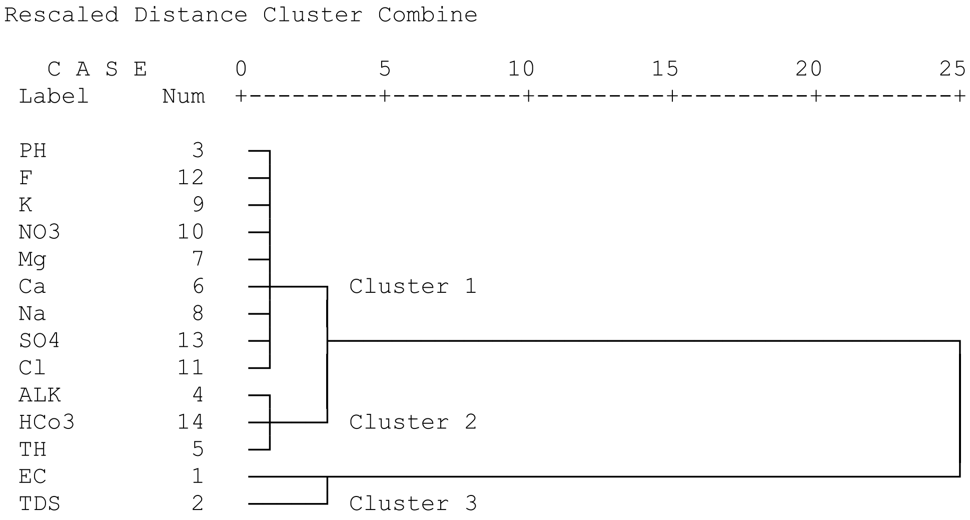


Fig. 15 Dendrogram for the groundwater assemblage with respect to their physico-geochemical parameters

study area. From this dendrogram analysis polluted water mainly in the northern and southern part of the study area. From the Table 5, polluted and unpolluted area matches with the Fig. 16. Polluted water is characterized by high amount of TDS, EC and as well as anions and cations. These 2 groups were alienated based on the increasing order of concentrations of variables in groundwater samples from above to below of the dendrogram.

