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SPATIAL ASSESSMENT OF GROUNDWATER QUALITY USING GIS TECHNIQUES IN TIRUVARUR TALUK, TIRUVARUR DISTRICT, SOUTHERN INDIA

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ABSTRACT

In Thiruvarur Taluk, Thiruvarur District, Tamil Nadu, India, this study assessed groundwater quality for drinking and irrigation. The geological and hydrogeological aspects of water samples were measured. Geographically, the study region located between North latitude is 10°48'54" N and 10°43'20", with East longitude between 79°40'45" and 77°33'24", respectively. The taluk's total area is 315.08 km². Overall, 40 groundwater samples were taken from bore wells, and various physicochemical parameters and major ion chemistry like pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, andNO_3^{-}were analysed. According to the groundwater quality, Piper, United States Salinity Laboratory and Wilcox's diagrams were plotted; and groundwater quality has been illustrated for domestic and agricultural purposes. The piper plot shows the scattering of the examples in different areas without clustering. So, the area comprises groundwater differing in quality in different areas. An Overview of the chemical relationships of groundwater with the help of a tri-linear diagram reveals that 82.5 % (of the samples are Alkalies exceed alkaline earth and Strong acids that exceed Weak acids.A sodium absorption ratio of 77.5%and a sodium percentage of 45% recommend that most of the sample falls under the acceptable border of irrigation and drinking utility.Doneen's diagrams show that 10 % of the samples are 100% percolation to the ground, and 65 % of the samples are 75% percolation to the ground.Using geospatial analysis, the water-quality index was calculated. In this study, the WQI ranges from 11.98 to 228.04, with 66.92 being the mean value. Based on the results, 80 % of samples fall into excellent to good classes, while 15 % and 2.5 % fall into poor to very poor categories, respectively. Based on the studies, groundwater quality is safe for drinking purposes, but in a limited sample, which exceeds the limit, due to anthropogenic activities.

INTRODUCTION

The world's most significant water source for domestic, industry, and agricultural use is groundwater, and determining its water quality is important for socioeconomic development (Stanly *et al*., 2022; Balamurugan *et al*., 2020; Prabhu and Sivakumar, 2018). Due to pollution and the rising cost of surface water treatment, many communities in developing countries rely heavily on groundwater (Gupta and Nath, 2020; Das, 2017). The quality of groundwater is influenced by factors such as the atmosphere, soils, water-rock reactions as well as pollutants from mining, agriculture, precipitation, and domestic and industrial wastes (Sakthivel and Manjula, 2021; Gopinath *et al*., 2019; Umarani *et al*., 2019; Samson and Elangovan, 2017; Subramani *et al*., 2010). For agricultural and industrial purposes, it is imperative to ensure groundwater quality for drinking, agriculture, and industrial purposes (WHO 2011). 80% of all diseases occur in developing countries due to poor sanitary conditions and drinking water. Water composition can affect crop yields by condensing salts in soils or water (Balathandayutham *et al*., 2015). Groundwater quality status for agricultural purposes is greatly influenced by the salt concentration in the aquifer, which can be evaluated by assessing environmental factors and indices. We are studying how groundwater quality changes are the purpose of the present study. Electrical conductivity is employed to determine dissolved solids (TDS) in groundwater to determine salinity. In the research region, the following factors, including residual sodium carbonate (RSC), sodium percentage (Na%), sodium adsorption ratio (SAR), and water quality index, were calculated to estimate the quality of the groundwater utilised for irrigation and drinking reasons (WQI).

