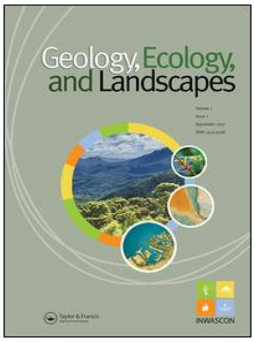

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RESEARCH ARTICLE

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Hydrogeochemical analysis of Groundwater in Thanjavur district, Tamil Nadu; Influences of Geological settings and land use pattern.

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ABSTRACT

The influence of land use patterns and geological settings on the hydrogeochemistry of the Thanjavur district in Southern India is assessed. Thirty-four samples were analyzed for groundwater quality in pre-monsoon and post-monsoon seasons. The water quality Index (WQI) values derived based on these values show that, over 80% of the samples were categorized as either as excellent or good quality for drinking. A spatial variation map of WQI is generated and compared with geological and land-use maps. The major hydrogeochemical processes acting are silicate weathering – evaporation deposition (post-monsoon) and carbonate dissolution (pre-monsoon). The results agree with the mineralogy of geological formations such as sandstone with clay and fluvial depositions. The main land-use pattern in the district is agricultural, built areas and industrial regions. The most common contaminant in agricultural lands is nitrate pollution from fertilizers. However, nitrate in the groundwater did not exceed the WHO standard of 50 mg/L. High salinity in many samples may be due to water logging as well as salt usage in the textile and chemical industries, which is correlated with the landuse as well as WQI Map. Overall, geology and land use have significant influence on groundwater quality of the region.

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Groundwater quality; geological influences; land use impacts; Thanjvur district; Tamil Nadu

Introduction

Groundwater is one of the most important sources for potable water supply, irrigation and industrial uses in many arid and semi-arid regions around the world (Khan, Khan, Shakeel, & Jerome, 2011). Around 30% of the available freshwater for human consumption is expected to be groundwater (Shiklomanov, 1993). The importance of groundwater for water supply has increased in the past few decades. The dependencies on groundwater are increased for the water supply is because of reasonably good quality of the same compared to the surface water resources. There is a natural filtering mechanism acting on the groundwaters during its filtration to the underground storage. Because of these advantages, groundwater is being over explored and there is utter mismanagement has led to the shortage of water worldwide (Punithavathi, 2011). In India, there is a special well-culture existing, i.e., each household and farming land in rural areas have their own well and these deep bore holes for agricultural developments impacted groundwater resources. Uncontrolled pumping of groundwater depleted many aquifers in the country and caused saline intrusion in the coastal aquifers (Sajil Kumar, 2016). Population growth and industrialization polluted the surface water and thus increased the pressure on groundwater. India is the largest user of groundwater in the world with more than 230 km^3 (World bank, 2012).

Natural groundwater chemistry is largely controlled by the geochemical process acting during its circulation through the subsurface. During this passage, there will be exchanges of ionic constituents between water and aquifer. A series of processes such as ion exchange, evaporation silicate weathering, dissolution, and deposition can possibly occur in the subsurface under favorable hydrogeochemical conditions – most importantly- the availability of source minerals, pH, temperature etc. (Sajil Kumar & James, 2016). Atmospheric deposition is also an important natural factor that affects the groundwater quality. On the other hand, quality degradation can also occur because of anthropogenic influences as well (Khatri & Tyagi, 2015).

Characterizing the natural parameters controlling groundwater chemistry is important to understand the natural background concentration and further identify the pollution potential of the groundwater. Geological framework and the land-use patterns are the most prominent factors coming under this context. Both natural and human interventions affect the geological settings and land-use patterns of an area and thus affect the groundwater chemistry in diverse ways. Land use

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directly impacts the biodiversity, local and regional climate change and cause global warming, and land degradation . Hydrochemical evaluations were studied by several researchers in many parts of the world (Alam, Rais, & Aslam, 2012; Aminiyan, Aminiyan, & Heydariyan, 2016; Barzega, Moghaddam, & Tziritis, 2016; Ranjan, Srivastava, & Ramanathan, 2017). Application of water quality index has also proved to be an effective tool to represent water quality (Liou, Lo, & Wang, 2004; Vasanthavigar et al., 2010; Sajil Kumar and James 2013; Varol & Davraz, 2015). Multivariate statistical analysis and geostatistical modeling approaches were used by many researchers for assessing water quality (Belkhiri & Narany, 2015; Chen & Feng, 2013; Dominick, Juahir, Latif, Zain, & Aris, 2012; Sajil Kumar, 2016; Zhaoa, Xia, Yang, & Wang,, 2012).

From the literature, it is well known that, groundwater chemistry is affected both by the natural and anthropogenic influences. Natural factor is marked by geological influences and anthropogenic influences by the land-use changes. Hence this study, we focus on the influences of geology and land-use patterns on the groundwater chemistry and quality of Thanjavur district in the state of Tamil Nadu. Similar studies have been done by a few researchers in different parts of the world (Fianko, Osae, Adomako, & Achel1, 2009; Lerner & Harris, 2009; Molénat & Gascuel-Odoux, 2002). Multiple methods such as hydrogeochemical evaluation, geostatistical modeling, and water quality index (WQI) were used to evaluate groundwater chemical variations in the different geological and land-use regions in the Thanjavur district.

Study area

The Thanjavur district is a part of the South Indian state of Tamil Nadu, forming parts of the Cauvery River basins and Vennar and Vettar sub-basins. Geographically the district lies between latitudes 10° 48′N to 11°12′N and longitudes 78°48′E to 79°38′E (see Figure 1). The city is in the deltaic regions of the Cauvery Basin and, due to its agricultural importance, is known as the rice bowl of Tamil Nadu. Thanjavur district is bordered by Nagapattinam district on the northeast, Tiruvarur district on the east, on the south by Bay of Bengal and Pudukkottai district on the west.

The average annual rainfall of the study area is 940 mm, predominantly fed by two monsoon seasons – the South West and the North-East monsoons. The South-West monsoon starts from June and ends in September. The North-East monsoon begins in October and extends until January. Rainfall during that period is much higher than that of the South-West monsoon period (Palanisami, 2008). Summer season begins in March and reaches its maximum in May. The average daytime temperature in this area ranges between 27°C in January and 36°C in May and June. The relative humidity varies between 70% and 85% (CGWB, 2009).