Correlation between case wise Dendrogram and WQI

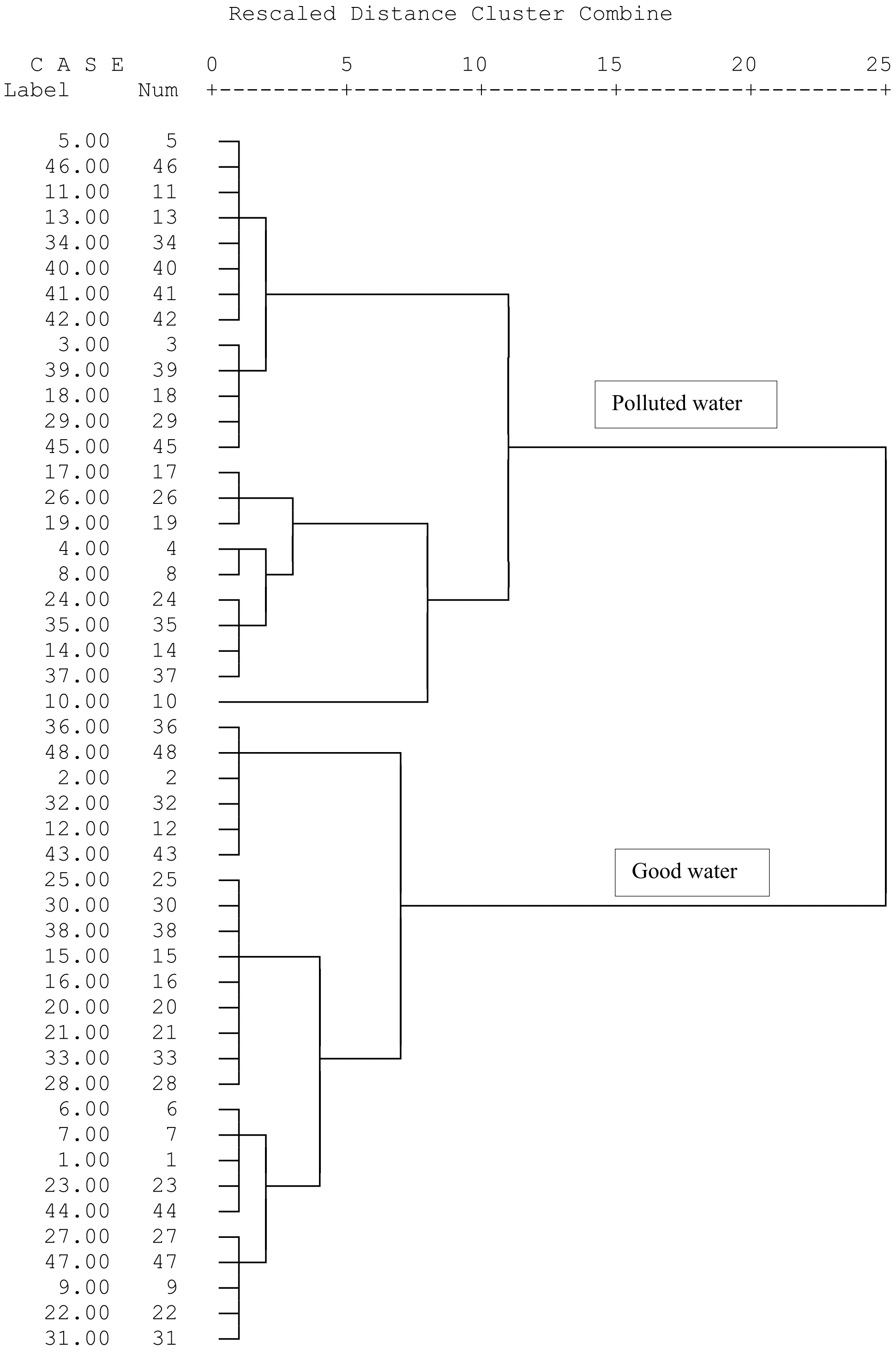
Cluster analysis results communicate with the WQI, therefore cluster analysis one of the main study to correlate with WQI and also validate the exactness of the WQI. From the dendrogram (Fig. 16) each and every sub cluster correlated with WQI. Figure 17 indicates every dendrogram wise samples align an ascending manner. It illustrate that the WQI also increase with the order of dendrogram samples wise.

Conclusion

Groundwater quality incorporate with WQI, GIS and the multivariate statistical analysis were carried out to conclude the geochemical processes accountable for quality deterioration in the study area. Based on this study EC, TDS, sodium, potassium, nitrate, chloride and fluoride were some of the locations exceeded the WHO permissible limits for drinking water. The groundwater samples were dominated by Na > Ca > Mg > K for cations and $HCO_3 > Cl > SO_4 > NO_3$ in anions. Maximum of the study area underlain by charnockite rock, it is one of the main reason for dominant of sodium.

WQI indicate northern and southern side of 23 samples fall in the poor water and one samples fall in the very poor water in the Kadavanur reserve forest. These locations mainly lie in charnockite and fissile hornblende biotite gneiss type of rocks. It reveals lithology also major reason for contamination of ground water in the study area. Maximum of lakes located in northern side of the study area also indicate poor quality, because of the contamination of waste water at or near the lakes such as organic as well as the inorganic waste migrate in the groundwater. As well as this area mainly fall the shallow groundwater it indicates the domestic, agricultural waste also contributed the groundwater impurity. The quality of groundwater was establish to be fit for drinking in spite a southern and northern parts of the study area. Correlation between WQI and Dendrogram analysis to prove this was able to correlate and appropriate study to gives proper result. Based on the result the correlation gives dendrogram cases and WQI S.No. aligned in a increasing order. From the correlation between stream wise analyses indicate element concentration changes random manner while mainly decreasing by the linear approach from the location to location upto the reservoir of the study area. This study also gives a better idea between the relation to case wise dendrogram and WQI. The overall geochemistry of groundwater in the study area is controlled by natural geochemical processes like rock water interaction and some places anthropogenic tempt activities like overexploitation of aquifers, fertilizer influences and agricultural return flow.