MATERIALS AND METHODS

Location and Geology

Thiruvarur Taluk is situated northwest of the Thiruvarur District, Tamilnadu. Located between the North latitude is 10°48'54" N and

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10°43'20", with the East longitude between 79°40'45" and 77°33'24", respectively. Parallel and sub-parallel drainage patterns are found in the area. Located in the Cauvery basin, the research region is of significance. Vettar and Bamini rivers flow into the Cauvery as tributaries. The taluk's total area is 315.08 km² (Fig.1). The area falls under the toposheets 58 N/09, 58 N/10, 58 N/13, and 58 N/14 of the Survey of India. More than 89 % of the district's irrigation water comes from surface water canals, while drilled wells and tube wells account for 11 % of the total area irrigated.The area delta with a gentle slope towards the Bay of Bengal. The fluvial deposits comprise the flood plain, flood basin, point bar, channel bar, and palaeo channels with mixed sand, silt, clay, and gravel. Sandy silt and clay along the river banks and flood basins are suitable for manufacturing bricks.

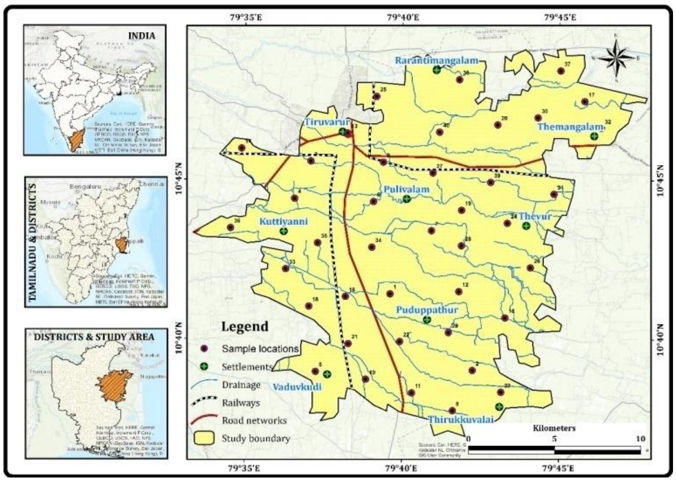

Fig.1 Water sample location map of the study area

Sampling analysis

A total of (n=40) groundwater samples were obtained in and around the study area(Fig.1). The accuracy and reliability of findings are assured by analysing and preserving all samples according to the methods (APHA 1995). Polythene bottles of one litre (1000 ml) were collected and washed with distilled water before use. The materials were filtered through a 0.45 lm filter paper during the analysis. The samples were then refrigerated at a temperature below 4°C. Field measurements were performed using pH and EC meters. The physical and chemical qualities were analysed pH, EC, TDS, main cations, and anions were determined in groundwater samples (Kalaivanan *et al*., 2018; Hem, 1991). Conductivity analysers and pH meters measure EC and TDS. Conductivity analysers and pH meters measure EC and TDS. Determine calcium (Ca^{2+}) and magnesium (Mg^{2+}) in solution; a trimetric technique using EDTA as a standard is used. The bicarbonate (HCO_3^-) and Chloride (Cl^-) content was determined using acid titration in conjunction with a standard solution of Silver Nitrate ($AgNO_3$) and HCL for titration. Flaming photometers measured sodium (Na^+) and potassium (K^+) concentrations. In addition, $SO_4^-$and NO_3^- spectrophotometer analyses were performed. Calibrating criteria were employed to ensure that all the equipment and instruments worked adequately. The sample coordinates were obtained using a Garmin GPS and imported into ArcGIS for base map creation. Eq. (1) was used to compute the accuracy of each sample using the charge balance error percentage (% CBE).

$$\% CBE = \frac{\Sigma\ cation - \Sigma\ anion}{\Sigma\ cation + \Sigma\ anion} \times 100 \qquad \text{Eq.1}$$

A % CBE of less than or equal to 5% is acceptable. The findings of this research may be regarded as accurate since the most significant relative error was 1.67 %, which is within the permissible error range (Sunitha *et al*., 2022).

Water Quality Index (WQI)

The general appropriateness of groundwater for drinking reasons was determined for each sample using a rating and index approach known as the water quality index (WQI). WQI, according to Kalaivanan *et al*. (2018), represents the combined effect of several water quality indices on the groundwater sources for most domestic uses. The calculation of WQI necessitates using acceptable influential parameters specified by the function in which groundwater is required.

