Groundwater quality mapping using geographic information system in Trichy district, Tamilnadu, India

G. Venkatesan and M. S. Senthil

ABSTRACT

Aquifers in general are prone to contamination due to various factors including anthropogenic activities; monitoring the water quality by cost-effective techniques is of great significance and use. To study the water quality of around 100 open wells in Trichy district, Tamilnadu, India, the analytical tool 'geographical information system' (GIS) was applied and the outcome analyzed. The district, based on the soil type, is categorized into three regions viz: unconsolidated (Recent), semi consolidated (Cretaceous to Miocene) and consolidated (Archaean), and this technique was applied for the water samples collected in those regions. A spatial variation in well waters in the district was studied using GIS based on 15 physico-chemical parameters. For the three regions in the district, the water quality information maps of the entire district have been prepared using a spatial interpolation technique for these parameters. Statistical analyses carried out for the parameters and the character of water related to source of supply and changes in water qualities are discussed. Also the Piper tri-linear diagram is plotted, which shows the essential chemical character of the groundwater in these open wells. The condition of the groundwater has been categorized as good, moderate and poor in the respective maps for the pre and post-monsoon seasons, with the perspective of location of the site as well as in the nature of aquifer formation. Suggestion is given for the strategies for the development and preservation of the groundwater condition in this region.

Key words | geographical information system, groundwater, lithology, open wells, physico-chemical parameters, spatial interpolation

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INTRODUCTION

Water contributes considerably to the robust economy of a country. Generally, water quality assessment involves evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses. Quality of water, which may affect human health and that of the aquatic life, has to be monitored regularly (United Nations Educational, Scientific and Cultural Organization (UNESCO)/World Health Organization (WHO)/United Nations Environmental Programme (UNEP 1996). For the supply of drinking and agricultural water, groundwater has been a significant, reliable source that supports different users (Afzali *et al.* 2014). There arises the need for developing models for the efficient forecasting of the contaminants in these soils and water (Sener & Devraz 2013). In developing countries, most diseases are water-borne, which is one of the world's greatest public health crises (Bierkens 2015). Activities, including anthropogenic, have been pernicious to the water table by the unwanted addition of contaminants.

To properly manage the groundwater resources in terms of availability in a particular area and the degree of contamination, a reliable tool is required (Cheronomelly & Mutua 2016). Geographic information system (GIS) is a computer system capable of assembling, storing, manipulating and displaying geographically referenced information (Abd Manap *et al.* 2014). The data identified according to their locations (USGS) is an emerging technique in groundwater studies.

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This may be used for site suitability analyses, managing the site inventory data, estimation of groundwater vulnerability to contamination, groundwater flow modelling, modelling solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create decision support systems (Elewa *et al.* 2013; Nampak *et al.* 2014). It has long been recognized that the GIS has the potential capabilities to capture, edit, manipulate, analyze, and display spatial and non-spatial data. In this method, spatial parameters such as latitude, longitude, slope, aspect etc. are used. Since its initial development in the 1960s, this technology has extensively been used to generate and spatially organize large volumes of data to support modelling of contaminant transport in the soil and in the groundwater (Jeihouni *et al.* 2014; Asadzadeh & Ali Abasiyan 2016).

Using GIS databases, comprehensive hydrologic simulation studies are now quite prevalent (Verma *et al.* 2013). Our study is intended to evaluate the parameters and accordingly help to take decisions to safeguard the quality of the open well waters in Trichy district. With the advent of the objective-oriented GIS programming languages available nowadays, there are no limitations as in earlier GIS applications (Abd Manap *et al.* 2013, 2014). In this case, the Trichy district sample data on the physico-chemical parameters of the open wells (around 100 in number) were used for spatial variation in well water to study the quality of water using the GIS technique (Gnanachandrasamy *et al.* 2015). The spatial data is used here for investigating groundwater quality information (Shinde *et al.* 2015). For the study, the following physico-chemical parameters were measured, viz: total dissolved solids (TDS), pH, electrical conductivity (EC), total hardness, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl^-), sulphate (SO_4), carbonate (CO_3), bicarbonate (HCO_3), and fluoride (F) (Sadat-Noori *et al.* 2015; Gharbia *et al.* 2016).

MATERIALS AND METHODS

Area of study

The study was carried out in Trichy District in Tamilnadu. The total geographical area of the Trichy district, nearly 90 percent is occupied by hard rocks of the Archaean age. The Trichy district lies on the geographical co-ordinates of 10°48′18″N and 78°41′8″E. The Cauvery river flows west to east in the centre of the district (Muthukumar *et al.* 2011). Owing to this, the study area is not drought prone. The soil types are: Red, Black, Alluvial and Red loam. There is a dam, Kallanai (also known as Grand Anicut) constructed around the 2nd century AD and is the fourth oldest water diversion or water-regulator structure in the world that is still in use. There are eight Taluks in the district – a Taluk is an administrative division denoting a sub district in the Indian context.

The water samples were collected from wells covering eight Taluks in the Trichy district. In many cases, there were different wells at a particular sample station. From each well, one litre of water was collected in a one litre bottle in the month of January (post-monsoon) and June/July (pre-monsoon) 2015. During the mentioned periods there was no precipitation that could alter the condition of the well water. For the assay of physico-chemical parameters, the following methods were adopted. pH was measured using pH meter, EC using reference electrodes, TDS was arrived at from calculation. The physico-chemical parameters are estimated by following the standard procedure prescribed by the American Public Health Association (APHA 1995). Parameters such as pH, EC, and TDS were analyzed by employing a Water Quality Analysis kit. The water is heterogeneous in nature, owing to recharge by rains, and in some areas the flow of Cauvery river water has its influence. There were variations in the depth of water in the open wells due to these factors.

RESULTS AND DISCUSSION

Groundwater samples in the Trichy district show that pH and sulphates are within the range of (6.5–8.5) and (200–400) mg/L specified by the WHO and Bureau of Indian Standards (BIS). Chlorides are higher than the specified normal and are of higher value in the post-monsoon period compared to pre-monsoon period. TDS is above the maximum desirable limit of 500 mg/L and maximum permissible limit of 600 mg/L in many sample stations. This may be attributed to the sewage in the area (Srinivas *et al.* 2013). Carbonate and bicarbonate make the total alkalinity, and this is slightly above the permissible limit of 600 mg/L recommended by Central Pollution Control Board (CPCB) in some samples. The bicarbonate ion is relatively high compared to chloride and sulphate ion concentrations. Total hardness is within the maximum permissible limit of 300 mg/L and 500 mg/L specified by BIS and WHO, and the water is categorised as hard to very hard. Among other parameters, calcium (Ca) and magnesium (Mg) are with in the permissible range, and chloride (Cl) and sulphate (SO_4) are exceeding the permissible limits specified by the BIS and WHO (Gharbia *et al.* 2016).