Geomorphologically, flood plain, delta plains, natural levees, and sedimentary high ground are present in the district. The northern area is predominantly flood plains, and sedimentary high grounds ranging between 60 and 80 m. The different types of soils found in the study area are shown in Table 1.

The geology of the study area is formed by the deposition of alluvial, cretaceous and tertiary deposits, and major portion of this area is formed by alluvial and tertiary deposits (see Figure 2; Palanisami, 2008). A small patched formation of cretaceous deposits occurs west and south-west of Vallam; this formation is likely to have a thick deposit of lateritic cap containing impure limestone and sandstone of clay calcareous, silt and argillaceous verities. The coastal region of this area is formed by the Cuddalore sandstone of tertiary age.

Groundwater occurs in six different aquifers, namely, Archaean, Cretaceous, Eocene, Miocene, Pliocene and Quaternary. In Archean aquifers groundwater occurrence is limited to weathered and fractured rocks in both confined and unconfined conditions. In cretaceous aquifers, coarse gravel bounded by clay with sand forming the aquifer material is mostly unconfined in nature. Eocene aquifers, having a thickness around 80 m, are made up of sand, silt, and clay with confined conditions. Miocene, Pliocene, and quaternary aquifers are mainly formed by sand, stone, gravel with clay and limestone.

The land-use pattern of Thanjavur district is dominated by primarily by agricultural fields and secondarily by Build-up areas. Tanks and waterbodies are numerous and drainage networks are well developed. A detailed land-use map of the region is presented in Figure 3.

Materials and methods

Groundwater sampling and analysis

A detailed field study in the Thanjavur district, Tamil Nadu was carried out by collecting 34 water samples from various wells before and after monsoon season in 2010. Cleaned polythene bottles of 500 ml capacity with proper labels to indicate source, date and time were used to collect samples which were then stored under laboratory conditions at 4°C until analysis. Complete chemical analysis was carried out with reference to the methods suggested from APHA (1992). EDTA titration was used in analyzing major ions such as chlorides (Cl), bicarbonates (HCO_3^-), magnesium (Mg) and calcium (Ca). Further, pH and Electrical Conductivity (EC) were examined using a field kit. A flame photometer was used in analyzing Sodium

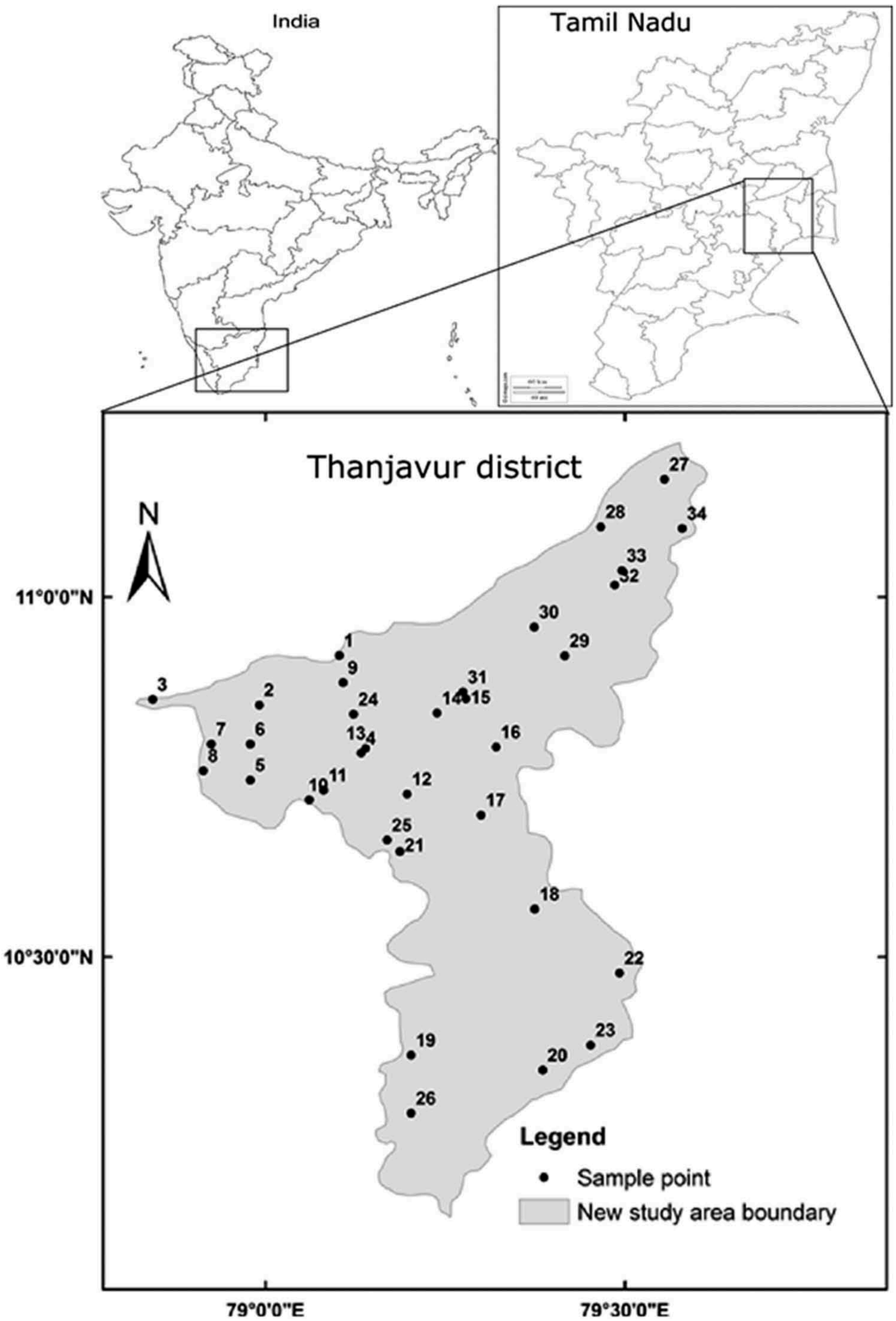

Figure 1. Study area map showing the location of the sample wells.

Table 1. Soil types in Thanjavur district (CGWB, 2009).

Geological Age	Soil type
Quaternary	Sand, silt and clay super imposed sand, natural levee complexes
Pliocene	Clays, weathered formations
Miocene	Sands, clay bound, clays gravels
Cretaceous	Reddish and yellowish calcareous sand stones, clays and lime stones.