Various factors (cations and anions as well as heavy metals) that influence human health were used to determine the drinking quality of groundwater. The following parameters were chosen in this work to estimate the WQI: pH, EC, Ca, Mg, Na, K, Cl, SO4, NO3, and F. Due totheir importance to human health, nitrate (NO3) and fluoride (F) were given the greatest weights of the five (5). Using the relationships in equations (2), (3), (4), and (5), the water quality index (WQI) is calculated for each groundwater source (borehole), and the findings are then compared to the standards established by Sahu and Sikdar (2008);

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \text{(Eq.2)}$$

Wi refers for relative weight or the weight given to a parameter that significantly influences how well water is used for human health purposes. Sahu and Sikdar (2008) state that the water quality rating (qi) is provided by;

$$q_i = \frac{c_i}{s_i} \times 100 \qquad \text{(Eq.3)}$$

Where Ci and Si are the measured concentration in the groundwater samples, and the corresponding standards for the ith important parameter, respectively, and qi is the water quality rating. (WHO, 2008) Each important parameter's (SIi) estimated water quality sub-index was as follows:

$$SI_i = q_i \times W_i \qquad \text{(Eq.4)}$$

$$WQI = \sum_{i=1}^{n} SI_i \qquad \text{(Eq.5)}$$

For a sampled groundwater, the water quality index is the average of all of the environmental quality sub-indices for the i^{th} important parameter.

RESULT AND DISCUSSION

Spatial analysis of groundwater quality

In Table 1, the WHO (2011) recommends water quality limits for cations and anions based on their maximum, minimum, average, and standard deviation, respectively.

Physical parameters

The study area's pH values varied from 8.90 to 7.40, with an average of 8.54, according to the World Health Organization (WHO 2011). Based on the pH values on the spatial maps, it reveals that the 28 nos. of samples fall under the not permissible (> 8.5). The remaining 12 nos. of samples fall in the most desirable (6.5 to 8.5) category (Fig.2). Groundwater quality is generally acceptable for drinking. Therefore, the pH of the water in the study area is within permissible limits. The EC value is 15680; the general pattern of EC value in Thiruvarur taluk is shown in Figure 3. The result revealed that 18 nos samples show higher EC values than the permissible limit. The TDS value of the samples varies from 10125 to 140 mg/L, with an average is 1190.03 mg/L Table 1.

Table 1 Result of physio-chemical parameters of the study area

Elements	WHO Standard-2011					
	Most desirable	**Maximum allowable**	**Not Permissible**	**Max.**	**Min.**	**Avg.**
pH	6.5 to 8.5	-	<6.5 and >8.5	8.90	7.40	8.54
Electrical Conductivity	<1500 µS/cm	-	>1500µS/cm	5680	140	1760
Total Dissolved Solids	<500 mg/L	500 to 1500 mg/L	>1500mg/L	10125	89	1190.03
Total Hardness	<100 mg/L	100 to 500 mg/L	>500 mg/L	1682	40	300.18
Calcium (Ca^{2+})	<75 mg/L	75 to 200 mg/L	>200 mg/L	215	4	34.88
Magnesium (Mg^{2+})	<50 mg/L	50 to 150 mg/L	>150 mg/L	423.58	4.86	53.25
Sodium (Na^{+})	<200 mg/L	-	>200 mg/L	2306	3	325.55
Potassium (K^{+})	<10 mg/L	-	>10 mg/L	211	0.10	21.08
Nitrate (NO_3^{-})	<45 mg/L	-	>45 mg/L	11	0.10	3.57
Chloride (Cl^{-})	<200 mg/L	200 to 600 mg/L	>600 mg/L	3382	14	418.43
Sulphate (SO_4^{2-})	<400 mg/L	-	>400 mg/L	1168	5	160.40
Fluoride (F^{-})	<1.5 mg/L	-	>1.5 mg/L	1.94	0.05	0.35

Chemical parameters (Cations and Anions)