Statistical quality analysis and types of water

Water quality parameters of Trichy district are presented in Tables 1–6 for pre and post-monsoon seasons and plotted in Figures 1–4.

pH

All the collected water samples were alkaline in nature, with a range of 7.3–8.9 in the post-monsoon season with a mean value of 8.29 and with a range of 6.9–8.29 with a mean value of 8.03.

Electrical conductivity

EC is a measure of the ability of water to pass an electrical current. EC in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminium cations (ions that carry a positive charge). EC in groundwater is affected primarily by the geology of the area through which the water flows. To diagnose and categorize the total concentration of soluble salts in irrigation water, it is expressed in terms of specific conductance.

The term salinity refers to the concentration of salts in water and can take three forms: (i) primary salinity (natural salinity), (ii) secondary salinity (dry land salinity) and (iii) tertiary or integrated salinity (irrigation salinity). Categorization of salinity hazard classes specified by the United States Regional Salinity Laboratory (US Regional Salinity Laboratory 1954) and for the study area are shown (Table 7).

It is found from the EC values of pre-monsoon samples, they are highly suitable for irrigation purposes, except three samples, and 12 samples are not suitable for irrigation purposes in the post-monsoon period.

Total dissolved solids

TDS constitute inorganic salts, principally containing calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphate with small amounts of organic matter. The permissible limit of TDS in water is 500 mg/L and 1,000 mg/L suggested by BIS, WHO and USEPA. However, in this study, the TDS value were in the range of 242 mg/L to 2,465 mg/L in the post-monsoon season with a mean value of 964.7 mg/L and 230 mg/L – 3,102 mg/L with a mean value of 875.52 in the pre-monsoon season. Among the 60 samples, 16 (27%) of them exceeded the permissible limit of 1,000 mg/L of the WHO standards and 14 (23%) of them were below the 500 mg/L BIS standards. The remaining 30 samples are within the range of 500 mg/L to 1,000 mg/L.

Table 1 | Statistics of physical parameters in post-monsoon

	TDS	pH-GEN	EC- GEN	TH	SAR	RSC
Mean	964.70	8.29	1,663.10	404.03	4.04	0.62
Maximum	2,465.00	8.90	4,450.00	1,200.00	12.46	8.70
Minimum	242.00	7.30	460.00	115.00	0.85	0.00
SD	608.22	0.28	1,018.85	265.90	2.36	1.46
Median	746.00	8.30	1,310.00	325.00	3.39	0.00
Variance	369,932.8	0.08	1,038,046	70,702.95	5.58	2.13

Table 2 | Statistics of cation parameters in post-monsoon season

	Ca	Mg	Na	K
Mean	48.27	68.70	179.63	32.92
Maximum	176.0	194.40	488.00	313.00
Minimum	10.00	13.37	31.00	0.100
SD	36.37	45.64	119.15	63.49
Median	36.00	57.10	137.00	11.00
Variance	1,322.67	2,083.13	14,197.63	4,031.68

Table 3 | Statistics of anion parameters in post-monsoon season

	Cl	SO_4	CO_3	HCO_3	F
Mean	293.87	98.55	11.47	311.10	0.77
Maximum	1,276.00	576.00	90.00	805.20	3.52
Minimum	3.00	2.00	0.00	103.70	0.06
SD	266.92	105.87	17.83	139.12	0.62
Median	193.00	67.00	3.74	292.80	0.60
Variance	71,247.95	11,207.57	317.84	19,355.45	0.39

Higher TDS of water have a heavier taste and a much more prominent ‘mouth feel’ taste, which includes saltiness due to an appreciable sodium content in the water. Lower TDS have no taste and ‘express’ airy or light mouth feel.

Hardness

Water systems using groundwater as a source are concerned with hardness and primarily by the cations such as calcium and magnesium compounds and anions such as carbonate, bicarbonate, chloride and sulphate in groundwater. General guidelines for classification of waters are: 0 to 60 mg/L as calcium carbonate is classified as soft; 61 to 120 mg/L as moderately hard; 121 to 180 mg/L as hard; and more than 180 mg/L as very hard. The present study reveals that most of the samples are under the category of hard to very hard water.

Sodium adsorption ratio

The index used is the sodium adsorption ratio, which expresses the relative activity of sodium ions in the exchange reactions with the water. This ratio measures the relative concentration of sodium to calcium and magnesium. SAR is defined by the following equation:

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

A high sodium ion level in water affects the permeability of soil and causes infiltration problems. The analysis of groundwater samples in the study area with respect to SAR is shown in Table 8. From this study, the value of SAR during pre and post-monsoon seasons, all values are classified as good for irrigation practices.

Residual sodium carbonate

The residual sodium carbonate index of irrigation water is used to indicate the alkalinity hazard. The RSC index is used to find the suitability of the water for irrigation in clay soils that have a high cation exchange capacity. When dissolved sodium in comparison with dissolved calcium and magnesium is high in water, clay soil swells or undergoes dispersion, which drastically reduces its infiltration capacity. The formula used for calculating RSC index is:

$$\mathrm{RSC\,index} = \mathrm{HCO}/61 + \mathrm{CO}/30 - \mathrm{Ca}/20 - \mathrm{Mg}/12.$$

Table 4 | Statistics of physical parameters in pre-monsoon season

	TDS	pH-GEN	EC- GEN	HAR-TOTAL	SAR	RSC
Mean	875.52	8.03	1,542.37	360.15	4.11	0.75
Maximum	3,102.00	8.90	5,270.00	1,200.00	16.80	7.60
Minimum	230.00	6.90	250.00	125.00	0.29	0.00
SD	609.38	0.43	1,042.76	248.97	2.90	1.63
Median	660.00	8.10	1,265.00	282.50	3.42	0.00
Variance	371,342.70	0.18	1,087,348	61,988.54	8.42	2.65

Table 5 | Statistics of cation parameters in pre-monsoon season

	Ca	Mg	Na	K
Mean	39.18	63.38	177.70	33.28
Maximum	168.00	204.12	680.00	297.00
Minimum	6.00	10.56	11.00	0.10
SD	34.59	42.96	141.65	60.97
Median	31.00	51.64	133.00	10.50
Variance	1,194.32	1,845.89	20,066.04	3,717.40

Table 6 | Statistics of anion parameters in pre-monsoon season

	Cl	SO_4	CO_3	HCO_3	F
Mean	270.06	82.52	6.31	305.09	0.62
Maximum	1,333.00	528.00	48.00	664.90	2.40
Minimum	1.00	5.00	0.00	98.45	0.05
SD	298.23	93.54	11.74	133.35	0.55
Median	179.00	58.00	0.32	284.75	0.44
Variance	88,943.96	8,749.95	137.75	17,781.15	0.31

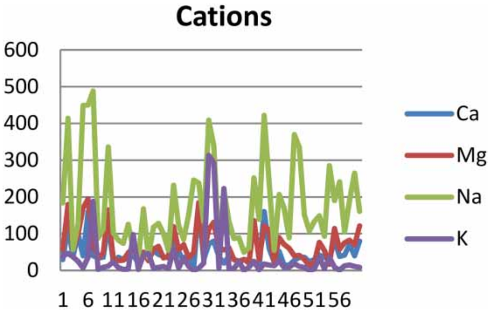

Figure 1 | Post-monsoon cations.