(Na) and Potassium (K). Sulfates were estimated by an UV-visible spectrophotometer. Finally, fluoride concentration was analyzed by using SPADNS method.

Spatial mapping using kriging

Kriging is a geostatistical method used to create a continuous surface from the dataset having X, Y, Z values. X and Y represent the longitude and latitude whereas Z values represent the data points. Over the other spatial mapping techniques like inverse distance weighing (IDW), kriging has its own decision-making capacity, in addition to that kriging use statistical models with a special feature called autocorrelation. With this, we can measure the accuracy of the predicted surfaces. This is possible by the assumption that

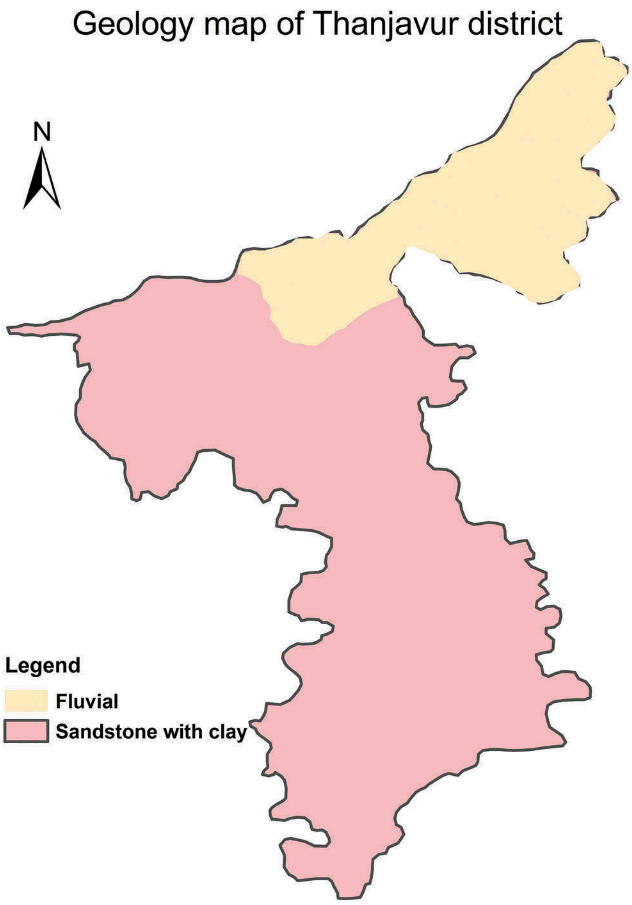

Figure 2. Geology of the study area.

the distance and the direction between the samples possess a spatial correlation, which can be an indicator of the spatial variation. In the first step, a mathematical model is fitted to the data under consideration and the output for each location is being calculated. In the second step, Semi variogram modeling is done, which is important in providing the information about the spatial autocorrelation. This method has high significance when we know already that there is some spatial correlation in the distance. The best fit is identified by the line that represents points in empirical semivariogram cloud graph, which appraises the spatial autocorrelation. With consideration to spatial autocorrelation between predicted and measured locations, the kriging weights that are assigned to different measured parameters are obtained.

The value parameter for any location can be calculated using the obtained kriging weight, and can be calculated by below formula.

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda i Z(Si) \quad (2)$$

where S_0 = prediction location, λi = unknown weight for the measured sample location, Si = measured value at the ith location, N = number of sample locations.

Water quality index (WQI)

WQI provides a single value representation of water quality addressing all the parameters considered (Mitra, 1998). In this study, 10 parameters, namely, TDS, Ca, Mg, Na, K, HCO_3, Cl, SO_4, NO_3 and F were considered. WQI is calculated based on a series of interlinked equations as outlined below.

$$\mathrm{WQI} = \sum \mathrm{SI}i \quad (1)$$

$$\mathrm{SI}i = \mathrm{Rw}i \times \mathrm{q}i \quad (2)$$

$$\mathrm{Rw}i = \frac{\mathrm{Awi}}{\sum_1^n Awi} \quad (3)$$

$$\mathrm{q}i = (\mathrm{C}i/\mathrm{S}i) \times 100 \quad (4)$$

Awi = weights assigned; Rwi = the relative weight, Aw_i = the assigned weight of each parameter, n = the number of parameters; qi = quality rating for each parameter.

The calculated relative weight (RW) values of each parameter and water quality standards are given in Table 2.

