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Spatial distribution of Groundwater quality assessment using Water Quality Index and GIS techniques in Thanjavur Taluk, Thanjavur District, Tamil Nadu, India

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Abstract: Assessment of groundwater quality is of utmost importance to ensure sustainable use of water. Since the availability of water, irrespective of quantity and quality, varies from area to area in Thanjavur taluk. The present paper attempts to determine the spatial distribution of groundwater quality parameters and identify locations with the best quality for drinking and irrigation in the study area using GIS and WQI. Using IDW interpolation methods with ArcGIS 10.8, the spatial distribution maps of physical parameters, anions, cations, WQI, and irrigations indices have been generated. Piper pilot shows that Ca-Mg-Cl (mixed), Na-Cl, Ca-Cl, and Ca–Mg–HCO3 water types are found in the study area. Using a water quality index with a rating scale, 42.85%, 28.57%, and 14.3% of groundwater samples are fit, good, and very poor for drinking purposes, respectively. The obtained results of higher SAR, RSC, Na% show that 75% of groundwater samples are perfectly fit for irrigation purposes due to the long residence time of water, dissolution of minerals from lithological composition, and the addition of chemical fertilizers. The results of groundwater quality analysis have been used to suggest models for assessing water quality. The present study ascertained that the area's groundwater must be treated prior to consumption and protected from the perils of contamination.

Keywords: Groundwater, Spatial analysis, IDW, WQI, Irrigation Indices, Thanjavur Taluk.

1. Introduction

Groundwater is widely used for domestic, industrial, and irrigation worldwide [1, 2]. It is one of the most precious natural resources for mankind and socio-economic development. According to Foster (1998), groundwater accounts for 97% of the total fluid freshwater [3]. Over time, the exploitation of groundwater for different uses is growing due to rapid population growth [4]. However, the pollution of groundwater limits its use. Groundwater quality is affected both by natural and human activities [5, 6]. Human activities are affected by groundwater quality and quantity worldwide, especially in developing countries [7]. For instance, agricultural activities result in groundwater pollution [8]. In addition, urban waste discharges and appropriate waste disposal affect the quality of groundwater [9-13]. Globally, anthropogenic activities such as urbanization, industrial development, and agricultural intensification deteriorate the quality of groundwater. The risk of contamination of this precious resource increases day by day due to both geogenic and anthropogenic sources [14-17]. Therefore, monitoring groundwater quality is essential to detect and protect groundwater from pollution. The analysis of groundwater chemistry can be used as a tool to check the suitability of groundwater for drinking and irrigation purposes, a lot of studies have been conducted [18-30].

A groundwater quality map is important to determine water suitability for various purposes and to identify polluted groundwater zone. Map of groundwater quality provides valuable information to protect and manage water well fields. The mapping groundwater quality and investigating its spatial-temporal variation is essential for suitable use of groundwater and water well development. The Geographic Information System (GIS) is one of the most important groundwater quality assessment tools widely used by many researchers for the analysis of spatial and temporal variations in groundwater quality [31-35]. Many researchers used different interpolations found in GIS to map groundwater quality. For instance, the Inverse Distance Weighted (IDW) interpolation was widely used to investigate the spatial distribution of physicochemical parameters [36-38]. IDW is an algorithm used for spatially interpolating data or estimating measurement values. Weights are calculated inversely from the observation location to the point's estimated site [39]. The water quality index (WQI) is one of the techniques to check and classify groundwater quality in different categories [40-45]. It provides the composite influence of individual water quality parameters on the overall quality of water for human consumption [46].

From the literature concludes that the assessment of water quality is important as it directly relates to human health and provides basic information for the development of long-term groundwater management programs in all areas [17, 47]. As groundwater quality is not generally potable in rural areas of the Thanjavur District, part of the taluk is selected for this purpose. The study area is located in the Thanjavur district and is rapidly urbanized and developed with consequent water needs. Groundwater quality and its suitability for use in

Thanjavur City were evaluated as groundwater was a significant source of water for households and agricultural activities at the study site due to a lack of surface water supplies [48]. Poor water quality of groundwater has been used for irrigation purposes, which is a troublesome situation for several stakeholders to affect their irrigation process. This is due to increasing demand, a rapid increase in population density, rapid urban development expansion, high factory development and industrial activity on micro-and macro scales, and extremely poor management of waste and water-based management.

For the present study, the study of GIS and WQI-based groundwater quality is considered important for sustainable green socio-economic development, understanding vulnerability, and obtaining reliable information on the current water quality status in the study area. Therefore, this study aims to understand the spatial variation in groundwater quality in alluvial regions in Thanjavur Taluk and assess groundwater suitability for irrigation and drinking in sustainable agriculture and basic human needs. For these purposes, WQI and irrigation indices (SAR, Na%, RSC) were used to check groundwater suitability for drinking and irrigation purposes. The spatial variations of WQI, major cations, and anions were mapped using the IDW method in GIS.

2. Description of the study area

2.1 Location and climate

The study area, Thanjavur taluk, is found in the Thanjavur district, on the eastern coast of the Bay of Bengal, the southern region of India (Figure 1). The district occupies a major position in agriculture. Paddy, Sugarcane, Coconut, and Plantain are the major crops for cultivation in the district. The study area extends between 10° 31' to 10° 58'N and 78° 52' to 79° 12' E, it stretches from River Coleroon in the north. The study area falls in the four different Survey of India (1:50,000 Scale) toposheets 58 J/13, J/14, N/01, and N/02 with a total area of about 610 km^2 (Figure 1) and was extracted the study area boundary using ArcGIS 10.3 software. The normal annual rainfall in the study area is 1053 mm.

2.2 Geological Setting

The geological formation of Thanjavur taluk is made up of Cretaceous, Tertiary, and Alluvial deposits, and the major areas are occupied by the Alluvial and Tertiary deposits, as shown in Figure 2. The cretaceous formations occur as a small patch in the West and South-West of Vallam, an area in the district. These formations have very thick laterite consisting of impure limestones and sandstones of silt, clay calcareous, and argillaceous variety, in the coast, these formations are overlaid in Cuddalore, a coastal area and a place of sandstone of tertiary age. This sandstone of the Tertiary age is well seen in the west of Grant Anaicut canal and near Orathanadu. These sandstones are covered by a thin layer of wind brown sandy clays, unconsolidated sand, bound clay sands, and mottled clays with lignite seams.