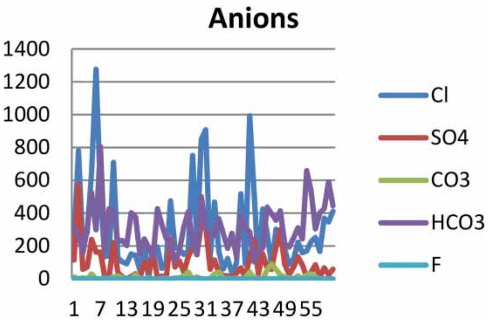

Figure 2 | Post-monsoon anions.

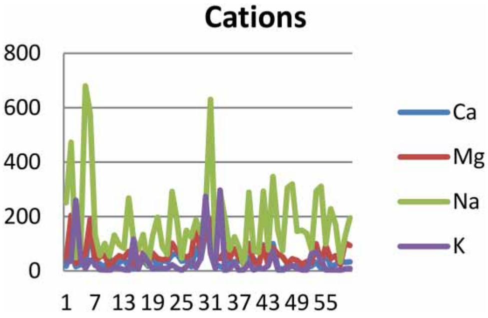

Figure 3 | Pre-monsoon cations.

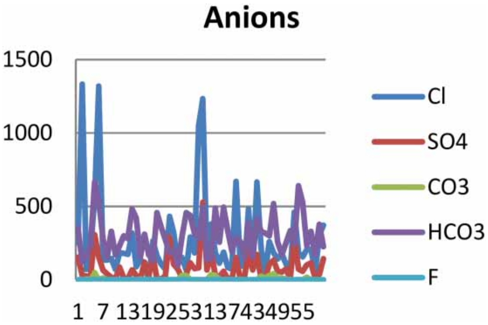

Figure 4 | Pre-monsoon anions.

Table 7 | United States salinity laboratory specified salinity hazard classes

Hazard class	EC in (micro mohs/cm)	Remarks on quality	Pre-monsoon samples	Post-monsoon samples
C1	100–250	Excellent	21	–
C2	250–750	Good	33	11
C3	750–2,250	Medium	4	39
C4	2,250–4,000	Bad	1	10
C5	>4,000	Very bad	2	2

Table 8 | Sodium hazard classes based on USSL classification

Sodium Hazard Class	SAR in Equivalents per mole	Remarks on Quality	Pre-monsoon Samples	Post-monsoon samples
S1	10	Excellent	–	–
S2	10–18	Good	0.29–16.80	0.85–12.46
S3	18–26	Doubtful		
S4	>26	Unsuitable	–	–

Groundwater of the study area classified on the basis of RSC is presented in Table 9 for both seasons. Based on the RSC values, over 49 and 53 samples out of 60 samples have

Table 9 | Residual sodium carbonate classes based on US Department of Agriculture

RSC (meq/l)	Category on quality	Pre-monsoon samples	Post-monsoon samples
< 1.25	Good	49	53
1.25–2.5	Doubtful	3	5
> 2.5	Unsuitable	7	2

less than 1.25 and are safe for irrigation in both the seasons. Over three and five samples out of 60 samples in pre and post-monsoon seasons are fair. The remaining samples are unsuitable for irrigation.

Calcium (Ca) and magnesium (Mg)

The common source of calcium and magnesium in Groundwater is erosion of rocks like limestone, dolomite, and calcites, which are the major contributors of water hardness. Calcium in the study area ranged between 10 mg/L–176 mg/L and 6 mg/L–168 mg/L in post and pre-monsoon seasons. In most of the samples (90% of 56 samples) in the study area, calcium values were below the desirable limits of 75 mg/L and 6% of 10 samples were above the desirable limits suggested by drinking water specifications. In all the samples in the study area during both pre and post-monsoon seasons, the Calcium values were within the permissible limits of 200 mg/L. Calcium has potential effects when ingested, and it blocks the absorption of heavy metals in the body and prevents certain types of cancer. High concentrations may affect the absorption of the other minerals in the body. The accumulation of excess calcium can result in impairment of kidney function, which then increases the absorption of iron, zinc, magnesium and phosphate. Kidney stones, consisting of calcium oxalate, might develop and cause pain. It may cause hyperparathyroidism, which is a condition in which the parathyroid glands over-produce parathyroid hormone. The magnesium levels in the study area ranged between 13.37 mg/L–194.4 mg/L and 10.56–204.12 mg/L in post and pre-monsoon seasons. The values of Mg in the pre-monsoon season in six stations were exceeding the permissible limit of 100 mg/L. In post-monsoon season the value of Mg was exceeding the permissible limit of 100 mg/L in 12 stations.

Magnesium contributes to an undesirable taste to water. Sensitive people may feel the unpleasant taste at 100 mg/L, and the average person feels the same at about 500 mg/L. Mg in drinking water has a laxative effect with a magnesium sulphate concentration of about 700 mg/L.

Sodium (Na) and potassium (K)

Sodium and potassium belong to a group of ‘alkali earth metals’ and are often associated with chloride and bromide, and in these forms they readily dissolve in water. There are no health based drinking water standards for sodium and potassium. Sodium intake may lead to hypertension and is a concern for people with average heart condition.