Major Cations

The calcium values are from 4 to 215 mg/L, and the average is 34.88 mg/L (POM-2016 in the region, which, as per the WHO standards (2011) found to be very high in concentration (>200 mg/L). Spatial distribution maps (Figures 4.11 and 4.12) show that 1 % of the area groundwater quality as per the calcium is not permissible for drinking purposes. Mg^{2+} ranges from 4.86 mg/L to 423.58 mg/L with averages of 53.25 mg/L. A higher concentration (423.58 mg/L) indicates a contribution from silicate minerals, Mg-calcite, dolomite and sulphate (Appelo and Postma, 2005). The sodium rates in groundwater vary from a minimum value of 2 mg/L to 2306 mg/L and a mean of 325.55 mg/L. As per the results, 35% of samples had an extreme level of WHO irrespective of seasons (Fig.4.15 and 4.16). The main source of sodium is due to weathering of feldspar minerals in the study region. The potassium rates in groundwater varyfroma minimum value of 0.10 mg/L to a maximum of 211 mg/L, averaging 21.08 mg/L. the results, 40% of location fall under the recommended limit. Because of sodium concentration, spatial maps were primed for two different seasons by fixing the removed furthest reaches of 10 mg/L.

Major Anions

The water sample analysis revealed that the amount of chloride varies between 14 to 3382 mg/L, and the average is 418.463 mg/L. In Thiruvarur taluk, the chloride concentration in the groundwater is within the permissible limit except for the well's 15 locations, which shows a high concentration above 600 mg/L. The approved value is 400 mg/L of SO_4^{2-} in groundwater from 5 to 1168 mg/L (Table 4.1). Sulfate concentration indicates the additional sources of dissolved sulfate ions from gypsum (Srinivasamoorthy *et al*. 2008). The Nitrate concentration of the Thiruvarur taluk ranges between 0.10 and 11 mg/L, respectively. Hence, the nitrate concentration of the groundwater is within the permissible limit according to WHO standards. The groundwater concentration of fluoride in the study area varied between 0.05 to 1.94 mg/L, by a mean of 0.35 mg/L. The centralisation of fluorides in different seasons, addressed in Figures 4.25 and 4.26, is very less concentration.

Piper

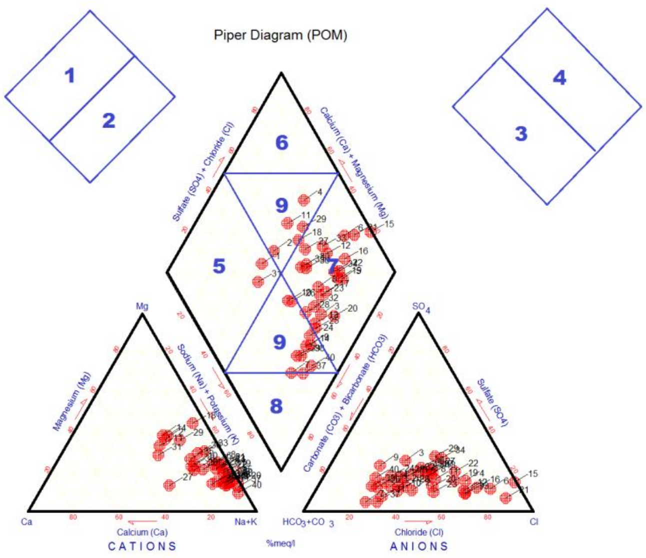

Fig.2 Hydrochemical facies of the study area**.**

The area's groundwater having different compositions, is classified using Piper's tri-linear diagram (Piper 1944). The general quality of the water is addressed in the diamond-formed field by extending the situation of the plots in the triangular field. Minor alkalies are clubbed with the major ions. The important water types revealed by Piper's tri-linear diagram are as follows. The plot (Figures 2) shows the scattering of the examples in different areas without any clustering. So, the area comprises groundwater differing in quality in different areas.