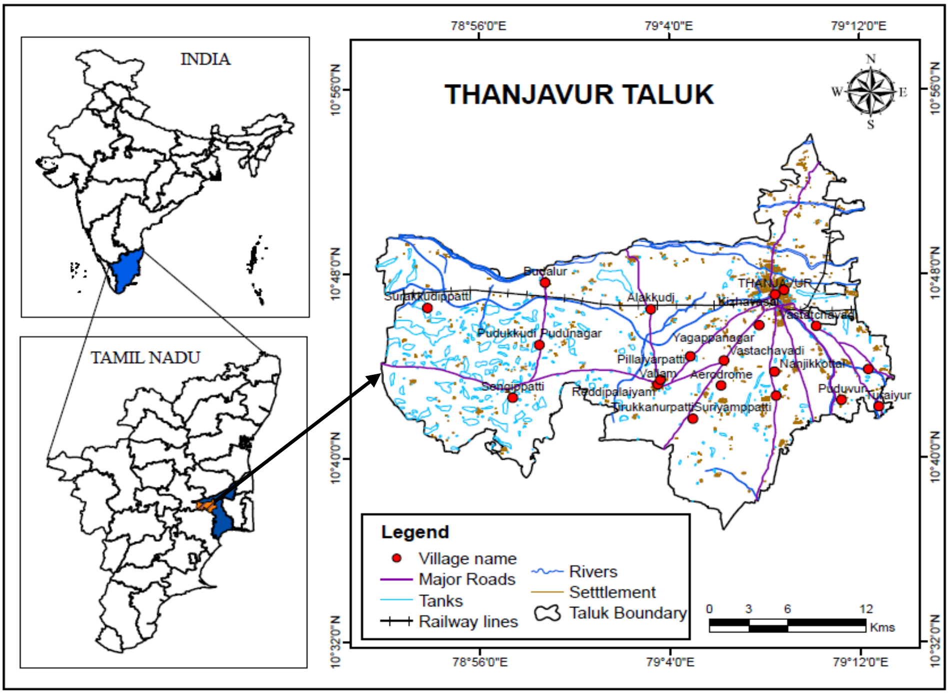

Figure 1. Base Map of the study area

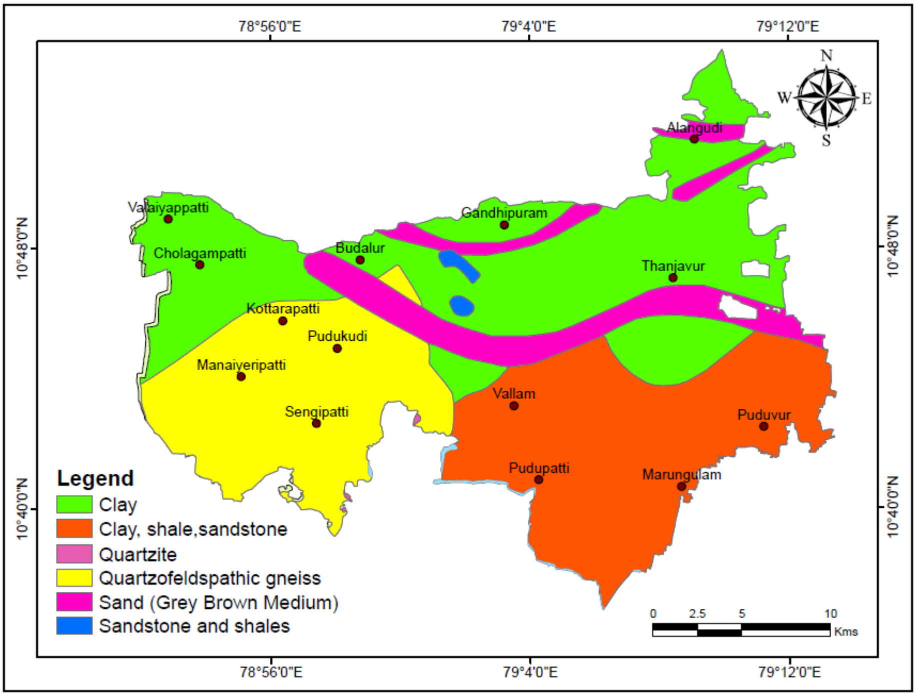

Figure 2. Groundwater sample location and geology map of the study area

This tertiary formation is invariably capped by laterite. In the east, the alluvial deposits of the river Cauvery and its tributaries lie over the Tertiary sandstone. Moreover, it consists of sands, gravelly sands, clays, and sandy clays.

3. Materials and Methods

Fourteen sample locations were identified, and samples were collected during the Pre-Monsoon (PRM) period (January-2018). The locations of collected groundwater samples are shown in Figure 2. Samples were collected after sample bottles were soaked with a 1:1 ratio of HNO_3, cleaned with a detergent, and rinsed using double distilled water samples. Then collected samples were stored in 500 ml polyethylene bottles. Total dissolved solids (TDS), Electrical Conductivity (EC), and hydrogen-ion concentration (pH) were measured on-site using a portable water quality analyzer. Major anions and cations are determined in the laboratory according to the standard methods prescribed by the American Public Health Association APHA (2012) [49]. Magnesium (Mg^{2+}) and calcium (Ca^{2+}) are determined using the titrimetric method, and Sodium (Na^+) and Potassium (K^+) are determined by the flame photometric method. Titrimetrically, chloride (Cl^-) and bicarbonate (HCO_3^-) are analyzed, while fluoride (F), nitrate (NO_3), and sulfate (SO_4^{2-}) are determined using spectrophotometric techniques. Duplicates are also carried for quality assurance and quality control (QA / QC) analysis. The ionic balance error is calculated to check errors (permissible limit of ± 10 %.).

3.1 Preparation of spatial distribution maps

The spatial distribution map of groundwater quality parameters was plotted using ArcGIS v10.3 with spatial statistical analyst module and interpolation technique (IDW). The spatial distribution maps of groundwater quality parameters such as pH, TDS, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, WQI, SAR, Na% and RSC were generated using Inverse Distance Weighted (IDW) interpolation methods with ArcGIS v10.8 [33, 35, 50, 51]. IDW follows a model approach that measures undefined values on the basis of near points rather than distant points. This interpolation method is more precise, and results can be easily expressed compared to other interpolation methods [35, 52]. Moreover, this type of interpolation fits well with the parameters of the real world.

3.2 Water Quality Index (WQI) calculation

Groundwater chemistry has been utilized as a tool to outlook water quality for drinking purposes [53, 54]. We used drinking water standards recommended by WHO (2011) [55] and BIS (2012) [56] to calculate the WQI of the study area. In order to calculate WQI, a weight (p_i), relative weight (Rw_i), and rating quality scale (Rs_i) for each physico-chemical parameter (p_i) are needed [35, 57, 58]. C_i is the concentration of each chemical parameter in each water sample in mg/l, and S_i is the drinking water standard for each chemical parameter in mg/l according to the guidelines. In the first step, weights (pi) for the physicochemical parameters shown in Table 1 were assigned based on the relative significance of the groundwater parameter [44]. In this study, 10 physico-chemical parameters in mg/l were used to calculate the WQI of the study area. In the second step, the relative weight (Rw_i) and rating quality scale (Rs_i) is calculated using equations 1 and 2. Finally, WQI is computed using equation 3.