Chloride (Cl)

Chlorides commonly found in water, include the chlorides of calcium, magnesium and iron. All these cause the permanent or noncarbonated hardness and may materially increase the corrosive action of water. All chloride salts are highly soluble and so chloride is rarely removed from water by precipitation. Chloride is not affected by exchange, absorption or biological activity and when chloride goes into solution, it is not removed through natural processes. The concentration of chloride in natural groundwater does not ordinarily exceed 100 mg/L. Water containing less than 250 mg/L of chloride is satisfactory for supplying water to agricultural or industrial use. With 500 mg/L of chloride, the water gets a disagreeably salty taste. This study reveals the chloride values were varied between 1 mg/L and 1,333 mg/L in the pre-monsoon season with a mean value of 270.06 mg/L and ranged between 10 mg/L and 176 mg/L with a mean value of 48.27 mg/L in post-monsoon season. The mean value of chloride in both the seasons exceeds the desirable limit of 250 mg/L and is within the permissible limits of 1,000 mg/L prescribed by BIS Standards.

Sulphate (SO_4)

Sulphate is sometimes called vitriol or the salt of sulphuric acid and it comes from dissolved minerals like sodium sulphate, magnesium sulphate and calcium sulphate and fertilizers. Most of the samples in the study were found to be below the desirable limit of 200 mg/L (BIS) in both seasons and the value of SO_4 in station 31 of pre-monsoon season, exceeds the permissible limits of 400 mg/L. Ingestion of 8 g sodium sulphate and 7 g of magnesium sulphate caused catharsis (USEPA 1985) and dehydration is the side effect.

Carbonate and bicarbonate (alkalinity)

The property of alkalinity in groundwater is its ability to neutralize acid, and alkalinity is produced almost exclusively by carbonate and bicarbonate ions. Hydroxide and silicate ions have influence on alkalinity when pH is above 9.0. But natural water with pH above 9.0 is rare. Alkalinity is a reliable measure of carbonate and bicarbonate ions for more natural waters. Groundwater generally constitutes 10 mg/L–1,000 mg/L of bicarbonate and carbonate concentrations of 50 mg/L–400 mg/L are common. However, there is no prescribed desirable and permissible limit for this ion. This study finds that carbonate values varied between 0 mg/L and 90 mg/L in post-monsoon season with a mean value of 11.47 mg/L and ranged between 0 mg/L and 48 mg/L with a mean value of 6.31 mg/L in pre-monsoon season. Bicarbonate values varied between 103.7 mg/L and 805.2 mg/L with a mean value of 311.10 mg/L and ranged between 98.4 mg/L and 664.9 mg/L with a mean value of 305.09 in post and pre-monsoon seasons. Bicarbonates of calcium and magnesium decompose in steam boilers to form scale and release corrosive carbon dioxide.

Fluoride (F)

The main sources of fluoride are the minerals fluorite and apatite. Most fluorides are low in solubility and amounts of fluorides present in ordinary waters are therefore limited. Natural concentration of fluoride commonly ranges from about 0.01 to 10.00 mg/L. This study finds the fluoride values varied between 0.06 mg/L and 3.52 mg/L in post-monsoon season with a mean value of 0.77 mg/L and ranged between 0.05 mg/L and 2.4 mg/L with a mean value of 0.62 mg/L in pre-monsoon season. The desirable and permissible limits of fluorides are 1.0 mg/L and 1.5 mg/L respectively. Four stations in the pre-monsoon season and three stations in the post-monsoon season are exceeding the permissible limits prescribed by BIS standards. Fluoride in small amounts in drinking water reduces the incidence of tooth decay during the period of enamel calcification. Fluoride in excessive concentration may cause dental defects and affects bone structure.

GIS analysis and interpretation

Figure 5 is the GIS diagram for the Taluk wise sample stations in which the locations of the open wells are indicated. In many cases, there were different wells in a particular sample station. Figures 6 and 7 are the GIS maps taking into consideration the physico-chemical parameters categorized as cation and anion elements, showing the spatial interpolations for pre and post-monsoon water quality respectively by the GIS overlay method (Mosaferi *et al.* 2014) and laboratory tests conducted by the standard procedure prescribed by APHA. The open well waters have been classified as good, moderate and poor, quality wise, based on the fuzzy overlay method of arriving at the spatial positions in a given area.

The fuzzy overlay refers to the analysis of the possibility of a phenomenon belonging to multiple sets in a multi-criteria overlay analysis on the basis of set theory analysis. It is observed that the area classified as good in the case of pre-monsoon is more than that of post-monsoon period. The reason for this could be attributed to the increase in contaminants entering into the wells during the recharge during monsoon. The GIS interpretation reveals that wells in Peruvallapur, Kilarasur, Pullampadi, Melaarasangui and Thandaiputhur are poor in water quality in both the seasons (Figures 6 and 7) and belong to unconsolidated aquifer formations (Figures 8 and 9). Changes in water quality were observed from moderate to good from post-monsoon season to pre-monsoon season in Mahadevi, Eragudi and Uppiliyapuram (Figures 6 and 7) and wells of Sembarai and Manjampatti turn from poor to good. Wells in Thuvakkudi turn from moderate to poor condition. No changes in water quality were observed in the remaining wells (Figures 6–9).

The surface runoff brings more contaminants into the open wells, which get depleted after the monsoon when