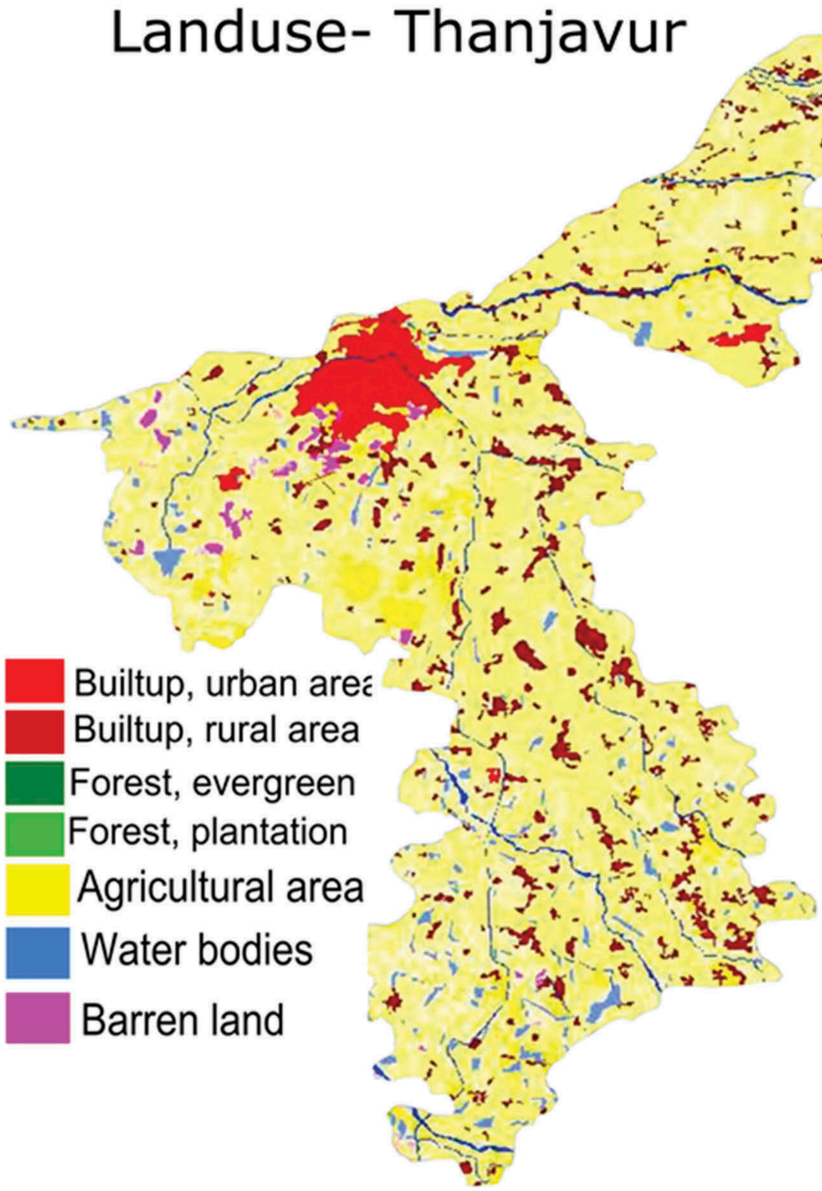

Figure 3. Land-use map of Thanjavur District.

Results and discussion

Physical water quality

Statistical Summary of groundwater quality parameters for pre-monsoon (July 2010) and post-monsoon (Jan 2010) seasons are shown in Tables 3 and 4, respectively. Groundwater in the study area shows an alkaline nature for both seasons, i.e., 7.7–8.6 and 7.3–8.9 for pre-monsoon and post-monsoon samples, respectively. The average pH suggests that most of the samples within the WHO (2011) standard value of 6.5–8.5. Electrical conductivity (EC) was 1172 µS/cm and 1117µS/cm in the pre- and post-monsoon, respectively. The lowest value was 110µs/cm in July and the highest was 5300 µS/cm in January. The total-dissolved solids (TDS) of the water are directly related to the solute load in the water. TDS in the pre-monsoon season was in the range of 143–2941 mg/L. While in the post-monsoon season, the concentration is ranged from 67 to 1737 mg/L. As per WHO standards, the permissible limit of TDs in groundwater is 1000mg/L, and the results show that in both seasons, TDS was within the limits. It is an indicating that groundwater is not much affected by the anthropogenic influences.

Chemical parameters of water quality

Analysis of the anions and cations along with the cross-examination of geology and landuse can yield valuable information about rock–water interactions and related processes in hard rock terrains (Elango, Kannan, & Senthil Kumar, 2003; Sajil Kumar & James, 2016; Subramani, Rajmohan, & Elango, 2010). Abnormal concentration of the ions could be attributed to the anthropogenic inputs to groundwater.

Na dominated among the cations in both seasons, which varied from 12 to 665 mg/L and 3 to 536 mg/L

Table 2. Classification of water quality based on WHO and Indian standards with assigned Weights.

Parameters used	Indian Standard (BIS 10,500, 1991)	WHO Standards (1996)	Assigned weight(Awi)	Relative weight(Rw) $= Awi/\sum_{1}^{n} Awi$
TDS	500	1000	5	0.128
Bicarbonate (mg/L)	-	-	1	0.0256
Chloride (mg/L)	250	250	5	0.128
Sulphate (mg/L)	200	250	5	0.128
Calcium (mg/L)	75	75	3	0.0769
Magnesium (mg/L)	30	30	3	0.0769
Sodium (mg/L)	-	200	5	0.128
Potassium (mg/L)	-	-	2	0.0523
Nitrate (mg/L)	45	50	5	0.128
Fluoride (mg/L)	1.20	1.5	5	0.128
			$\sum_i Awi = 39$	$\sum_i Rwi = 0.999$

in the pre-monsoon and post-monsoon periods, respectively. Ca is the next dominant cation after Na, and it has concentration 8–112 mg/L (pre-monsoon) and 10–62 mg/L (post-monsoon). The permissible concentration of Mg in drinking water is 30 mg/L (WHO, 2011), which is exceeded in both seasons. Concentrations of K are in a range of 1–44 mg/L (pre-monsoon) and 0.10–47 mg/L (post-monsoon). The slight increase in K concentration is seen in the post-monsoon season may be due to the higher dissolution of K during the monsoon rain as well as the high flow rate of groundwater decreased the residence time and adsorption rate to clay layers. Pyroxenes and amphiboles are the common calcium and magnesium bearing minerals in silicate rocks, which contribute Ca^{2+} and Mg^{2+} ions to groundwater through weathering (Subramani et al., 2010). Dissolution of dolomite and calcites is the other origins of these ions. The dominance of Na over Ca in certain locations suggest the inverse cation exchange process, through which Na from the aquifer is replaced by Ca from the groundwater.

Chloride represents the dominant anion in the study area with a range in concentration, 28–1517 mg/L (pre-monsoon) and 18–674 mg/L (post-monsoon). The major origin of chloride can be attributed to anthropogenic influences such as domestic sewage and fertilizer use in agricultural fields. Obviously, there is natural origin of Cl is also reported in literature, mainly from the dissolution of halite and atmospheric deposition. However, there is a deficiency of Na compared to Cl in certain samples is an indication of direct ion exchange. Bicarbonate is the dominant anion next to Cl, in the study area. The most important origin for this ion is the dissolution of carbonates. The average concentrations of HCO_3 are 266.6 (pre-monsoon) and 254.18 (post-monsoon) mg/L. Carbonate is mostly absent in the study area. Its concentration is ranged as 0–60 mg/L. Sulphate concentration is high in certain locations. High values of SO_4 along with Ca suggest a possible dissolution of gypsum.

Nitrate and fluoride are two important drinking-water quality parameters, as it has serious effects on human health. NO3 in groundwater is mostly derived from the fertilizers usage for agriculture, domestic sewages, untreated wastewater disposal, human and animal excreta, leaking of septic tanks (WHO, 2011). The maximum allowable limit of NO3 in drinking is 45 mg/L (WHO, 2011). Important health impacts are, namely, Methaemoglobinaemia in which abnormal amount of methemoglobin is generated in blood and subsequently reducing the oxygen circulation in human body. This study shows that groundwater is not contaminated with Nitrate in any of the samples.