WQI range suggested by Sahu and Sikdar (2008) [46] was used to identify the groundwater type of the study are: excellent (<50), good (50–100), poor (100–200), very poor (200–300), and intolerable (> 300). Then, the study's spatial distribution map of WQI was investigated using IDW interpolation in GIS.

$$Rw_i = \frac{p_i}{\sum_{i=1}^{n} p_i} \quad \text{.......1}$$

$$Rs_i = \frac{C_i}{S_i} x100 \quad \text{.......2}$$

$$WQI = \sum Rwi * Rsi \quad \text{.......3}$$

3.3 Water quality for irrigation

High salts and dissolved ions in the water used for irrigation affect agricultural productivity. For instance, sodium and boron affect plants [59]. Further, excess salinity in water reduces osmotic activity and thus prevents water and soil nutrient absorption [60]. In the study area, surface water is used for irrigation, and the irrigation activity is mainly concentrated along the Cauvery River and streams. Groundwater is also used for irrigation use in the study area. Therefore, Sodium percentage (Na %), Sodium Absorption Ratio (SAR), and Residual Sodium Carbonate (RSC) were calculated to evaluate the suitability of groundwater for irrigation use in the study area.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \text{.......4}$$

$$Na\% = \frac{(Na^{+} + K^{+})x100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \quad \text{.......5}$$

$$RSC = (HCO_3^{-} + CO_3^{-}).-(Ca^{2+} + Mg^{2+}) \quad \text{.......6}$$

4. Results and Discussion

4.1 Spatial analysis of groundwater quality

The minimum, maximum, average, and standard deviation of determined cations and anions as well as their drinking water quality limits suggested by the BIS, 2012 [56] and WHO, 2011 [55], are presented in Table 1.

Table 1 Statistical summary of groundwater analysis and relative weight of ions

Ions	Min	Max	Average	Standard deviation	WHO 2011	BIS 2012	Weight (Pi)	Relative weight (Rw_i)
pH	7.8	8.9	8.51	0.33	6.5-8.5	6.5-8.5	4	0.114
EC	230.0	4970.0	1566.43	1564.63	1000	-	4	0.114
TDS	118.0	2817.0	865.86	870.41	500	500	4	0.114
Ca^{2+}	14.0	240.0	59.29	72.58	75	75	3	0.085
Mg^{2+}	9.7	272.2	69.00	72.98	50	30	3	0.085
Na^{+}	2.0	587.0	147.36	176.11	200	-	2	0.057
K^{+}	1.0	55.0	20.07	19.81	-	-	1	0.028
Cl^{-}	21.0	1475.0	358.50	475.57	-	-	2	0.057
HCO_3^{-}	54.1	622.2	211.63	146.40	200	200	1	0.028
SO_4^{2-}	5.0	58.0	25.36	20.57	200	200	2	0.057
NO_3^{-}	0.1	41.0	7.86	12.37	50	45	5	0.142
F	0.1	1.4	0.35	0.39	1.5	1	4	0.114
						$\Sigma w_i =$	35	1.001

4.1.1 Physical parameters (pH, EC, TDS)

Figure 3a. shows the spatial distribution map of pH in the study area. The pH of groundwater samples ranges between 7.8 -8.9. This shows that the groundwater of the study area is mainly alkaline in nature. The alkaline nature of the groundwater is due to the presence of alkalies in the fluvial sediments adjacent to the Cauvery River and coast. Figure 3b. shows the spatial distribution map of EC of the study area. The EC values in the Cholagampatti area range between 2250-4000 µs/cm, and it falls in the doubtful class. In Sengipati and Pudupatti areas, EC values are greater than 4000 µs/cm and fall in an unsuitable water class. High EC helps to create acidic soils, while high concentrations of Na^{+} form alkaline soils [48]. The occurrence of high EC values in groundwater samples of the study area might be from agricultural activities and dumping of wastages.

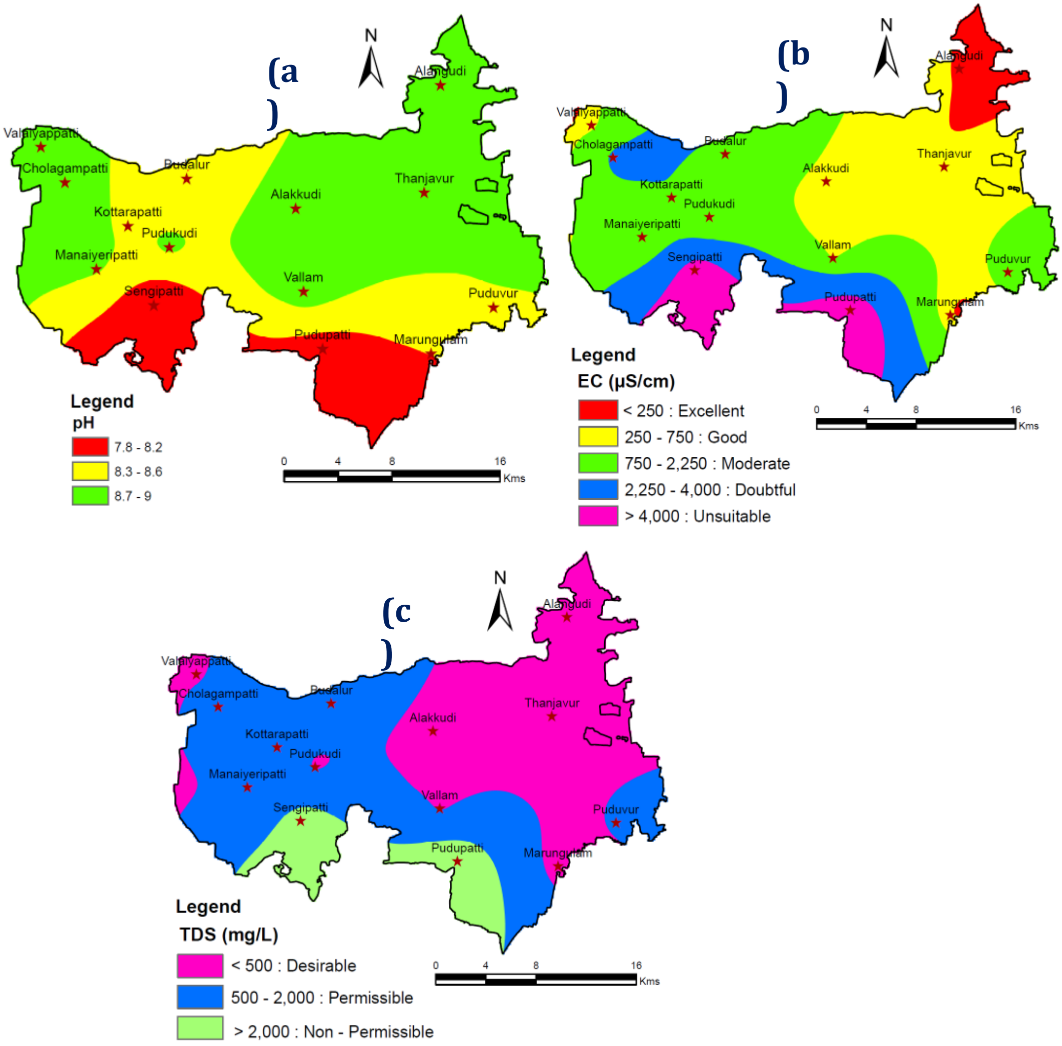

Figure 3. Spatial distribution map of pH (a), EC (b), and TDS(c) in Thanjavur Taluk

A TDS value is essential to classify the groundwater and to check its suitability for various uses [61, 62]. Figure 3c. shows the spatial distribution map of TDS in the study area. In the study area, the TDS values range between 118 - 2,817 mg/l. The TDS values of 12 groundwater samples fall within the permissible limit of 2,000 mg/l (Table 1). However, TDS values in Sengipati and Pudupatti area falls within the non-permissible water class (>2,000 mg/l). A higher value of TDS has resulted from salts in the thick soil and the weathered rock. Further, the longer residence time of groundwater in contact with the aquifer resulted in high TDS concentration in groundwater. As the host rocks belong to alluvial sand, there can be some oxidation and reduction processes in groundwater and surface water, thereby to cause enrichment in the total dissolved solids.

