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Groundwater Quality Assessment through Hydrogeochemical Analysis: Implications for Drinking Water and Pollution

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ABSTRACT
The quality of groundwater and its geochemical features as a source of drinking water are under investigation in the current research. The physical characteristics, cation, and anion chemistry of 201 samples of groundwater were determined. The investigation was conducted in the Southern Indian province of Tamil Nadu, specifically, the Karur District, which is situated between 10°30′ – 11°00′ North latitude and 77°45′ – 78°30′ East longitude, and covers an area of approximately 2900.63 km^2. Safe drinking water standards established by the WHO were used for comparison. The majority of samples on the Gibbs plot are inside the rock dominance zone, showing that the chemical of the rock interacts with the groundwater to affect the chemistry of the groundwater. The study region's Piper plots reveal that most of the samples contain CaCl or CaMgCl. The WQI results for almost all samples were either "excellent" or "good," suggesting they are suitable for human consumption.

Keywords: groundwater, hydrogeochemistry, Karur district, water quality index.

INTRODUCTION

Groundwater is one of the most important sources of nutrient resources in all of Earth's life. In 1984, the World Health Organization (WHO) stated that about 80% of communicable diseases are caused by contaminated water (Egbueri, 2022). The availability of water resources can be assessed through the measurement of underground water volume and quality. The water demand is constantly increasing due to the growing human population (Mukherjee et al., 2019; Karunanidhi et al., 2020). The progress of nations is often linked to the availability of water resources, as this affects food production and, in turn, a country's economy. Economic development depends on the availability of freshwater sources, such as streams, rivers, lakes, tube wells, and a rich water table (Zeng et al., 2017; Palanisamy et al., 2020).

Governments in developing countries often face a crucial water crisis, especially concerning potable water for consumption. The increasing human population and economic expansion have led to water scarcity. The study region, located in the Southern Indian province of Tamil Nadu and specifically the Karur District, relies solely on Northeast monsoon rains for its water supply and has a rocky terrain. The water table is replenished during the monsoon period, mainly just before the monsoon sets in. Underground water resources are used for irrigation, household, and industrial activities (Singh and Turkiya, 2017; Sharma and Rupini, 2021). However, the region is also affected by anthropogenic activities, such as tannery waste effluent discharge and groundwater exploitation, which have altered the water chemistry in the area and led to decreased water usage for irrigation (Ahamed, 2015; Loganathan and Ahamed, 2017; Kalaivanan et al., 2018).

Several studies have been conducted based on India's groundwater quality index (WQI) aspects (Vasanthavigar et al., 2010; Selvam et al., 2015; Sapna et al., 2018; Kumar & Balamurugan 2018; Meenalochini & Annal, 2018; Arthika &

Maheswari, 2019; Jeyaraj et al., 2019; Selvaraj et al., 2020; Kamalanandhini et al., 2021). The water quality index (WQI) is a useful measure of whether a community's drinking water is safe and for disseminating that data to the public and those in positions of influence. It generates a single numerical indicator of water quality depending on input groundwater characteristics and the desired outcome (Karunanidhi et al., 2020). The WQI considers physical and chemical data to determine water quality attributes (Kom et al., 2021; Rajkumar et al., 2019).

This study's main objective is to investigate the WQI and GIS applications that may be used to assess the drinking water quality in the Karur area of Tamil Nadu, India. This study aims to clarify the geochemical classification of groundwater and the hydrochemical processes in the hard rock area. Using the WQI approach, the purpose of the study is to determine whether or not there are any issues with the quality of the drinkable water in the region.

STUDY AREA

The investigation was conducted in the Karur District of the Southern Indian province of Tamil Nadu. The district is situated between 10° 30′ – 11° 00′ North latitude and 77° 45′ – 78° 30′ East longitude, covering an area of 2900.63 km^2 (Fig. 1). The climate in the district is tropical and subtropical, receiving an average of 620 to 745 mm of rain per year. The hot and dry weather dominates from March to May, while November to January is a pleasant time with higher humidity levels in the mornings. Temperatures in the area range from a high of 26.7 °C to a low of 18.7 °C to a high of 29.3 °C. The average temperature in the area is 38.56 °C. A structural hill, pediments, shallow pediments, buried pediments, and alluvial plain are the five primary geomorphic units that may be identified in this region. The soil types in the region include thin red soil, red loam, and red soil, while the main rock types are Charnockite and Hornblend Biotite Gneiss. The Central Ground Water Board (CGWB) monitors groundwater and conducts systematic hydrogeological and groundwater studies, and the CGWB has carried out geophysical investigations to assess the subsurface litho-units and select sites for exploratory drilling.