An Overview of the chemical relationships of groundwater with the help of a tri-linear diagram reveals that 82.5 % (POM) of the samples are Alkalies exceed alkaline earth and Strong acids exceed Weak acids. In the study area, 57.5 % are found to be of Sodium Chloride type. It is polluted by external influence (untreated industrial effluent). The remaining groundwater samples are unpolluted by any internal or external influence. 37.5 % of the samples as not affected by the Mixed type (No Cation-Anion exceed 50%), and 5 % by the Magnesium bicarbonate type.

Water quality index

The chemistry of groundwater can be easily used to validate drinking water quality (Subba Rao 2006; Vasanthavigar *et al*. 2010; Kumar *et al*. 2015). The water Quality Index (WQI) was calculated based on the concentrations of TDS, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}, EC, and pH at several sites. In this study, the WQI ranges from 11.98 to 228.04, with 66.92 being the mean value. WQI value ranges from 11.98 to 228.04, with a mean of 66.92. The result shows that 80 % of the sample falls into the excellent to good class, and 15 % and 2.5 % fall under the poor to the very poor category, respectively (Fig.3). From this result, it is confirmed that the quality of groundwater in the study area is suitable for drinking purposes.The process of leaching and dissolving the gypsum-bearing formations and rock salts may contribute to this result. This study shows that EC, chloride, sodium, and calcium absorption are the most significant factors affecting the water quality in the study area.

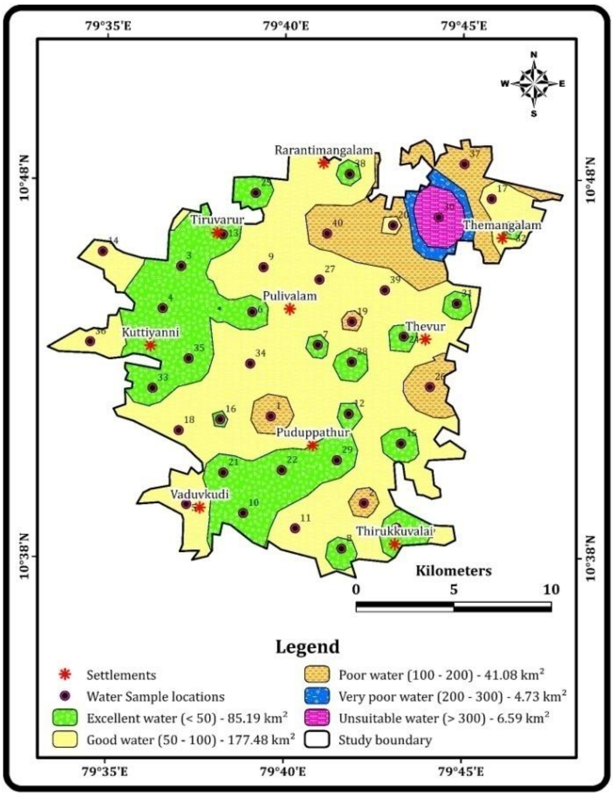

Fig.3 Spatial distribution map of WQI

Groundwater quality assessment for irrigation purposes

Water shortages are becoming an increasing problem in India, particularly in the arid and semi-arid portions of the country, due to the scarcity of surface water, the erratic nature of the monsoon, and the growing population. More than a quarter of the world's groundwater is used by India, which is the world's greatest consumer (230 cubic kilometres per year) (World Bank 2012). Groundwater supplies 53% of the overall irrigation demand and 50% of the total irrigated area (FAO 2006; Central Water Commission 2006). Groundwater supplies around 60% of the water used to irrigate crops (Shah *et al*. 2000). The low power price, incentives such as credit for irrigation, equipment, and subsidies for electric supplies, have resulted in overexploitation in certain sections of the country, which has led to a decline in groundwater levels.In water system settings, overuse of groundwater lowers the water table (Rao *et al*., 2021). At a lower water table, there may be land subsidence and groundwater quality corruption (Dashand Kalamdhad, 2021). Many scientists have observed groundwater-constrained places (Tilman *et al*., 2002; Sinha *et al*., 2018; Arumaiselvi&Tharini, 2019), whereas unmaintained performances risk local nutrient production (Kumariand Rai, 2020). Sodium Absorption Ratio (SAR), Wilcox diagram, US Salinity Laboratory (USSL) diagram, Kelly ratio, permeability index, percentage of sodium, and magnesium dangers are used to analyse groundwater quality (Chitsazan *et al*. 2019, Adimalla *et al*. 2019c, Adimalla *et al*. 2019b). According to FAO (2006), limits such as Na %, RSC and SAR are evaluated for agricultural purposes.