4.1.2 Chemical parameters (Cations and Anions)

Major Cations

In the study area, calcium concentration ranges between 14 mg/L to 240 mg/L with an average of 59.3 mg/L. Calcium concentration was found to be more in groundwater samples of the study area, and it is released from sedimentary sandstone. The spatial distribution map of the study area shows that Budalur, Sengipati, and Pudupatti fall in poor groundwater quality zone, and other parts of the area falls in good and moderate groundwater quality zones (Figure 4a). Mg concentration in the groundwater samples of the study area ranges between 9.7 to 272.2 mg/L with an average of 69 mg/L. If the magnesium concentration in groundwater is less than 30 mg /L, it falls within a safer zone for drinking. It is extended to 100 mg / L as per BIS standards (2012) [56]. Magnesium concentration in groundwater was found to occur above 30 mg/L in the NW, SW & south of the study area (Figure 4b). The Source of Mg is generally from SiO_4 and feldspathic rocks [63]. Magnesium and calcium are the two parameters primarily responsible for the hardness of the water. The concentration of Sodium in groundwater samples of the study area ranges from 2 to 587 mg/L, with an average of 147.4 mg/L. Sodium concentration is higher in pre-monsoon. Therefore, weathering of sodic plagioclase feldspar results in a high concentration of sodium in groundwater [64]. In addition, human activities can also result in high concentrations of sodium in the groundwater [63]. Spatially NW and the southern part of the study area have a poor groundwater quality zone (Figure 4c). Potassium in groundwater is generally lesser due to its lesser mobility. Due to weathering of Mica and Orthoclase Feldspars (sedimentary rock), it was observed that. Potassium in groundwater samples of the study area ranges between 1 to 55 mg/L with an average of 20 mg/L. According to WHO'S standard, Potassium < 50 mg/L is classified as a good zone and suitable for drinking, from 50-100 mg/ L is classified as a moderate zone and also suitable for drinking, and 100 mg/ L is the standard fixed for domestic consumption. The potassium concentration above 200 mg / L is classified as poor groundwater quality zones. As per WHO (2011) [55], the allowable limit for Potassium is 32 mg/l (Table 1). All groundwater samples in the study area are within the desirable limits for drinking (Figure 4d).

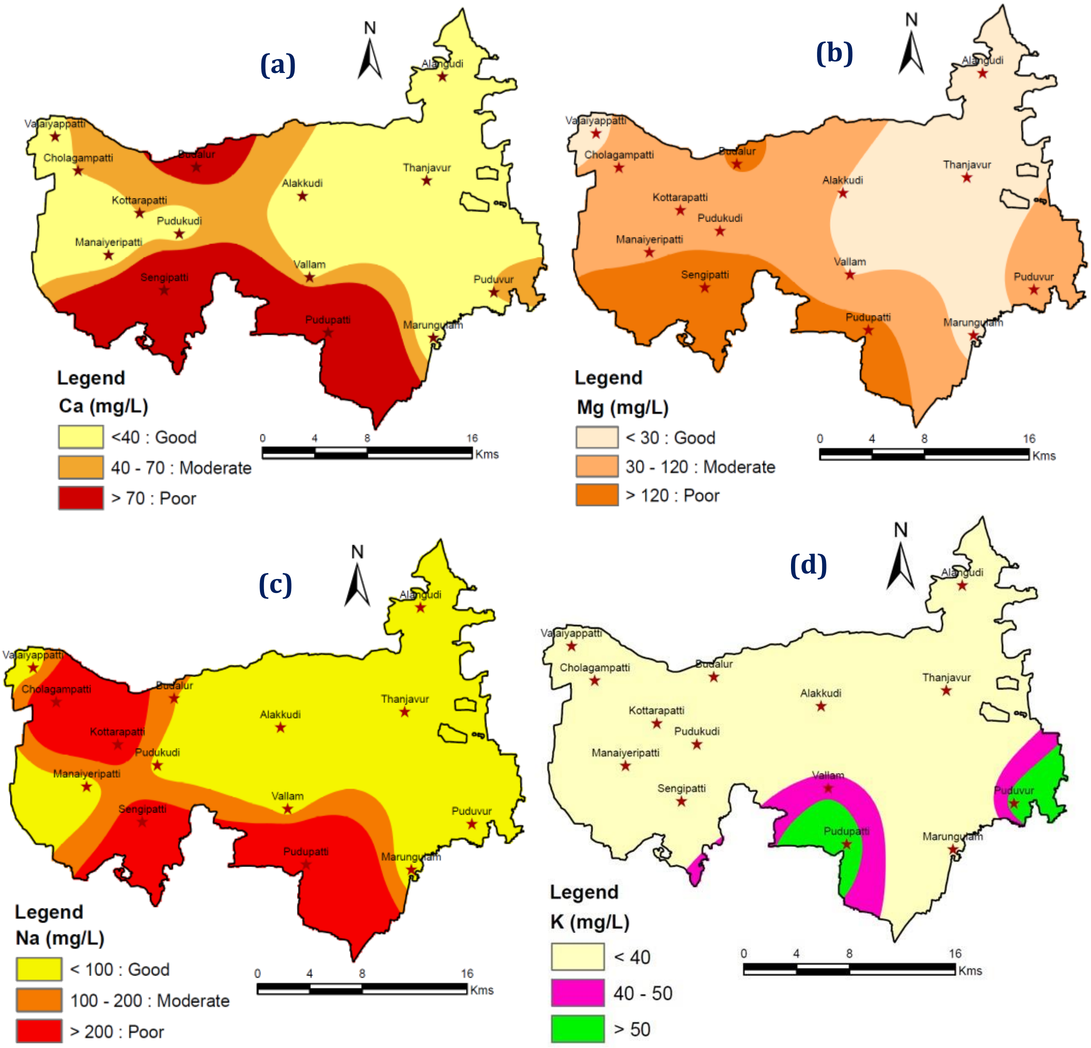

Figure 4 Spatial distribution of Ca^{2+} (a), Mg^{2+} (b), Na^{+} (c), and K^{+} (d)

Major Anions

The silicate and carbonate weathering the process resulted in a high concentration of HCO_3^- in groundwater. The effluents of chemical industries have also resulted in a high concentration of HCO_3^- in groundwater [4]. According to WHO'S standard (2011), HCO_3^- concentration <100 mg/L is categorized under a good zone that is suitable only for industrial activity. About 85% of the study area falls within good and moderate based on HCO_3^- concentration in the groundwater of the study area. However, a few parts of the study area which is found in the eastern part, have HCO_3^- concentration > 250 mg/L and fall within a poor zone (Figure 5a). Leaching from industrial and domestic activities and dry climates has resulted in high Cl^- concentration in groundwater [64]. The Cl^- concentration in groundwater of the study area, exceeds the maximum allowable limit of 200 mg/l (Table.1). The spatial distribution of chloride concentration in the groundwater of the study area is shown in Figure 5b. The spatially northwestern and southern part of the study area has a poor groundwater quality zone based on the Cl^- concentration.