Fig. 16 Dendrogram for the groundwater quality assemblages with respect to groundwater samples



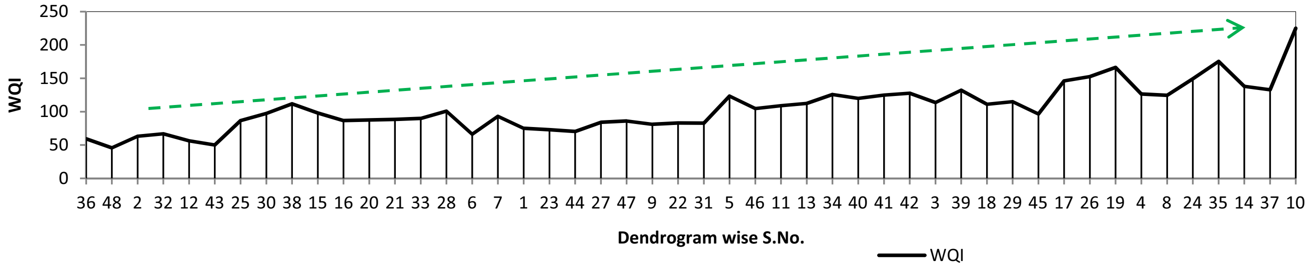


Fig. 17 Correlation between case wise Dendrogram and WQI

References

Alobaidy AHMJ., Abid HS, Maulood BK (2010) Application of water quality index for assessment of Dokan Lake ecosystem, Kurdistan Region, Iraq. J Water Resour Prot 2:792–798

Amadi AN (2011) Assessing the effects of Aladimma dumpsite on soil and groundwater using water quality index and factor analysis. Aust J Basic Appl Sci 5(11):763–770

American Public Health Association (APHA) (1998) Standard methods for the examination of water and wastewater, 20th. American Public Health Association, American Water Works Association, Water Environment Federation, Washington, DC

Arulbalaji P, Gurugnanam B (2016) Groundwater quality assessment using geospatial and statistical tools in Salem District, Tamil Nadu, India. Appl Water Sci. https://doi.org/10.1007/s13201-016-0501-5

BIS (1991) Bureau of Indian Standards—Indian standard specification for drinking water, IS, p 10500

Boateng TK, Opoku F, Acquaah SO (2016) Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana. Environ Earth Sci. https://doi.org/10.1007/s12665-015-5105-0

Burrough PA, Mc Donnell RA (1998) Principles of geographical information systems for land resources assessment. Oxford University Press, New York, pp 1–333

Cerling TE, Pederson BL, Damm KLV (1989) Sodium calcium ion exchange in the weathering of shales: implication from global weathering budgets. Geology 17:552–554

Chan HJ (2001) Effect of land use and urbanization on hydrochemistry and contamination of groundwater from Taejon area, Korea. J Hydrol 253:194–210

Deepa S, Venkateswaran S, Ayyandurai R, Kannan R, Vijay Prabhu M (2016) Groundwater recharge potential zones mapping in upper Manimuktha Sub basin Vellar river Tamil Nadu India using GIS and remote sensing techniques. Model Earth Syst Environ. https://doi.org/10.1007/s40808-016-0192-9

Edmunds WM, Smedley PL (2000) Residence time indicators in groundwater: The East Midlands Triassic sandstone aquifer. Appl Geochem 15:737–752

Ehteshami M, Salari M, Zaresefat M (2016) Sustainable development analyses to evaluate groundwater quality and quantity management Model Earth Syst Environ. https://doi.org/10.1007/s40808-016-0196-5

Elkrail AB, Obied BA (2013) Hydrochemical characterization and groundwater quality in Delta Tokar alluvial plain, Red Sea coast-Sudan. Arab J Geosci. https://doi.org/10.1007/s12517-012-0594-6

Elliot T, Andrews JN, Edmunds WM (1999) Hydrochemical trends, paleorecharge and groundwater ages in the fissured Chalk aquifer of the London and Berkshire basins UK. Appl Geochem 14:333–363

Fantong WY, Satake H, Aka FT, Ayonghe SN, Asai K, Mandal AK (2009) Hydrochemical and isotopic evidence of recharge, apparent age, and flow direction of groundwater in Mayo Tsanaga River Basin, Cameroon: bearings on contamination. Environ Earth Sci. https://doi.org/10.1007/s12665-009-0173-7

Fisher RS, Mullican WF (1997) Hydrochemical evolution of sodium sulphate and sodium chloride groundwater beneath the Northern Chihuahuan desert, Trans-Pecos, Rexas, USA. Hydrogeol J 10:455–474