Fluoride in groundwater is largely controlled by the geology of the area through with water percolate. Rock formations like charnockites, granites, and gneisses are rich in minerals such as fluorite, apatite and Mica are the important source of fluoride in groundwater. It is found in minor quantities in groundwater and the maximum allowable limit is 1.5mg/L (WHO, 2011). Excessive fluoride intake for long term may cause skeletal and dental fluorosis. Concentration of fluoride exceeded in more than 1% in the pre-monsoon seasons and in post-monsoon the samples are within the limit.

Table 3. Statistical Summary of water quality parameters in July 2010.

	pH	EC	TH	TDS	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3	NO_3	F
Min	7.7	230	95	143	18	10.94	12	1	28	5	0	83.94	0.10	0.05
Max	8.6	5300	1200	2941	112	223.56	665	44	1517	245	60	1018.70	9.00	1.56
Mean	8.18	1172.65	307.94	658.50	37.65	51.96	132.71	8.41	230.53	50	5.18	266.60	2.04	0.33

Table 4. Statistical Summary of water quality parameters in January 2010.

	pH	EC	TH	TDS	Ca	Mg	Na	K	Cl	SO_4	CO_3	HCO_3	NO_3	F
Min	7.3	110	50	67	10	4.86	3	0.10	18	2	0	29.87	0.10	0.07
Max	8.9	3090	500	1737	62	106.92	536	47	674	394	24	542.90	28	1.24
Mean	8.25	1117.65	235	624.41	27.65	40.31	145.18	10.29	195.56	51.15	6.46	254.18	3.16	0.31

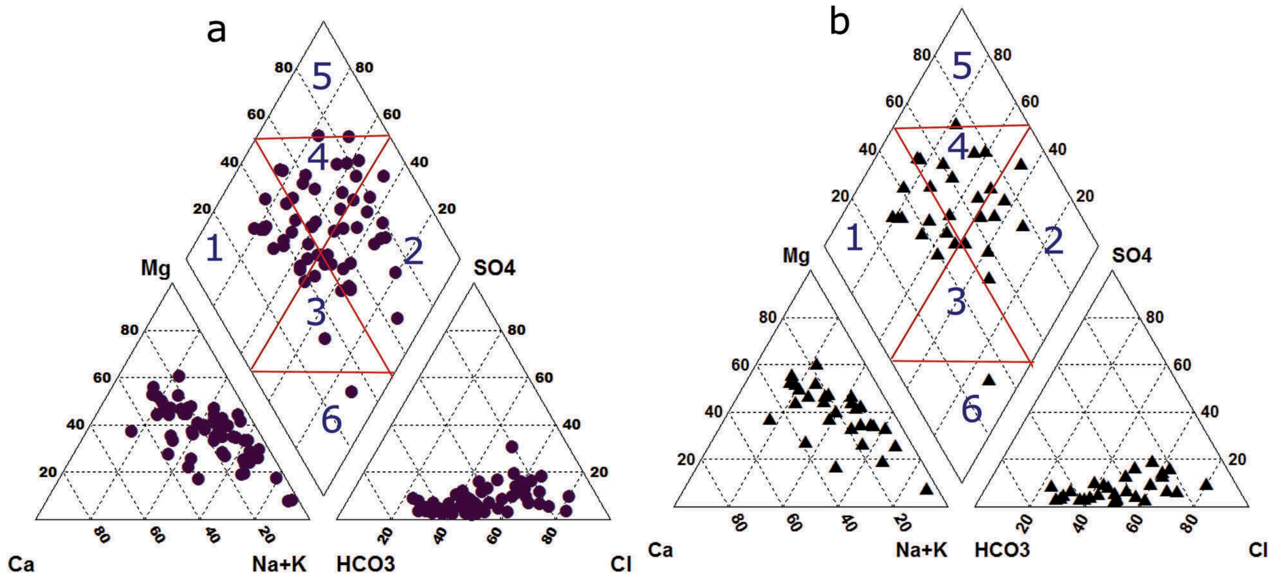

Figure 4. Piper diagram showing groundwater types in the study area for a. Pre-Monsoon and b. Post-Monsoon.

Groundwater types

Piper plot is used to interpret groundwater types based on the major ion chemistry in the study area (Piper, 1953). The major cations and anions were converted into meq/L, then plotted in the left and the right triangle, respectively. The diamond-shaped field can be classified into six types: 1. Ca-HCO_3. 2. Na-Cl, 3. Mixed Ca-Na-HCO_3, 4. Mixed Ca-Mg-Cl 5. Ca-Cl type 6. Na-HCO_3 type. Figure 4a and b show the piper trilinear plot for pre-monsoon and post-monsoon groundwater samples. The majority of the samples fall into the mixed Ca-Mg-Cl type, Ca-HCO_3 type and lastly Na-Cl types. The presence of the Ca-Mg-Cl type shows the mixing of fresh groundwater mixing with anthropogenically affected water.

Mechanism controlling groundwater chemistry

The Gibbs (1970), diagram (1970) is an effective method in groundwater chemical analysis to identify the natural mechanisms that control the