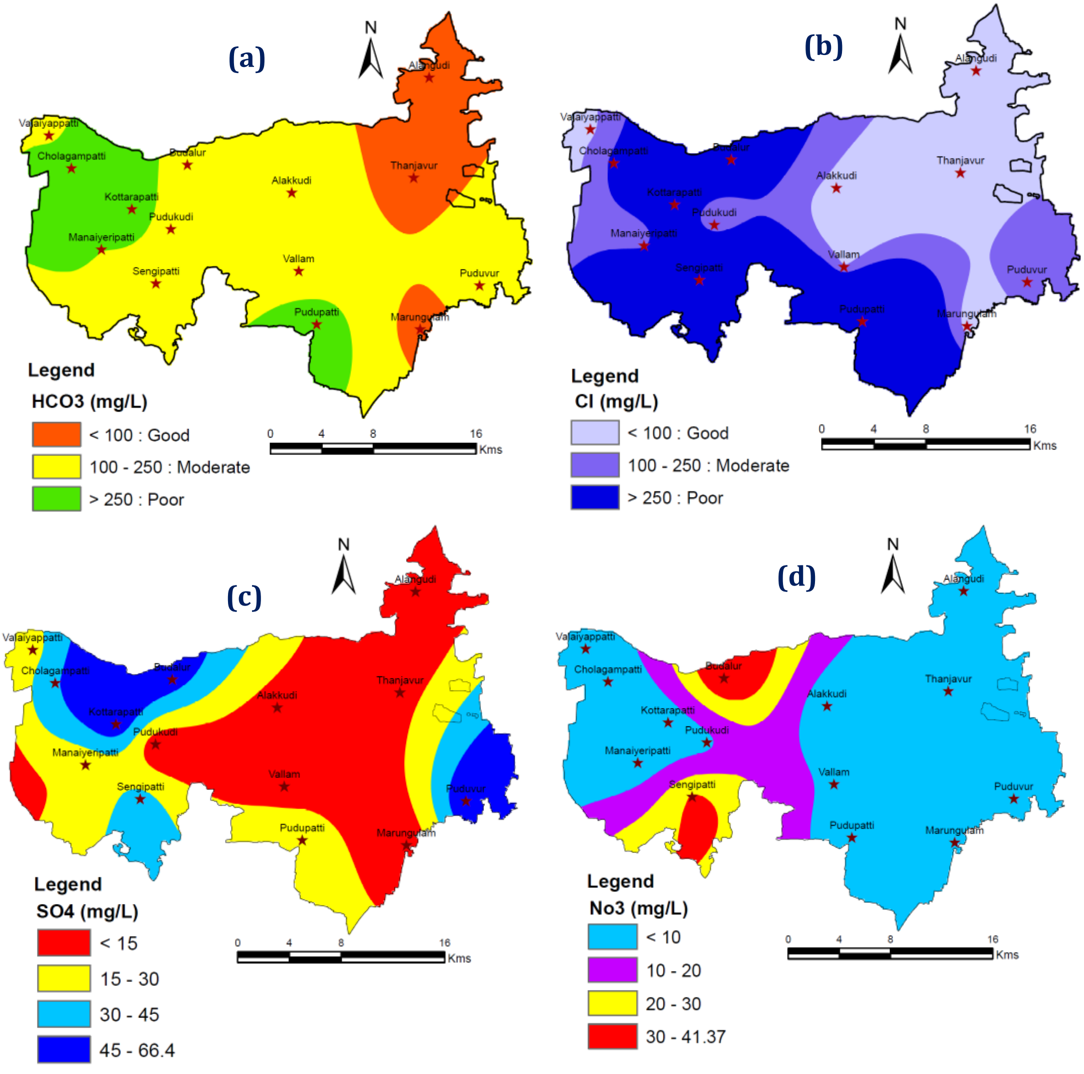

Figure 5 Spatial distribution of HCO_3^- (a), Cl^- (b), SO_4^{2-} (c), and NO_3^- (d)

BIS (1991) [56] and WHO, 2008 [65] recommended the highest desirable and maximum permissible limits of sulphate; nitrates are 200 - 400 mg/L; 45 - 50 mg/L, respectively (Table.1). SO_4^{2-} and NO_3^- in the groundwater samples of the study area are found to be within the prescribed limit for drinking purposes. The spatial distribution of groundwater at high concentrations of SO_4^{2-} was observed in the northwest and southeastern areas (Figure 5c), and concentrations of NO_3^- were found in the north and southwestern parts of the study area (Figure 5d). The concentration of nitrogen in groundwater is derived from the biosphere [60]. Nitrogen is fixed initially from the atmosphere and then mineralized by soil bacteria into ammonium [66]. Fluoride concentration in groundwater is within the desirable limit of WHO standards of 1.5 mg/L in the study area.

4.2 Hydrogeochemical Facies

Hill Piper plot [67] was used to infer hydrogeochemical facies of groundwater in the study area. Figure 6. shows the piper plot for the groundwater samples in the study area. From the plot, an alkali (Na and K) exceeds alkaline earth (Ca and Mg), and a strong acid (Cl and SO4) exceeds weak acid (HCO_3). Mixed Ca-Mg-Cl was the dominant water types are in the followed by Na- Cl > Ca-Cl> mixed Ca-Na- HCO3 > Ca-HCO3.

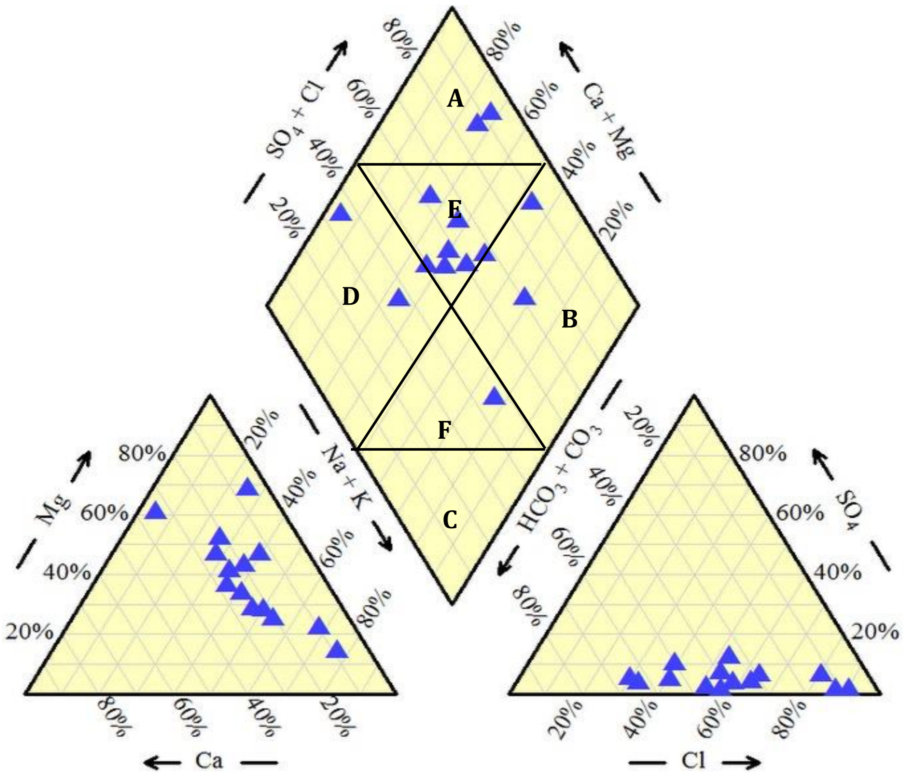

Figure 6. Hill piper plot for the groundwater in the study area

Mixed water types Ca-Na-HCO_3 and Ca-HCO_3 demonstrate mineral dissolution and freshwater recharge. Water types (Ca-Mg-Cl and Na-Cl) indicate mixing water with existing water after ion exchange reactions with high salinity water from soil contamination sources such as irrigation return flows, household wastewater, and septic tank effluents [48]. Calcium-sodium bicarbonate water is more likely to be derived from the recharging of rainfall that carried saline water mixing along with recent recharge water. The Ca–Mg–HCO_3 type combination present in the study area to a certain extent in the study area is due to irrigation return flow and anthropogenic activities [68].