Freeze RA, Cherry JA (1979) Groundwater. Prentice-Hall, New Jersey, p 604

Ganyaglo SY, Banoeng-Yakubo B, Osae S, Dampare SB, Fianko JR (2011) Water quality assessment of groundwater in some rock types in parts of the eastern region of Ghana. Environ Earth Sci 62(5):1055–1069

Gibrilla A, Bam EKP, Adomako D (2011) Application of water quality index (WQI) and multivariate analysis for groundwater quality assessment of the Birimian and Cape Coast granitoid complex: Densu river basin of Ghana. Water Qual Expo Health. https://doi.org/10.1007/s12403-011-0044-9

Gnanachandrasamy G, Ramkumar T, Venkatramann S, Anithamary I, Vasudevan S (2012) GIS Based hydrogeochemical characteristics of groundwater quality in Nagapattinam District, Tamilnadu, India. Carpath. J Earth Environ Sci 7(3):205–210

Gnanachandrasamy G, Ramkumar T, Venkatramanan S (2015) Accessing groundwater quality in lower part of Nagapattinam district, Southern India: using hydrogeochemistry and GIS interpolation techniques. Appl Water Sci. https://doi.org/10.1007/s13201-014-0172-z

Gopinath S, Srinivasamoorthy K, Vasanthavigar M, Saravanan K, Prakash R, Suma CS, Senthilnathan D (2016) Hydrochemical characteristics and salinity of groundwater in parts of Nagapattinam district of Tamil Nadu and the Union Territory of Puducherry, India. Carbonates Evaporites. https://doi.org/10.1007/s13146-016-0300-y

Guler C, Thyne GD, McCray JE, Turner AK (2002) Evaluation of graphical and multivariate statistical methods for classification of water chemistry data. Hydrogeol J 10:455–474

Herczeg AL, Torgersen T, Chivas AR, Habermehl MA (1991) Geochemistry of groundwaters from the Great Artesian Basin, Australia. J Hydrol 126:225–245

Howitt D, Cramer D (2005) Introduction to SPSS in Psychology: with supplement for releases 10, 11. and 13. Pearson, Harlow, p 12

Irawan DE, Puradimaja DJ, Notosiswoyo S, Soemintadiredja P (2009) Hydrogeochemistry of volcanic hydrogeology based on cluster analysis of Mount Ciremai, West Java, Indonesia. J Hydrol 376:221–234

Jalali M (2009) Geochemistry characterization of groundwater in an agricultural area of Razan, Hamadan, Iran. Environ Geol 56:1479–1488

Jasmin I, Mallikarjuna P (2014) Physicochemical quality evaluation of groundwater and development of drinking water quality index for Araniar River Basin, Tamil Nadu, India. Environ Monit Assess. https://doi.org/10.1007/s10661-013-3425-7

Kazi TG, Arain MB, Jamali MK, Jalbani N, Afridi HI, Sarfraz RA, Baig JA, Shah AQ (2009) Assessment of water quality of polluted lake using multivariate statistical techniques: a case study. Ecotoxicol Environ Saf 72:301–309

Kim TH, Chung SY, Park N, Hamm SY, Lee SY, Kim BW (2012) Combined analyses of chemometrics and kriging for identifying groundwater contamination sources and origins at the Masan coastal area in Korea. Environ Earth Sci. https://doi.org/10.1007/s12665-012-1582-6

Kumar S (2016) Deciphering the groundwater–saline water interaction in a complex coastal aquifer in South India using statistical and hydrochemical mixing models. Model Earth Syst Environ. https://doi.org/10.1007/s40808-016-0251-2

Kumar M, Ramanathan AL, Rao MS, Kumar B (2006) Identification and evaluation of hydro- geochemical processes in the groundwater environment of Delhi, India. Environ Geol. https://doi.org/10.1007/s00254-006-0275-4

Kumar SK, Rammohan V, Sahayam JD, Jeevanandam M (2009) Assessment of groundwater quality and hydrogeochemistry of Manimuktha River basin, Tamil Nadu, India. Environ Monit Assess. https://doi.org/10.1007/s10661-008-0633-7

Kumar SK, Chandrasekar N, Seralathan P, Godson PS, Magesh NS (2011) Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island, India. Environ Monit Assess 184(7):4127–4139

Kumar SK, Logeshkumaran A, Magesh NS, Godson PS, Chandrasekar N (2015) Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. Appl water sci doi. https://doi.org/10.1007/s13201-014-0196-4