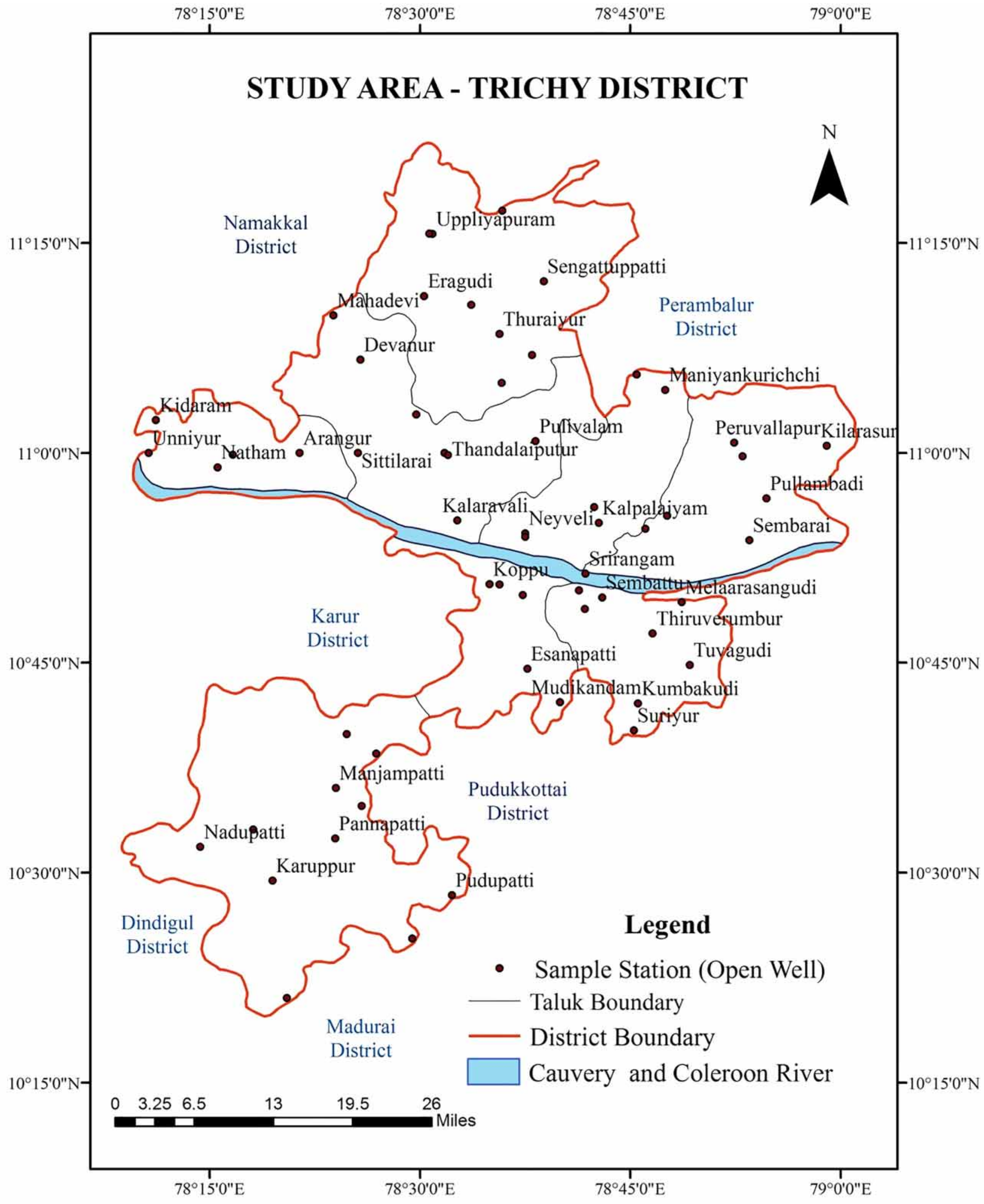

Figure 5 | Study area – well points in Trichy district.

the groundwater is drawn from the wells. When the water is drawn, pure water springs in the wells from the aquifers have lesser concentration of the elements than during the rains (Umamaheswari *et al.* 2015). Hence, in the post-monsoon diagram, a lesser amount of good area coverage is found in the GIS diagram. There is an increase in the moderate region from one to the other season. In the Cauvery river basin, the contamination is due to the effluents put

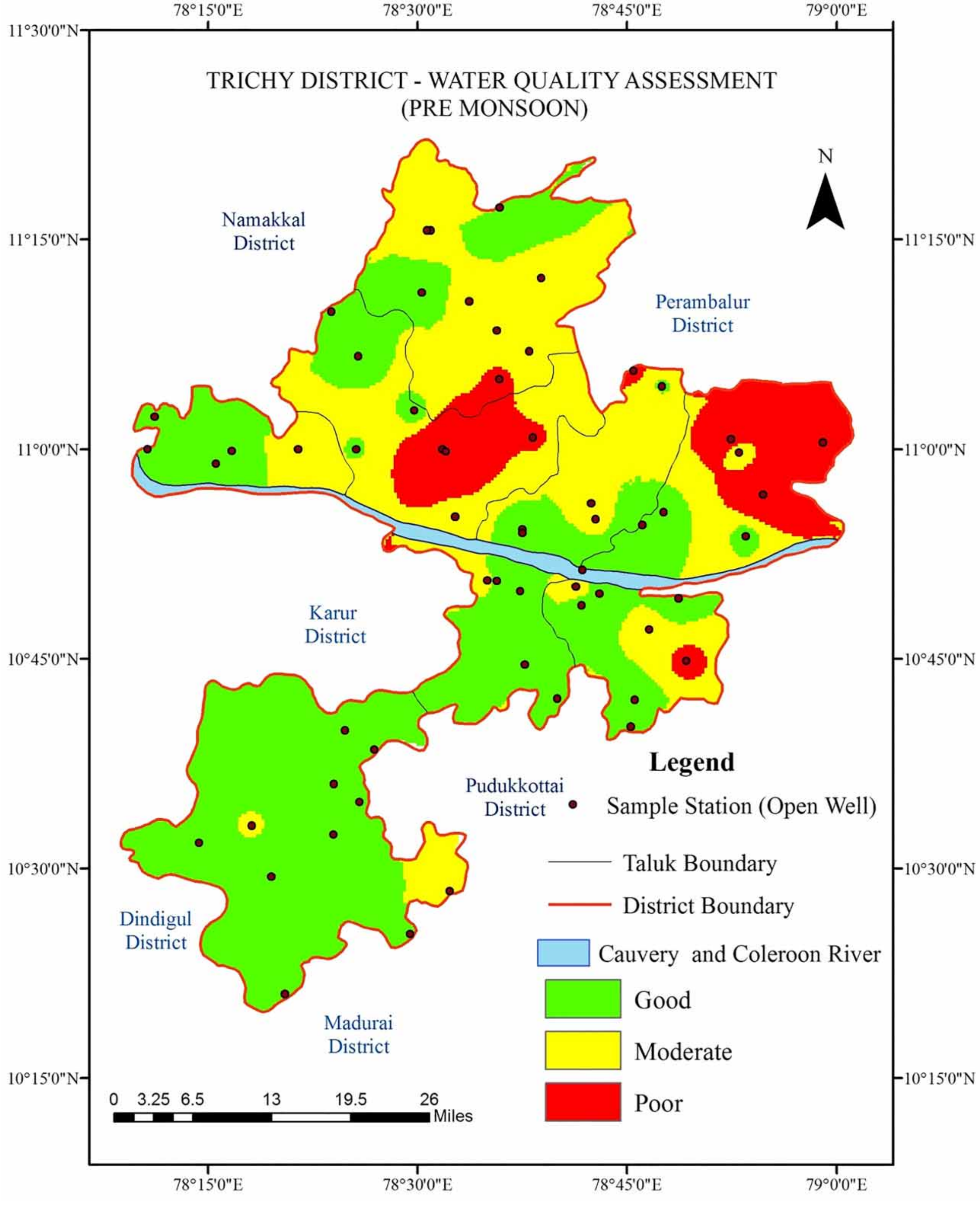

Figure 6 | Water quality assessment in pre-monsoon season.