4.3 Suitability for drinking uses

4.3.1 Estimation and Mapping of Water Quality Index (WQI)

The minimum and maximum values of calculated WQIs are 26 and 236, respectively. Samples reveal an excellent water quality of 42.9%, good water of 28.6 %, Poor and very poor water 14.3%, respectively (Table. 2). Figure 7 shows the spatial distribution of WQI in the study area. The spatial distribution of WQI shows larger parts of the study area fall within excellent and good quality groundwater (Figure 7). However, Cholagampatti, Budalur, Sengipati, and Pudupatti regions fall within poor and very poor water types. The major sources of contamination are rock water interaction, weathering of rocks, and anthropogenic activities such as disposal of domestic and industrial waste and excess utilization of fertilizer for agricultural activities in the study area. In general, the groundwater of the study area was found to be of good quality for drinking purposes. The higher WQI value indicates deteriorated water quality. The WQI is a very useful and efficient tool to summarize and report on the monitoring data to the decision-makers in order to be able to understand the status of the groundwater quality and to have the opportunity for better use in the future as well. This study demonstrates that the use of GIS and WQI methods could provide useful information for water quality assessment.

Table.2. Water Quality Index and the status of groundwater in the study area

Range	Type of water	Percentage of the samples
< 50	Excellent water	42.85
50 - 100	Good water	28.57
100-200	Poor water	14.28
200-300	Very poor water	14.28
> 300	Unsuitable	0

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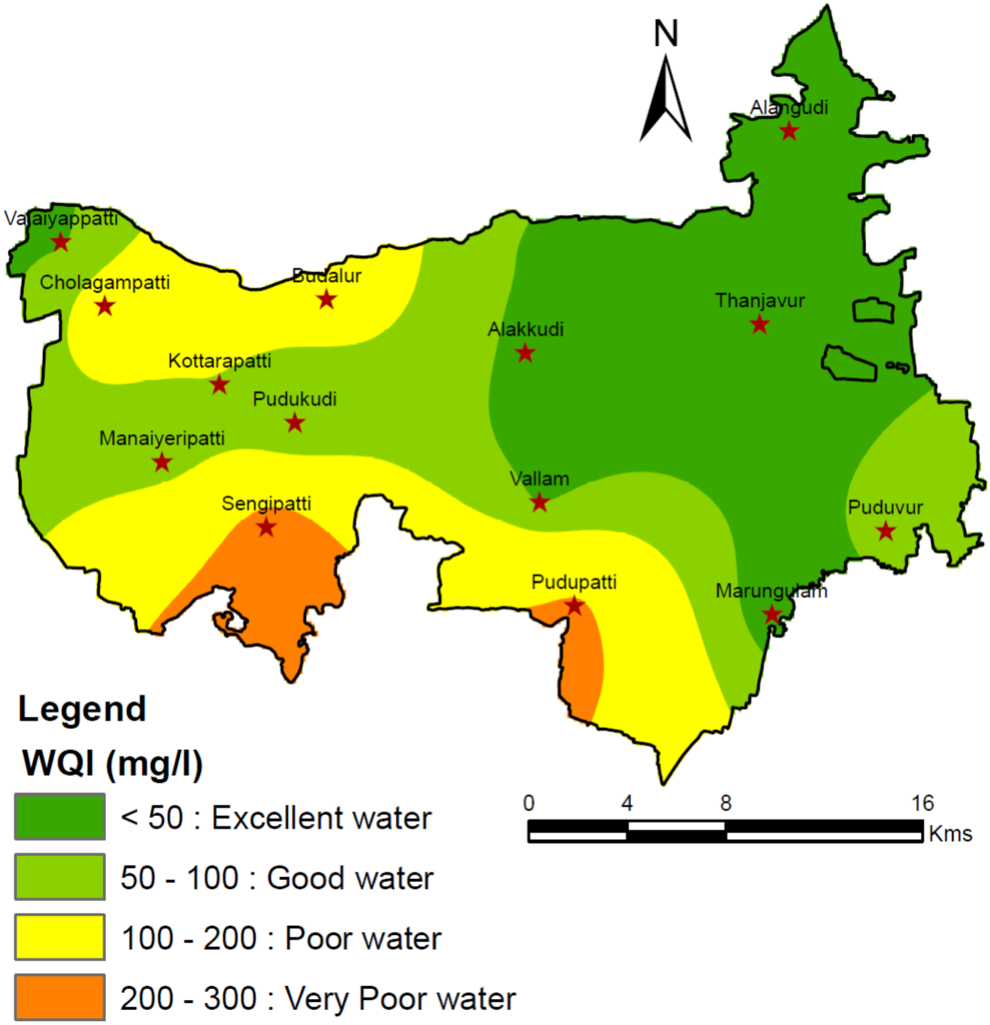


Figure 7 Spatial distribution of WQI in the study area

4.4 Suitability for Irrigation Purposes

Water quality, soil types, and cropping practices play an important role in a suitable irrigation practice because excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, reducing productivity. The physical effects of these ions are to lower the osmotic pressure in the plant structural cells, thus preventing water from reaching the branches and leaves, while the chemical effects disrupt plant metabolism. The groundwater samples are categorized according to their irrigation usage (Table 3). A soil property loses its life when the dissolved ions are in excess, affecting the soil's fertility. Infertility of the soil affects the growth of plants or crops. The excess amount of salt content in water modifies the osmotic pressure in the root zone. As a consequence of the limited absorption of water, the growth of plants or crops gets terminated [69, 70]. When Salt concentration is high in the soil, it limits the growth of plants or crops due to the change in its metabolic processes [71].