Sodium Percentage (Na^{+}%)

The amount of sodium in water is given as a ratio, also known as the soluble sodium percentage (Na %). Because sodium reacts with soil to diminish its permeability and support little or no plant development, determining whether or not groundwater is suitable for irrigation depends on the presence of sodium in the soil. The sodium percentage is calculated based on the proportional amount of cations in the water (Wilcox 1948). Sodium content is usually expressed in terms of percentage sodium calculated by:

$$Na^{+}\% = \left(\frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \right) \times 100 \quad (1)$$

The percentage of Na^{+} of the groundwater in the examination regions increased from 30.01 to 92.19 meq L^{-1}.The chemical quality of water samples was studied from the percentage of sodium vis-a-vis specific conductance on the Wilcox diagram (Fig.4). Out of 40 samples, 17.5 % of the sample belongs to excellent to good, and 17.5 % of samples fall into good to permissible type. Most of the samples fall in the Permissible to Doubtful category. Figures 4 show that the groundwater near the upstream is good for irrigation, and the contaminations are high near the downstream. Its may be due to the effluents from the industries and the domestic sewages directed into the river.

Sodium Adsorption Ratio (SAR)

The water used for irrigation includes high Na^{+} ions and low Ca^{2+} and Mg^{2+} ions when it passes through cation exchange sites, becoming saturated with Na^{+} ions that degrade the soil structure by dispersing clay particles (Todd 1980). Itdiminishes plant growth and osmotic activity (Subramani *et al*. 2005). The sodium adsorption ratio estimates the increase in sodium owing to cation exchange with calcium and magnesium (SAR). SAR is the ratio of sodium concentration to the square root of the average calcium plus magnesium concentration in irrigation water or soil solution. The U.S.Salinity Laboratory (1954) defined the sodium-adsorption ratio (SAR) of water as where ion concentrations (in parentheses) are indicated in milli equivalents per litre.

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \quad (2)$$

The SAR value of the groundwater in the investigation regions is from 0.67 to 33.08 meq L^{-1}. The higher concentration of SAR in groundwater, the greater the risk of Na^{+}, which leads to the development of an alkaline (Todd 1980). In the plots of groundwater chemistry of Thiruvarur Taluk U.S. Salinity Laboratory diagram (USSL 1954), 17.5% of samples fall in the C2-S1 class is excellent for irrigation, 22.5% samples fall in the C3-S1 class, and 35% samples in C3-S2 class are indicating medium and high salinity respectively and low alkalinity (Fig.5). Agricultural fields with frequent cation exchange can suffer adverse effects from representing such water in the study area, and gypsum can overcome this (Karanth, 1987).

Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate was calculated by Richards (1954). Bi-carbonate and carbonate ions are reacted as calcium and magnesium ions.

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

The RSC value of the groundwater in the examination regions is from -38.16 to 17.20 meq $L^{-1,}$ respectively. According to Eaton's (1950) developed classification, the most extreme of the example falls under the safe (all sample) (<1.25), category in the POM season. The outcome contained qualities for the examination region under 1.25 meq L^{-1}, connoting that the groundwater is of acceptable quality for agricultural purposes.