Kurumbein WC, Graybill FA (1965) An introduction to statistical models in geology. McGraw-Hill, New York

Liu CW, Lin KH, Kuo YM (2003) Application of factor analysis in the assessment of ground water quality in a Back foot disease area in Taiwan. |Sci Total Environ 313(1–3):77–89

Machender G, Dhakate R, Reddy MN (2014) Hydrochemistry of groundwater (GW) and surface water (SW) for assessment of fluoride in Chinnaeru river basin, Nalgonda district, (AP) India. Environ Earth Sci 72(10):4017–4034

Massart DL, Kaufman L (1983) The interpretation of analytical chemical data by the use of cluster analysis. Wiley, New York

May AL, Loucks MD (1995) Solute and isotope geochemistry and groundwater flow in the Central Wasatch Range, Utah. J Hydrol 170:795–840

Metcalf L, Eddy H (2003) Wastewater engineering, treatment and reuse, 4th edn. Tata McGraw-Hill Co, New York

Milovanovic M (2007) Water quality assessment and determination of pollution sources along the Axios / Vardar River, Southeastern Europe. Desalination 213:159–173

Mokarram M (2016) Modeling of multiple regression and multiple linear regressions for prediction of groundwater quality (case study: north of Shiraz). Model Earth Syst Environ. https://doi.org/10.1007/s40808-015-0059-5

Mondal NC, Singh VP, Singh VS, Saxena VK (2010) Determining the interaction between groundwater and saline water through groundwater major ions chemistry. J Hydrol 388:100–111

Nematollahi MJ, Ebrahimi P, Razmara M, Ghasemi A (2016) Hydrogeochemical investigations and groundwater quality assessment of Torbat-Zaveh plain, Khorasan Razavi, Iran. Environ Monit Assess. https://doi.org/10.1007/s10661-015-4968-6

Nwajei GE, Obi-Iyeke GE, Okwagi P (2012) Distribution of selected trace metals in fish parts from the River Nigeria. Res J recent sci 1(1):81–84

Oluseyi T, Olayinka K, Adeleke I (2011) Assessment of ground water pollution in the residential areas of Ewekoro and Shagamu due to cement production. Afr J Environ Sci Technol doi. https://doi.org/10.5897/AJEST11.039

Pradeep K, Nepolian M, Anandhan P, Kaviyarasan R, Prasanna MV, Chidambaram S (2016) A study on variation in dissolved silica concentration in groundwater of hard rock aquifers in Southeast coast of India. Mater Sci Eng. https://doi.org/10.1088/1757-899X/121/1/012008

Prakash R, Venkateswaran S (2014) Demarcation of site specific groundwater recharge structures in Manimuktha Sub Basin, Vilupuram District using GIS techniques. Environ Geo Chim Acta 1(2):147–152

Ramachandramoorthy T, Sivasankar V, Gomathi R (2010) Fluoride and other parametric Status of Ground water Samples at various locations of the Kolli hills, Tamil Nadu, India. J Iphe 3:431–438

Ramkumar T, Venkatramanan S, Anithamary I, Ibrahim SMS (2011) Evaluation of hydrogeochemical parameters and quality assessment of the groundwater in Kottur blocks, Tiruvarur district, Tamilnadu, India. Arabian J Geosci. https://doi.org/10.1007/s12517-011-0327-2

Rao GT, Rao VVSG., Rao YS, Ramesh G (2013) Study of hydrogeochemical processes of the groundwaters in Ghatprabha river sub-basin, Bagalkot District, Karnataka, India. Arabian J Geosci 6(7):2447–2459

Sadat-Noori SM, Ebrahimi K, Liaghat AM (2014) Groundwater quality assessment using the water quality index and GIS in Saveh-Nobaran aquifer Iran. Environ Earth Sci. https://doi.org/10.1007/s12665-013-2770-8

Saeedi M, Abessi O, Sharifi F, Meraji H (2010) Development of groundwater quality index. Environ Monit Assess 163:327–335

Sahu P, Sikdar PK (2008) Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. Environ Geol 55:823–835

Sakizadeh M (2016) Artificial intelligence for the prediction of water quality index in groundwater systems. Model Earth Syst Environ. https://doi.org/10.1007/s40808-015-0063-9