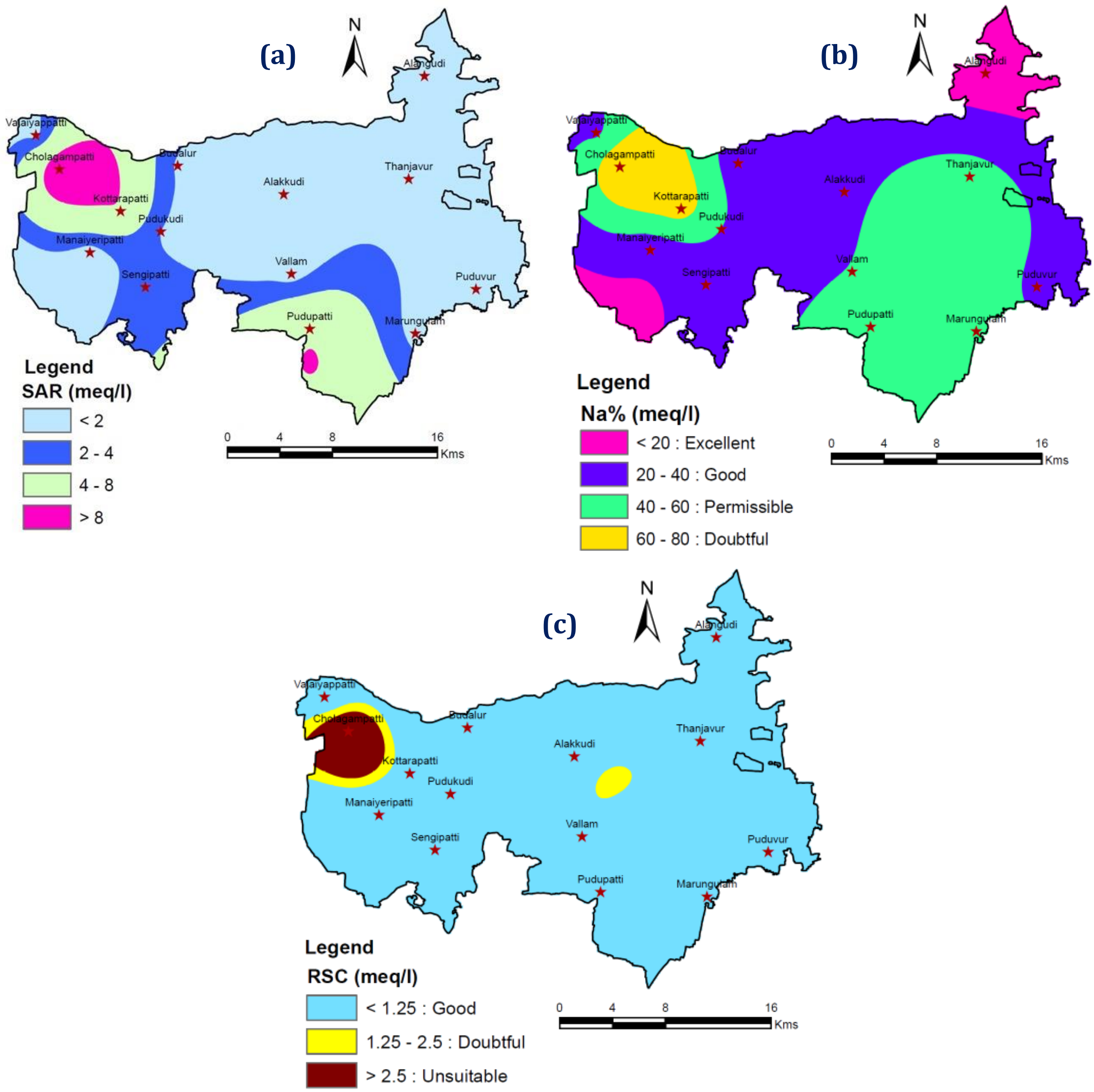


Figure 8 spatial distributions of SAR (a), Na% (b), and RSC (c)

Table 3 Classification of groundwater quality samples of the study area for irrigation purposes

Parameters (meq/l)	Sample range				Range	Classification	No. of samples
	Min	Max	Average	STD			
Alkalinity hazard (SAR) [73]	0.08	10.5	3	3.13	< 10	Excellent	13
					10 – 18	Good	1
					18 – 26	Doubtful	0
					> 26	Unsuitable	0
Na% [78]	4.87	76.86	40.76	18.21	< 20	Excellent	1
					20 – 40	Good	7
					40 – 60	Permissible	4
					60 – 80	Doubtful	2
					> 80	Unsuitable	0
RSC [77]	- 30.76	5	-5.16	9.24	< 1.25	Good	13
					1.25 - 2.5	Doubtful	0
					> 2.5	Unsuitable	1

Sodium Adsorption Ratio (SAR)

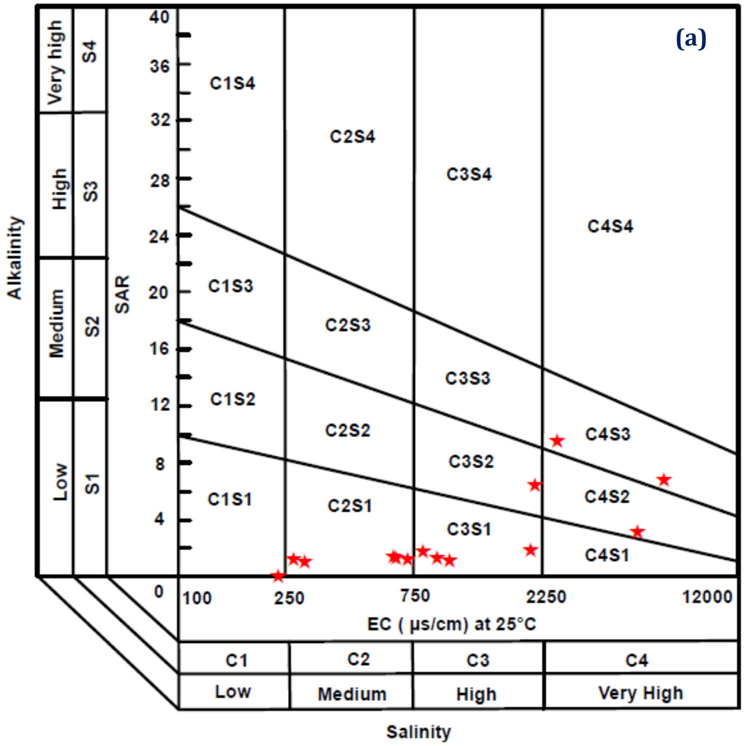
The spatial distribution of the SAR values of the study area is shown in Figure 8a. SAR is used to measure alkali/sodium levels to evaluate deleterious crop levels. According to Kumar et al. (2007) [72], the high concentration of Ca and Mg in irrigation water reduces soil permeability. The calculated value of SAR in this area ranges from 0.08 to 10.5 and has been classified as suitable for irrigation. Based on the Richards [73] classification, most groundwater samples have excellent to good (Table 3) water class, indicating that the samples are suitable for irrigation purposes. When SAR values are greater than 9, irrigation water will cause permeability problems on shrinking and swelling in clayey soils [60]. For irrigation waters, SAR is plotted against EC [74]. The plot shows that 36 % of the samples fall into the C2-S1 category with medium salinity and low sodium content, and 7 % of the samples fall into the C1-S1 category with low salinity and low sodium. Hence, it is suitable for irrigation on purpose (Figure 8a). About 29 % of groundwater samples fall into C3-S1, which indicates a high salinity of water with high sodium content, and 7 % of groundwater samples fall into C3-S2, which indicates a high salinity of water with a medium sodium content. Hence, it moderately fits for irrigation. Moreover, 14 % of groundwater samples fall into the C4-S3 category, which has very high salinity and high sodium, and 7 % of groundwater samples fall into the very high salinity and medium sodium category of C4-S2. Hence, it is unfit for irrigation. The groundwater samples of Cholagampatti, Pudupatti, and Sengipatti are not suitable for irrigation purposes (Figure 8a). The USSL diagram shows that 79 % of groundwater samples fall in good to moderate areas, with the exception of three samples that are not suitable for irrigation purposes. It is, therefore, suitable for irrigated salt-tolerant and semi-tolerant crops under favourable drainage conditions.