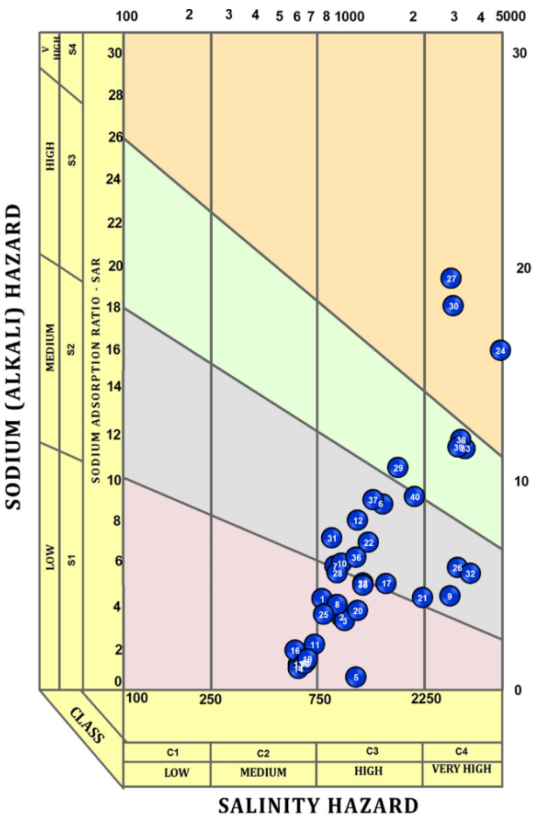

Fig.4 USSL diagram for Irrigation Classes

Wilcox's Diagram

Wilcox diagrams were used to assess the chemical quality of water samples by comparing sodium percentages with specific conductances (Fig.5). Out of 40 samples, 17.5 % belong to excellent to good, and 17.5 % of samples fall intothe good to permissible type. There may be some reason for this since domestic and industrial effluents are directed into the river.

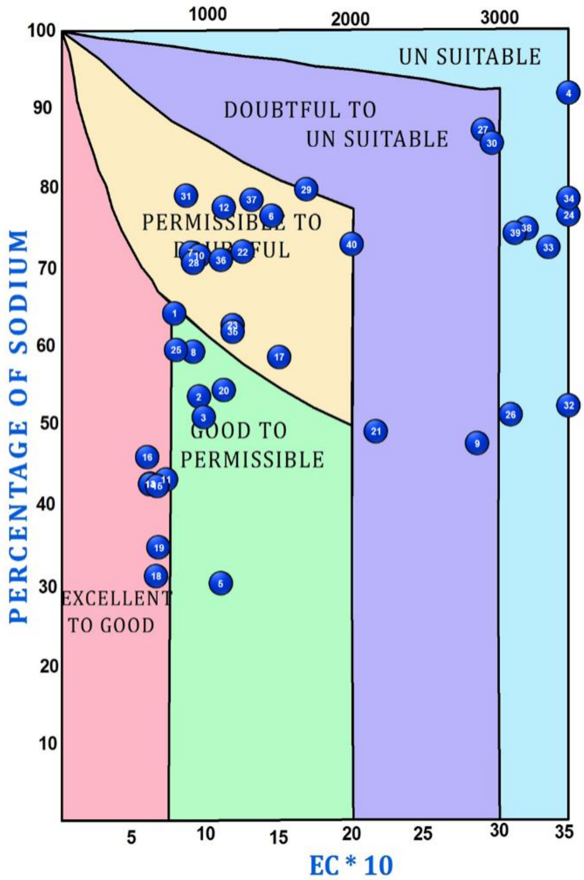

Fig.5 Wilcox's diagram for Irrigation Classes – POM

Doneen's Permeability Index

Long-term irrigation water use affects soil permeability. Calcium, magnesium, sodium, and bicarbonate content in the soil determine the pH. Based on Permeability Index (PI), Doneen (1964) has developed a criterion for assessing irrigation suitability:

$$Permeability\ Index\ Na + \sqrt{HCO_3 / Ca + Mg + Na^{+}} \times 100 \quad (4)$$

Where all ions are epm values

The permeability index indicates the soil structure and texture characteristics. It contributed to the soil permit to the water. The permeability index of the water samples collected from the study region is given in Figures 5. Doneen's diagrams show that 10 % of the samples are 100% percolation to the ground, and 65 % of the samples are 75% percolation to the ground (Fig.6). It is concluded that more than 95% of the study area soil is 75% to 100% permit to the ground, so the area aquifer type is unconfined. In the current study, all the samples have been found suitable for agricultural purposes.