into the river by neighbouring industries. In Trichy city, the contribution to contamination could be attributed to urbanization and consumerism. Also, on the outskirts of the city, there are many tanneries. The areas indicated as poor remain more or less the same. The above is in agreement with the report by Balakrishnan *et al.* (2011) for Gulbarga city in India. In the north east region of Trichy district, close to neighbouring Ariyalur district, the quality

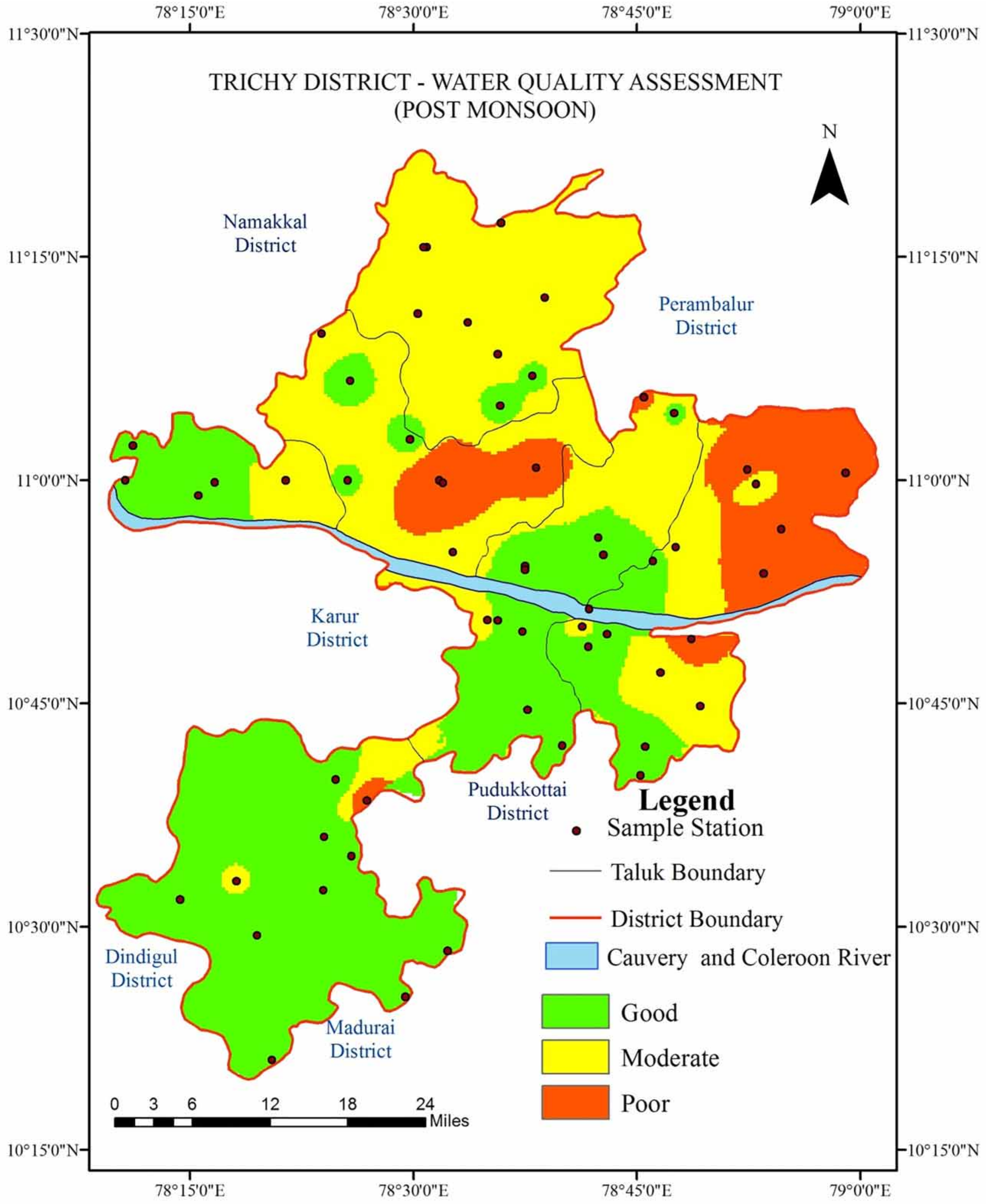

Figure 7 | Water quality assessment in post-monsoon season.

of water is poor according to analysis. The reasons for this could be attributed to the presence of cement and sugar factories in the region. This necessitates that they are closely monitored for further degradation of the water quality in the area. Another category of classification is based on the geological viewpoint. The district is mapped (Figures 8 and 9) as unconsolidated (Recent), semi consolidated (Cretaceous to Miocene) and consolidated (Archaean), and GIS