Saravanan K, Srinivasamoorthy K, Gopinath S, Prakash R, Suma CS, (2016) Investigation of hydrogeochemical processes and groundwater quality in Upper Vellar sub-basin Tamilnadu, India. Arabian J Geosci. https://doi.org/10.1007/s12517-016-2369-y

Selvam S, Venkatramanan S, Chung SY, Singaraja C (2016) Identification of groundwater contamination sources in Dindugal district of Tamil Nadu, India using GIS and multivariate statistical analyses. Arabian J Geosci. https://doi.org/10.1007/s12517-016-2417-7

Shanmugasundharam A, Kalpana G, Mahapatra SR, Sudharson ER, Jayaprakash M (2015) Assessment of Groundwater quality in Krishnagiri and Vellore Districts in Tamil Nadu, India. Appl Water Sci. https://doi.org/10.1007/s13201-015-0361-4

Singh UK, Kumar M, Chauhan R, Jha PK, Ramanathan AL, Subramanian V (2008) Assessment of the impact of landfill on groundwater quality: A case study of the Pirana site in western India. Environ Monit and Assess 141:309–321

Singh AK, Tewary BK, Sinha A (2011) Hydrochemistry and quality assessment of groundwater in part of Noida Metropolitan city, Uttar Pradesh. J Geol Soc India 78:523–540

Soltan ME (1999) Evaluation of groundwater quality in Dakhla Oasis (Egyptian Western Desert). Environ Monit Assess 57:157–168

Srinivasamoorthy K, Chidambaram M, Prasanna MV, Vasanthavigar M, Peter J, Anandhan P (2008) Identification of major sources controlling groundwater chemistry from a hard rock terrain. A case study from Mettur taluk, Salem district, Tamilnadu, India. J Earth Syst Sci 117:49–58

Srinivasamoorthy K, Nanthakumar C, Vasanthavigar M, Vijayaraghavan K, Rajivgandhi R, Chidambaram S, Anandhan P, Manivannan R, Vasudevan S (2011) Groundwater quality assessment from a hard rock terrain, Salem district of Tamil Nadu, India. Arabian J Geosci. https://doi.org/10.1007/s12517-009-0076-7

Srinivasamoorthy K, Gopinath M, Chidambaram S, Vasanthavigar M, Sarma VS (2014) Hydrochemical characterization and quality appraisal of groundwater from Pungar sub basin, Tamilnadu, India. J King Saud Univ Sci 26:37–52

Stallard R, Edmond JM (1983) Geochemistry of the Amazon. 2. The influence of geology and weathering environment on the dissolved load. J Geophys Res doi. https://doi.org/10.1029/JC088iC14p09671

Swan ARH, Sandilands M (1995) Introduction to geological data analysis. Blackwell Science, Oxford

Taheri TA, Voudouris KS (2008) Groundwater quality in the semi-arid region of the Chahardouly basin, West Iran. Hydrol Process 22:3066–3078

Tiwary R (2001) Environmental impact of coal mining on water regime and its management. Water Air Soil Pollut 132:185–199

USEPA (2002) Drinking Water from Household Wells. EPA 816-K-02-003. Washington, DC, US Environmental Protection Agency

Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, Ganthi RR, Chidambaram S, Anandhan P, Manivannan R, Vasudevan S (2010) Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environ Monit Assess. https://doi.org/10.1007/s10661-009-1302-1

Venkateswaran S, Deepa S (2015) Assessment of groundwater quality using GIS techniques in Vaniyar sub basin, Ponnaiyar River, Tamil Nadu (ICHWAM2014) 4th international conference. Aquat Procedia 4:1283–1290

Venkateswaran S, Kannan R (2015) An approach to evaluation of groundwater quality mapping in the Chinnar sub basin, Cauvery River, Tamil Nadu using geospatial techniques. J Appl Geochem 18(3):287–299

WHO (1996) Guidelines to drinking water quality. World Health Organisation, Geneva, vol 2, p 989

Yazdanpanah N (2016) Spatiotemporal mapping of groundwater quality for irrigation using geostatistical analysis combined with a linear regression method. Model Earth Syst Environ. https://doi.org/10.1007/s40808-015-0071-9

Yidana SM, Yidana A (2010) Assessing water quality using water quality index and multivariate analysis. Environ Earth Sci 59:1461–1473