Sodium Percentage (Na %)

The suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. When sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg and Ca ions, thus reducing soil permeability and eventually resulting in soil with poor internal drainage. Thus, air and water circulation is restricted during wet conditions, and such soils usually become hard when dry [60]. Na % is also used to evaluate the suitability of groundwater for irrigation [75]. The excess water content of Na^+ reduces the permeability of the soil and limits the circulation of air and water in winter. It's getting tough and dry during the summer [60]. It is widely agreed that the high percentage of sodium in irrigation water degrades the soil conditions. In the study area, Na% for groundwater in the PRM seasons varies in the range of 4.9 -76.9, respectively (Table. 3). Na% indicates that around 75% of samples fall in the field of excellent to the permissible limit. It was revealed from the analysis that the groundwater of doubtful quality (Cholagampatti and Kottarapatti) was found in less than 25% of the area (Figure 8b). The Wilcox diagram clearly shows Na% against EC of groundwater to evaluate its suitability for irrigation purposes (Fig. 9b). It shows that 43 percent of groundwater samples fall into the field of excellent to good, 29 percent of samples fall into the category of good to permissible, each category in 7 percent of samples is permissible to doubtful, doubtful to unsuitable and 14 percent of samples are not suitable (Figure 9b). The Wilcox diagram shows that the majority of the groundwater samples fall into the category of excellent to good, and it perfectly fits for irrigation. The Wilcox diagram shows that 75 % of groundwater samples fall in excellent to permissible areas, except for two samples (Cholagampatti and Kottarapatti) that are not suitable for irrigation purposes. Irrigation water with high Na% may cause sodium accumulation and calcium deficiency in the soil leading to a breakdown of its physical properties. Therefore, good drainage, high leaching, and use of organic matter are required for its management in the study area a moderate the soil to increase the crustal conductive property of the soil.

Residual sodium carbonate (RSC)

The excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the suitability of groundwater for irrigation. If the waters have high concentrations of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated.



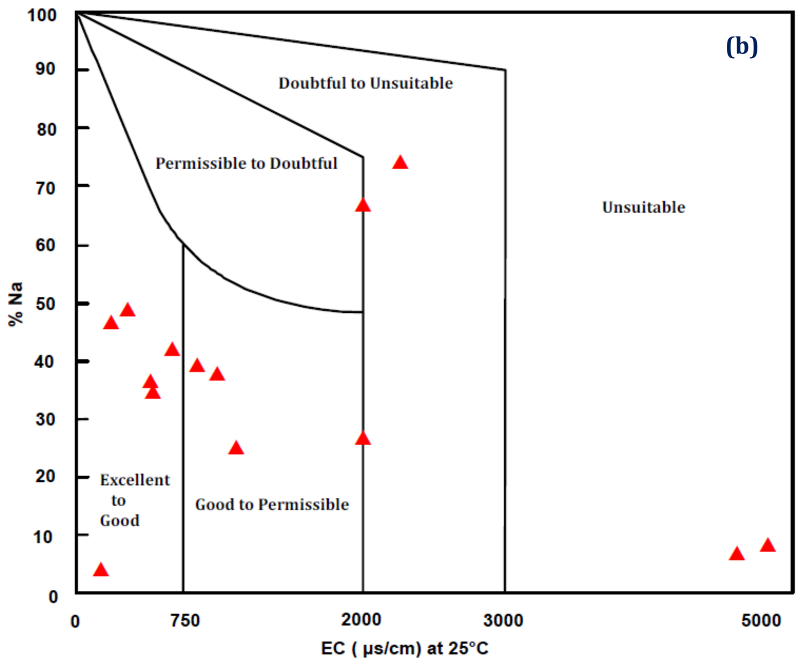


Figure 9. USSL (a) and Wilcox (b) diagram for classifying groundwater for irrigation

An excess quantity of sodium bicarbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes the dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. Hence, the relative proportion of sodium in the water is increased in the form of sodium carbonate, denoted as residual sodium carbonate (RSC) [76, 77]. According to the US Department of Agriculture, water with more than 2.50 epm of RSC is unsuitable for irrigation. RSC ranges from -30.76 to 5 meq/l with an average of -5.16 meq/l. Based on RSC values, most of the samples were considered good (Table 3, Figure 8c) for irrigation purposes (RSC < 1.25 epm). In Spatial distribution of RSC during PRM indicate that 95% of the samples fall in good quality, and the remaining 5% of samples fall in the category of Doubtful to unsuitable quality (Figure 8c), especially in the northwestern part of the study area in and around Cholagampatti, due to the occurrence of carbonate residue in the soil. Based on the RSC value of groundwater samples of the study is within the permissible limit (Table 3). Hence, the groundwater of the study area is excellent for irrigation purposes.

5. Conclusion

Groundwater is a major environmental parameter, and its quality degradation is an issue of significant societal and environmental concern. The aim of this study was to map and evaluate the groundwater quality in Thanjavur taluk. The spatial distribution of groundwater quality parameters was carried out through WQI, GIS, and geospatial techniques. These techniques have illustrated their ability to map the quality of groundwater in the study area. Further, these maps will also help people manage and plan the quality of groundwater. Some of the findings of our research study were summarized as follows:

- The observed pH range of groundwater samples indicates mostly alkaline in nature. The study area's EC and TDS values in Sengipati and Pudupatti represent the non-permissible water class.
- The concentration of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, and Cl^{-}, is high in the northwestern and southern part of Cholagampatti, Budalur, Sengipati and Pudupatti regions poor and very poor water.
- The Piper Trilinear diagram indicates that most groundwater samples fall in Mixed Ca-Mg-Cl, Na-Cl, and Ca-Cl, Ca–Na–HCO3, Ca-HCO_3 types.
- Higher SAR, RSC, and Na%, refer to 75% of samples are suitable for irrigation purposes due to the long residence time of water, dissolution of minerals from lithological composition, and the addition of chemical fertilizers by the irrigation waters. The irrigation indices analysis revealed that the groundwater not suitable for irrigation (the northwestern part of the area around Cholagampatti) was found to be less than 25% of the area.

- The overall view of the WQI of the present study zone shows a higher WQI value, indicating the deteriorated water quality. But, the east and northeastern regions (42.9 %) had a satisfactory result with excellent quality groundwater and a WQI below 50. This study demonstrates that the use of GIS and WQI methods could provide useful information for water quality assessment.

Water quality in the study area is slowly reaching an alarming stage so proper planning is essential in this venture to preserve the fragile ecosystem. Farmers should control anthropogenic activities, and the government should carry over the resources of water to break the pollution. It is recommended that a broad spectrum of groundwater quality parameters (major and trace elements) be promoted to avoid human health issues and ensure socio-economic development in the area.

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