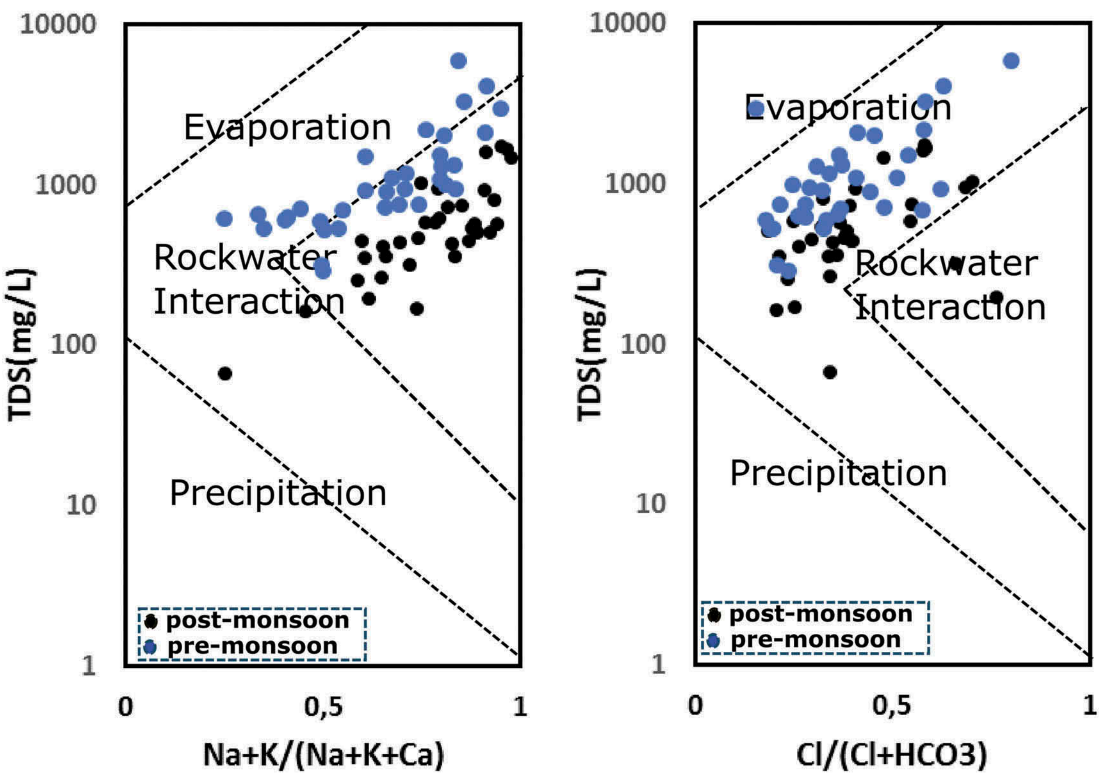

Figure 5. Gibbs diagram showing mechanisms controlling the hydrogeochemistry.

hydrogeochemistry. These natural mechanisms are generally termed as precipitation, rock–water interaction, and evaporation. The Gibbs plot for the Thanjavur district shows that most of the samples in both seasons were controlled by rock–water interaction and evaporation (Figure 5). Groundwater is interacting the aquifer matrix during its flow and this exchange of ionic constituents is responsible for the dissolved ions in groundwater. High concentration of Na-Cl in groundwater is an indication of the dominance of evaporation processes as well as anthropogenic influences like industrial contamination, irrigation return flow, etc. The land-use map shows that agricultural lands are widespread, indicating the impact of agricultural fertilizers and irrigation return flows.

Water quality index for the study area

Water Quality Index (WQI) of the Thanjavur district has been calculated using relative weights of water quality parameters based on their significance for drinking purposes. The highest weight of five is given to TDS, Sodium, Chloride, Sulphate, Fluoride, and Nitrate. Serious health impacts were reported by the excess use of fluoride and Nitrate. Consumption of fluoride in higher concentrations than the proposed 1.5 mg/L, can cause dental and skeletal fluorosis. In the same way nitrate can cause blue babies or methemoglobinemia disease in infants, gastric carcinomas, abnormal pain, central nervous system birth defects, and diabetes (Vasanthavigar et al., 2010).

WQI for pre-monsoon and post-monsoon seasons were calculated separately since water quality is one of the main problems especially in developing countries like India. Thirty-four samples were analyzed during pre-monsoon and post-monsoon seasons. During pre-monsoon season the WQI ranged from 14.4 to 286.6 and during post-monsoon season the WQI ranged from 7.7 to 169.6 (see Tables 5 and 6). The WQI showed that 20% of pre-monsoon samples and 15% of post-monsoon samples were poor/very poor for drinking purposes. In short, results show that more than 50% of the samples in both pre-monsoon and post-monsoon seasons are potable. The percentage of very poor and unsuitable water samples for drinking purpose in Table 2 in the post-monsoon season is zero which clearly indicates that the water quality improved after the monsoon.

Table 5. Classification of water based on WQI (pre-monsoon).

WQI range	Type of water	Well-ID	% of samples
<50	Excellent water	1,2,3,4,9,10,11,13,17,19,21,25,26, 28,29,30,31,32,33	56
50-100	Good water	6,12,14,18,20,24, 27,34	24
100-200	Poor water	5,7,8,15,16,22	18
200-300	Very poor water	23	2
>300	Water unsuitable for drinking	-	-

Impact of geology and land use on groundwater quality

In any region of the world, the origin of groundwater is either precipitation or the melting of snow. Thus, the initial concentration of groundwater will be either the same or nearly the same concentration as rainfall, i.e., 5 to 10 mg/L (Drever et al. 1997). Natural alteration of groundwater composition occurs when it is circulated through the connected pores, fractures, and faults present in sedimentary and hard rocks (Panno, Hackley, Cartwright, & Liu, 1994). This interaction is still one of the major contributors towards the chemical alteration of groundwater. The geology of the region shows that the major type of formations is sandstone with clay and fluvial deposition in the flood plains of Vennar and Vettar river basins. In the sandstones, the major mineral composition are quarts, both alkaline (K) fledspar and plagioclase feldspar (Na), and the cementing material is either silicate or calcite. Additionally, fragments of metamorphic and igneous rocks can also be found. On the other hand, the fluvial deposits have a thickness of 30–400 m. These soils mostly contain clay (40-45%) of montmorillonite (Nagarajan, Rajmohan, Mahendran, & Senthamilkumar, 2010; Tamil Nadu Agricultural University, 2002–2004).

To differentiate the processes controlling groundwater chemistry, we have drawn a bivariate plot of Na^+ normalized HCO_3– and Mg^{2+} versus Na+ normalized Ca^{2+} for pre-monsoon and post-monsoon seasons in the study area (see Figure 6). In the post-monsoon sea most of the samples were plotted primarily in the silicate weathering and secondly in the evaporite dissolution region. As we have seen already, silicate minerals are abundant in the study area, which is the

Table 6. Classification of water based on WQI (post-monsoon).

WQI range	Type of water	Well-ID	% of samples
<50	Excellent water	1,2,3, 11,13,17,18,19, 21,24,25,26,27,28,29,30,32,33	53
50-100	Good water	4,6,7,9,10, 12,14,15,16,20,	32
100-200	Poor water	5,8,22,23,31	15
200-300	Very poor water	-	-
>300	Water unsuitable for drinking	-	-

major reason for the dominance of silicate weathering in the post-monsoon season. The monsoon rainfalls, trigger the dissolution of the weathered materials, which is then Incorporated to the groundwater through its circulation. On the other hand, in the pre-monsoon season, most of the samples were plotted in or near the carbonate dissolution phase as well as the silicate weathering region. The most logical explanation of this geochemical phenomena is the dissolution of carbonate minerals such as $CaCO_3$ and Ca-Mg-CO_3 and silicate minerals. Compared to the post-monsoon season, the carbonate mineral concentration in the groundwater is increased substantially. In the pre-monsoon period the flow rate of the groundwater is comparably less than the post-monsoon season due to the lower water table and the subsequent pressure reduction. As the contact time of groundwater with the aquifer matrix increases, the concentration of the carbonate minerals may increase as well (Apambire et al. 2007).