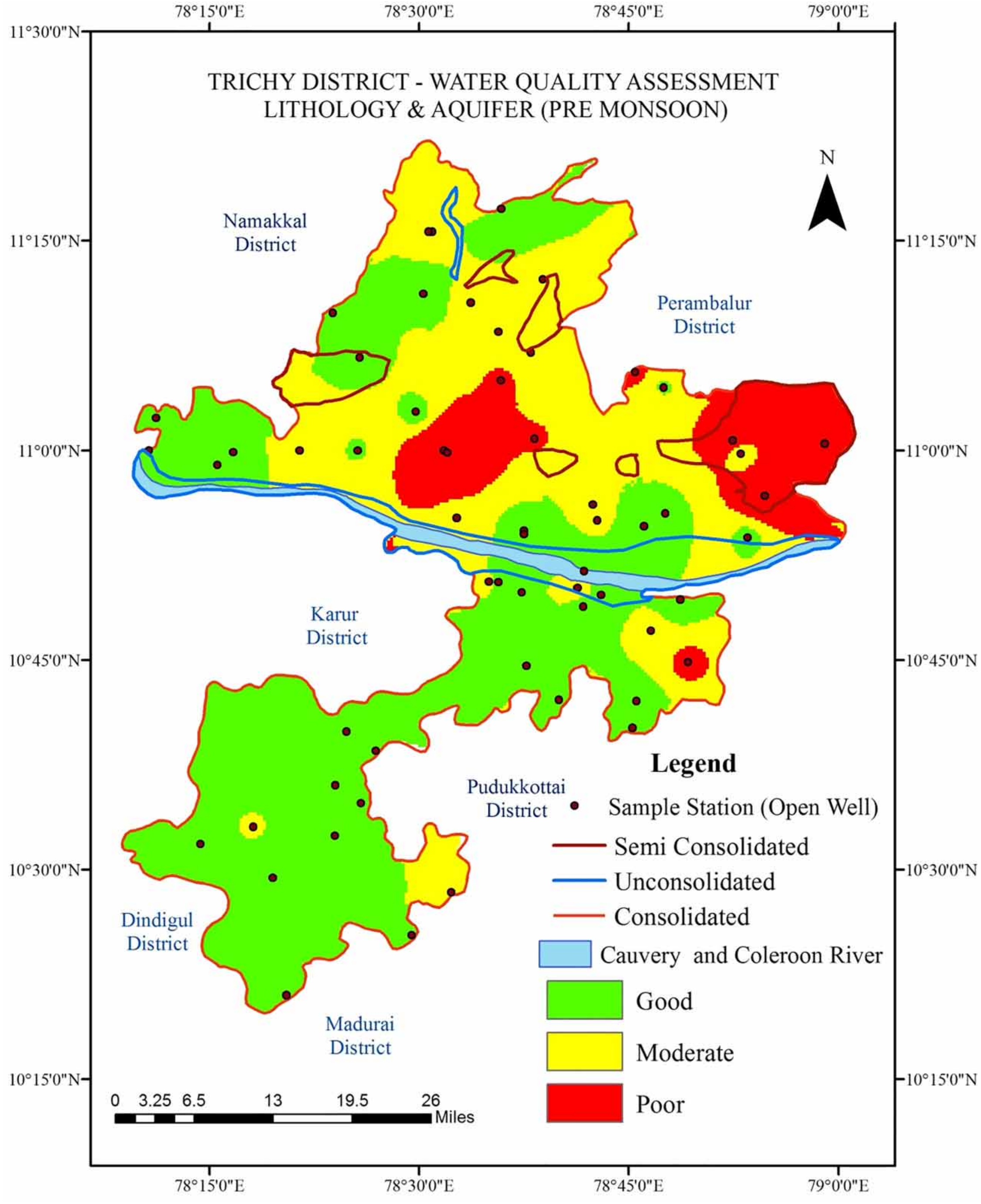

Figure 8 | Water quality assessment in lithology and aquifer (pre-monsoon).

was applied for the water samples collected in those regions. The GIS for this season corroborates with the previous case of Taluk wise mapping. The surface runoff into the wells during the rains brings contaminants from the environment due to anthropogenic activities and other industrial activities in the area. Drawing the water from the wells reduce the concentrations of the elements as discussed already. Hence, in the classification based on

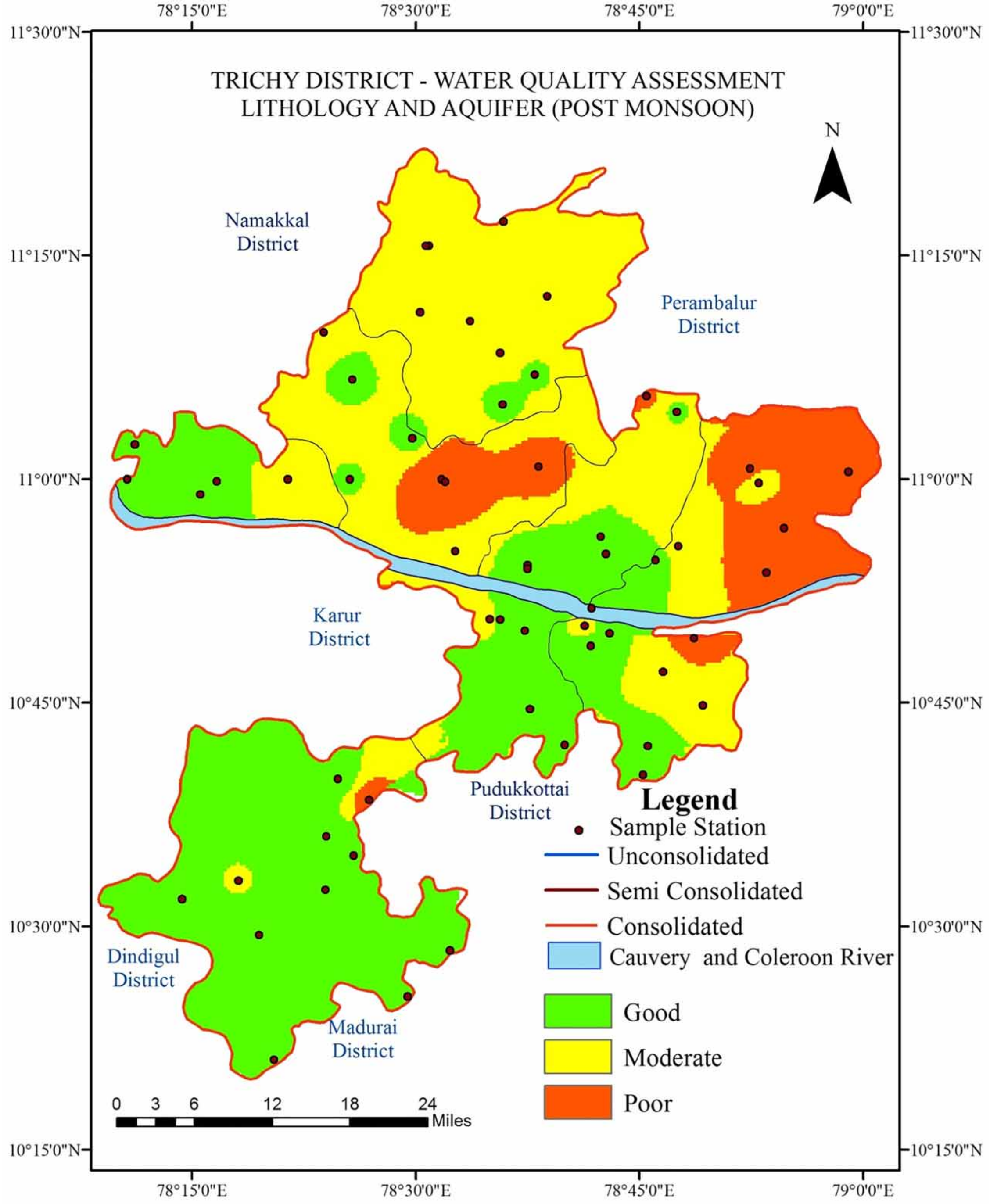

Figure 9 | Water quality assessment in lithology and aquifer (post-monsoon).

lithology, GIS mapping based on 15 physico-chemical parameters is also comparable to that of the previous case. Anthropogenic activities contribute the maximum to the rise in the concentration of the elements. Effluents put in to the Cauvery river because of industrial activities have to be necessarily minimized. In the case of the geological classification mapping, the contributions to the rise in contaminants could be pedogenic also, in addition to