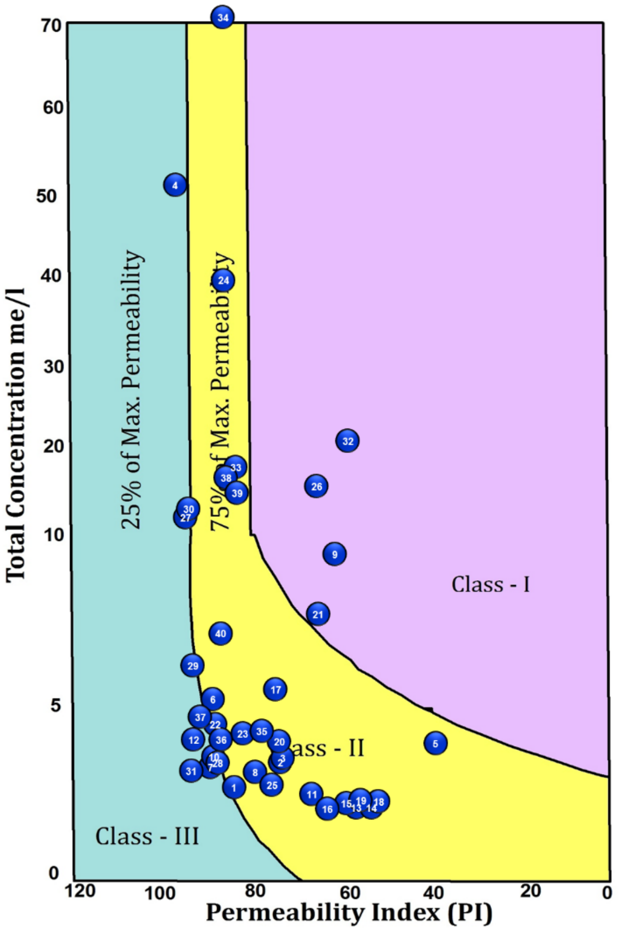

Fig. 6 Doneen's diagram for Irrigation Classes – POM

CONCLUSIONS

Hydrogeochemical characteristics of Thiruvarur Taluk groundwater were examined to determine its suitability for irrigation and drinking. Various natural and anthropogenic factors are responsible for chemical variations in groundwater in the region.In the plots of groundwater chemistry of Thiruvarur Taluk U.S. Salinity Laboratory diagram (USSL 1954), 17.5.5% of samples fall in C2-S1 class is excellent for irrigation, 22.5% samples fall in C3-S1 class, and 35% samples in C3-S2 class are indicating medium and high salinity respectively and low alkalinity.Wilcox diagrams were used to assess the chemical quality of water samples by comparing sodium percentages with specific conductances. Out of 40 samples, 17.5 % of the sample belongs to excellent to good, and 17.5 % of samples fall in the good to permissible type. Most of the samples fall in the Permissible to Doubtful category. According to the piper diagram, the chemical relationships of groundwater, with the help of a tri-linear diagram, reveal that 82.5 % of the samples are Alkalies exceed alkaline earth, and Strong acids exceed Weak acids.Doneen's diagrams show that 10 % of the samples are 100% percolation to the ground and 65 % of the samples are 75% percolation to the ground.The WQI ranges from 11.98 to 228.04, with 66.92 being the mean value. Based on the results, 80 % of samples fall into excellent to good classes, while 15 % and 2.5 % fall into poor to very poor categories, respectively. Public-NGO partnership is needed in the area to enhance water quality by implementing more rainwater harvesting and artificial recharge structures.

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