In the next step, the geology of the study area is compared with the groundwater quality. As a representative of all the water quality parameters, WQI is chosen to compare with the geological map (see Figure 2). The WQI for the Thanjavur district is mapped spatially using the kriging method and plotted for both seasons (see Figure 7). It is observed that the water quality in the alluvial plains has a higher quality

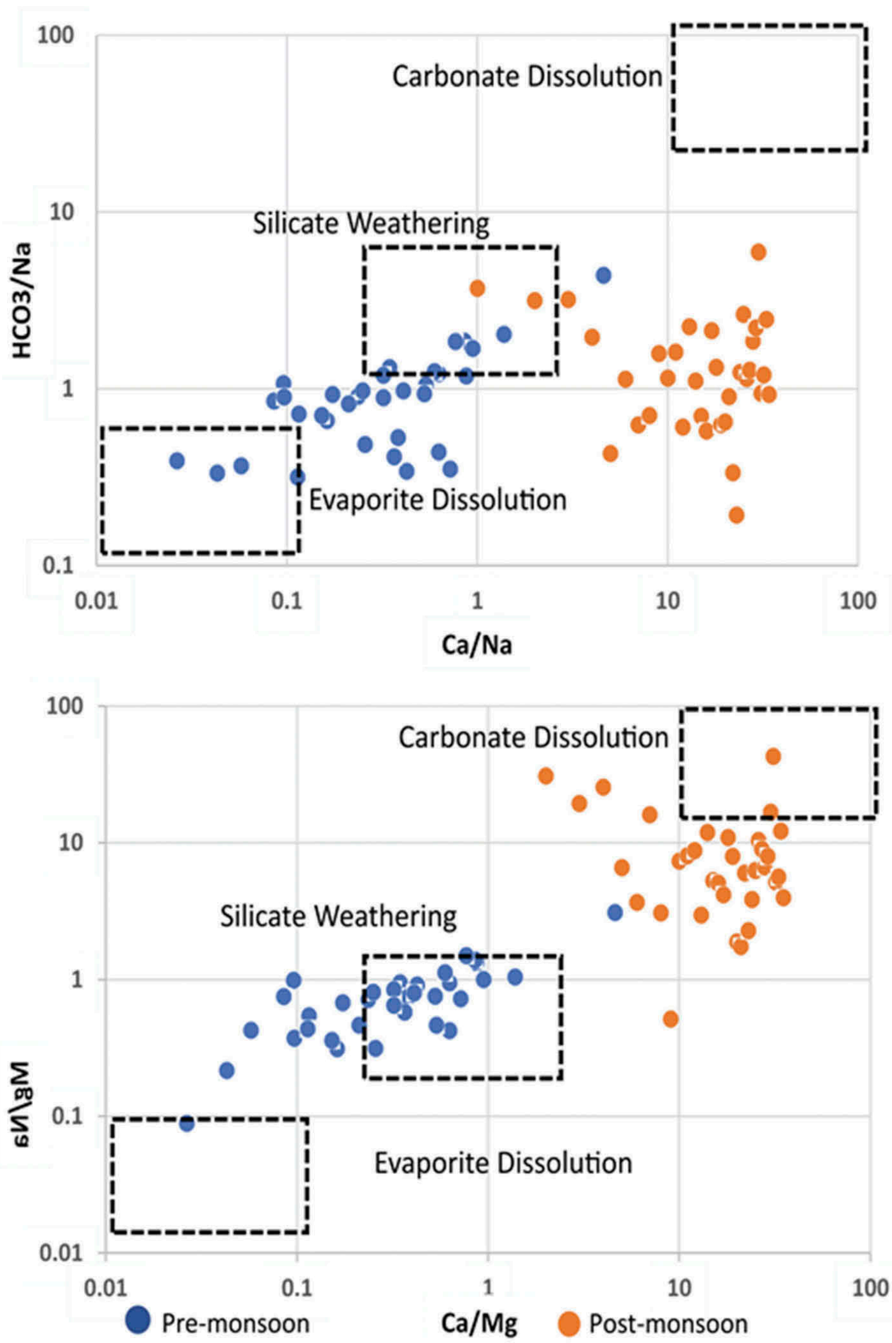

Figure 6. Bivariate plot Ca^{2+}/Na^{+} vs HCO_3^{-}/Na^{+} and Ca^{2+}/Na^{+} vs Mg^{2+}/Na^{+} to identify the mineral weathering in the study area.

compared to the sandstone regions. However, the expected interaction of river water with groundwater may be the reason for the improvement in the quality of the water in the NE region of the study area. However, other reasons for variation in groundwater quality may be anthropogenic, which is discussed in below in the land-use impacts on water quality.

Land-use change in any region is a result of human actions to support the developmental activities for the increasing population growth. The major land use in the Tamil Nadu state is agriculture and Thanjavur is no exception. The district is largely covered by agricultural areas and next is urban and rural built areas. Numerous waterbodies in the form of tanks and drainages are seen. In this section, groundwater quality is evaluated in the context of land use.

Impacts of major land-use agricultural activities are assessed along with water quality. The major contamination caused by the of agricultural fertilizers are the increase of nitrate content in groundwater and salinity increase by waterlogging. However, it is observed that the nitrate concentration in groundwater is comparably less than the drinking-water standard of 50 mg/L (WHO, 2011). This indicates that the major contributor to groundwater contamination is not fertilizers. On the other hand, the chloride concentration in the groundwater is much higher than the proposed level of 250 mg/L. As chloride is a non-geogenic ion, the increased concentration can be attributed to the groundwater salinization by the waterlogging, industrial pollution and domestic sewages. There are several industries working in the district, including leather, chemical, cotton, silk, wool, rubber, plastic, etc. Leather treatment and dying industries use high amounts of salt (Na-Cl) for processing and this may be the major reason for the increased level of chloride in the groundwater. Figure 8a and b show the relation between Na and Cl for post-monsoon and pre-monsoon seasons. The strong positive correlation between these ions confirms the impacts of these industries on groundwater quality. The WQI for both seasons were compared with the land-use map (see Figure 4), and the results agree with the above findings. Water quality has been polluted mainly