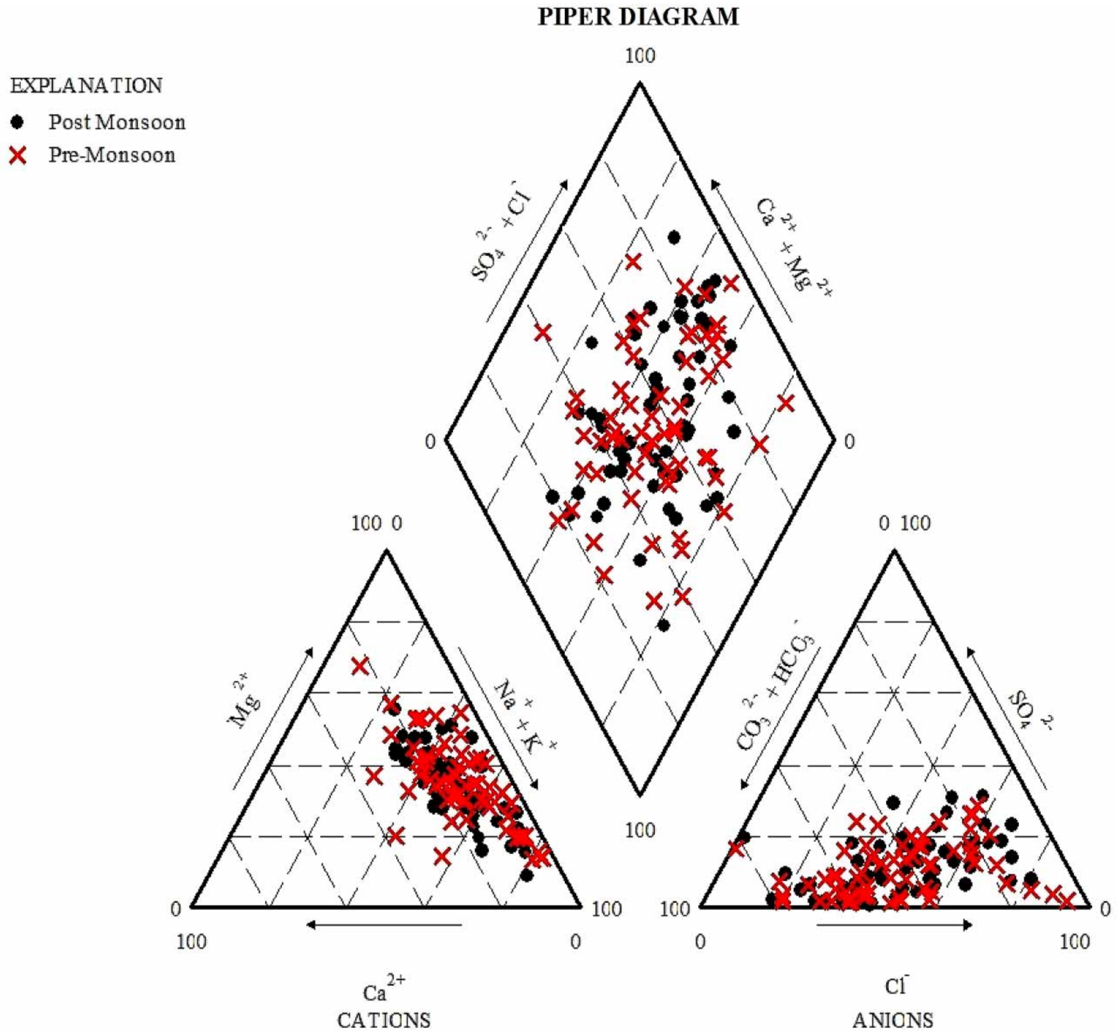

Figure 10 | Piper plot.

anthropogenic activities. There is dissolution of some of the elements during the monsoon season. For example, during the post-monsoon period the Mg dissolution takes place, which is also established by the Piper tri-linear plot (Figure 10). Piper diagrams graphically represent some of the multiple variables associated with major cation and anion data and aid rapid determinations of similarities and differences in water samples (Piper 1944). A Piper diagram is composed of two triangles and a rhombus. The two triangles depict mill equivalent percentages of three sets of components, totalling 100%. The components are displayed at the corners of the triangle. Typically, components of one triangle are cations with one corner representing Na +K, while the components of the other are $SO_4^{2-} + Cl$ and HCO_3.

It is evident that most of the groundwater samples come under the Na-Cl type. This is in accordance with the report by Muthukumar *et al.* 2011 on the assessment of water quality in Trichy city. From this plot, it could be observed that during the pre- monsoon period strong acids exceed weak acids, and only in the case of a few samples weak acids exceed the strong acids. In the case of the post-monsoon period, Mg content increases drastically owing to the dissolution of Mg, and a considerable decrease of Na + K could be observed. This is established by the plot. The reason for this could be attributed to the weathering pattern of basic and ultra-basic rocks of the Trichy region and the residence time of the groundwater in the area. In the case of anions, CO_3^{2-} and HCO_3^- slightly exceed other anions in many sites, which is indicative of the water being not very soft in proportion to the amount of dissolved solids. When there is adequate recharge of the groundwater during the monsoon period, there is considerable change in the ionic strength (Gnanachandrasamy *et al.* 2015).

CONCLUSION

The spatial distribution mapping in the study area of the Trichy district is given. The district is categorized based on Taluk boundaries and geological considerations. The areas are classified as good, moderate and poor in terms of the quality of the open well water during the pre and post-monsoon seasons. Fifteen physico-chemical parameters were taken into consideration for the analysis. GIS diagrams based on the parameters were obtained. The Piper trilinear plot is also indicative of the condition and is in agreement with the mapping done for the district for evaluating the water quality. The spatial mapping obtained has given the necessity of making the public, local administration and government aware of the quality of the groundwater in the open wells.

SUGGESTION FOR DEVELOPMENT

To minimize the anthropological activities in areas around the open wells, industrial effluents should be given suitable treatments and parameters well controlled to be within limits before discharge into the environment. Under lithological consideration, in the case of unconsolidated (recent – Alluvium) development should be carried through dug wells, shallow tube wells, in the case of the semi consolidated (Cretaceous to Miocene – sand stone, shale) development of shallow aquifer should be through dug wells and in the case of consolidated (Archaean – Granite, Gnesiss) development of weathered residuum through dug wells and fractures through bore wells are suggested. More attention should be given to those areas earmarked as 'poor', as they may cause serious health problems. The region north east in the district close to the Ariyalur district in which groundwater is categorized as 'poor' has cement and sugar factories, which necessitates close monitoring of the effluent treatment before they are put into the environment. The parameters of the effluent should be strictly followed for the safety of the groundwater in the region.

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