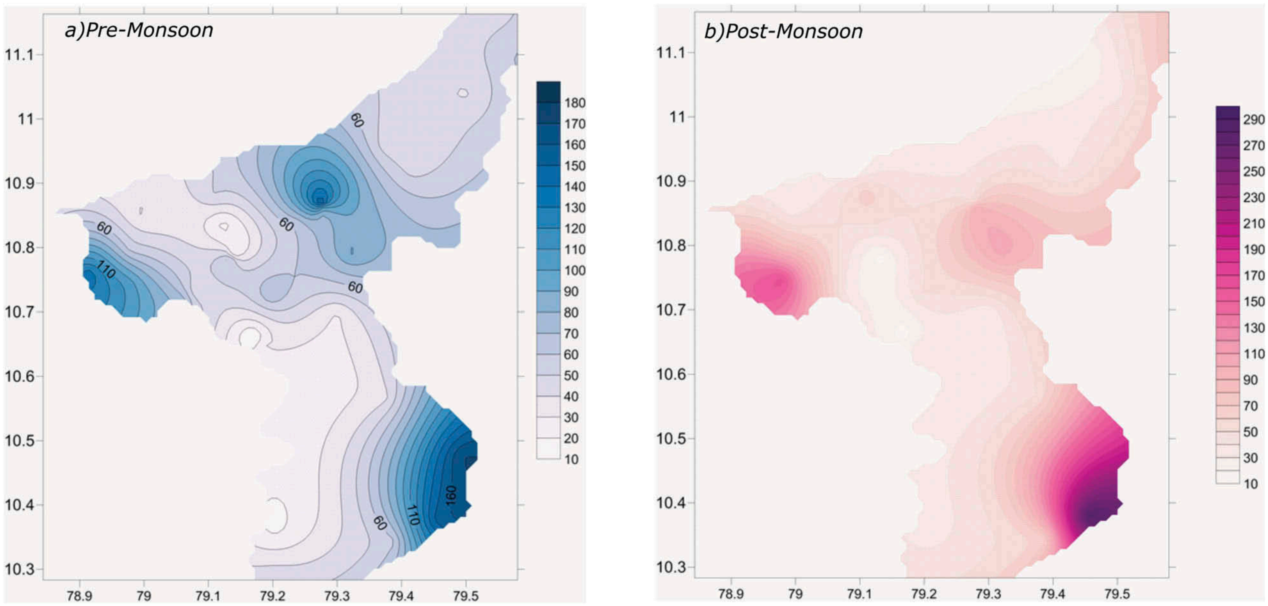

Figure 7. Spatial variation of water quality index in Thanjavur district a) pre-monsoon b) post-monsoon.

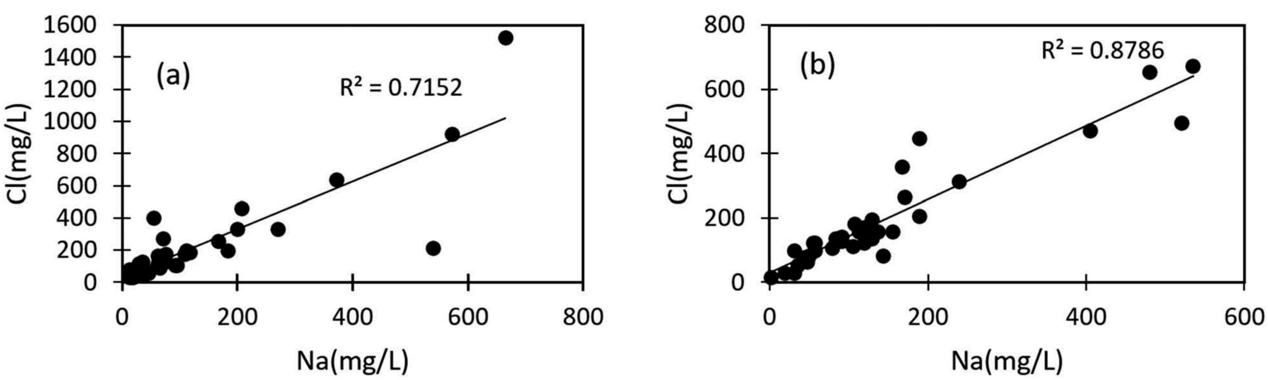

Figure 8. Bivariate plot between Na and Cl a) pre-monsoon b) post-monsoon.

inbuilt up areas, i.e.,, human settlements and industrial regions.

Conclusions and recommendations

The influence of geological formations and land use was studied based on the 34 groundwater samples and the results were analyzed using hydrochemical analysis, Water Quality Index (WQI), and spatial mapping techniques. Results from the Gibbs diagram show that the major processes controlling groundwater chemistry are rock–water interaction and evaporation depositions, which is confirmed by the water types mixed Ca-Mg-Cl type, Ca-HCO_3 type and lastly Na-Cl types. Groundwater quality analysis using WQI suggests that more than 80% of the samples in both seasons is good for drinking. Silicate weathering is the major hydrogeochemical process in both seasons and in addition to that carbonate weathering is also acting in the pre-monsoon season. Increased residence time induced by the sluggish flow in the pre-monsoon season is the reason for the dissolution of carbonate minerals. Increased residence time induced by the sluggish flow in the pre-monsoon season is the reason for the dissolution of carbonate minerals. From this result, it can be proved that geological formations influencing the chemistry of groundwater. The order of dominance among the different landuse are agricultural lands, human settlements, and Industries. The most common anthropogenic contaminants due to the use of fertilizers is nitrate, which was less than the permissible limit of the drinking (50Mg/L). However, it is not discarding the influence of the agricultural land, because the natural background level of nitrate in groundwater is far below this level. On the other hand, salinity is high in many samples, which is shows the influence of water logging in this area and also the industrial effluents. The positive correlation of Na with Cl confirms the salinity origin for the aforementioned sources. A spatial variation map of the WQI compared with geology and land-use maps showed positive correlations with the corresponding geological formations as well as land-use patterns. Thus, the clear influence of geology and land use on groundwater quality is confirmed.

This is only preliminary study that tried to evaluate the influences of geology and land-use patterns on groundwater quality. However, routine monitoring of the water quality and increased samples is suggested. More studies needed, if possible, on a monthly basis for at least 1 year to understand the nitrate concentration and its mobility. A natural background level of nitrate may be calculated in the future studies, which will help in understanding variation by anthropogenic influences.

Disclosure statement

No potential conflict of interest was reported by the authors.

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