Geology and hydrogeology

The geology map of the Karur District in Tamil Nadu, India, was digitized and georeferenced using the ArcGIS environment and the District Resource Map from the Geological Survey of India. The dominant rock type in the research region is Hornblende Biotite Gneiss, which belongs to the Archaean Migmatite Complex and covers over 87% of the study area, as shown in Figure 2. The surface of these deposits is covered by sand and

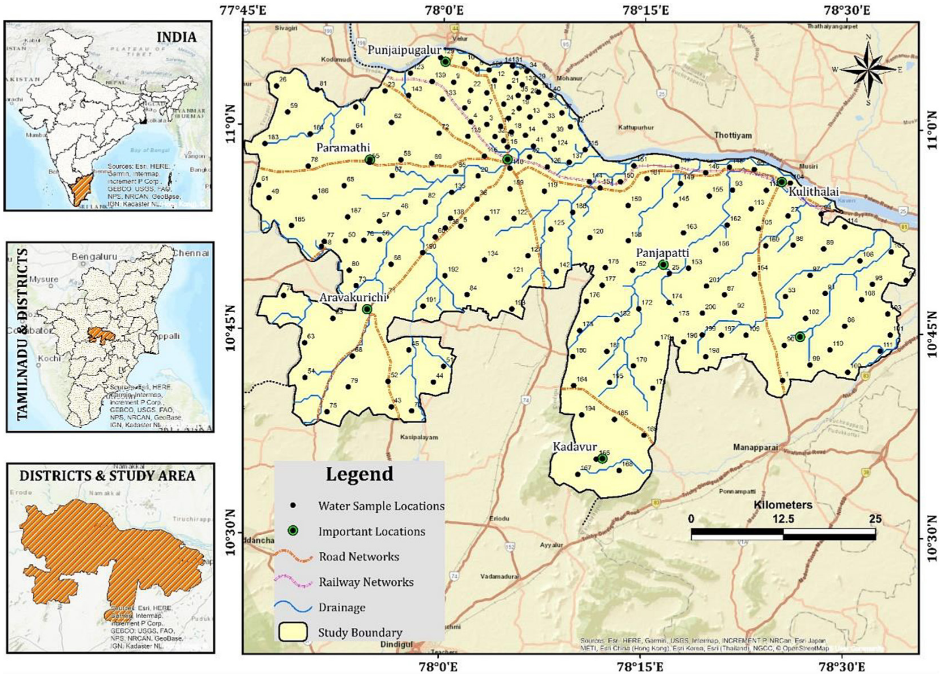

Figure 1. Sample location map of the study area

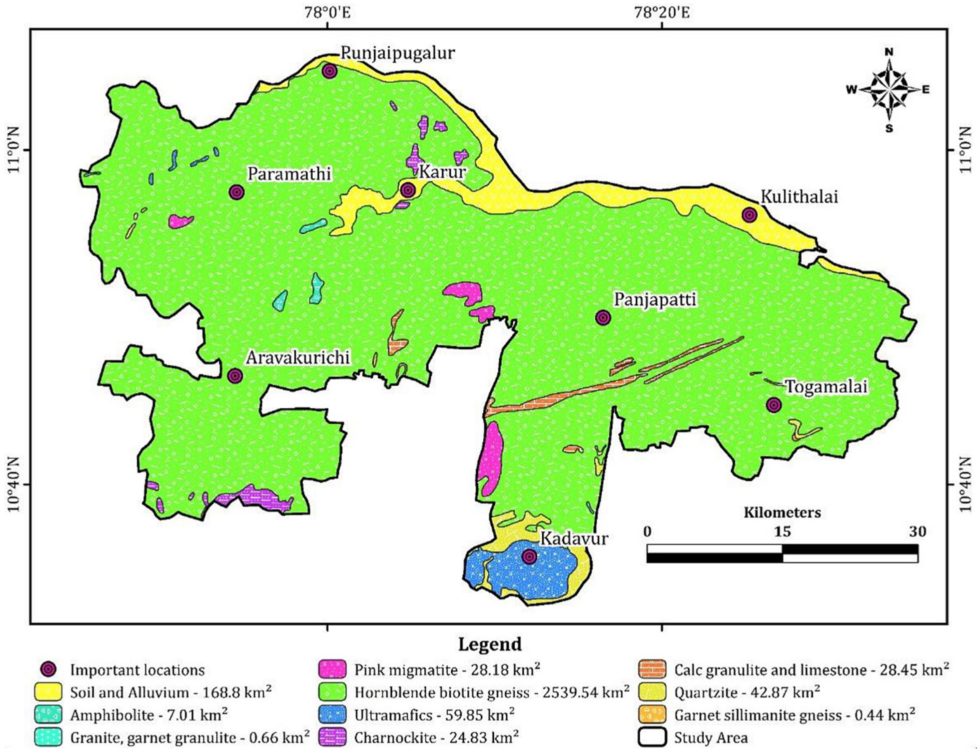

Figure 2. Geology map of the study area

alluvium from the Quaternary era. In addition to the dominant gneiss, there are a few relatively minor igneous rock types from the Archaean, such as the Khondalite Group, which includes Quartzites and Garnet-Sillimanite Gneiss and is situated on the rim of the Kadavur basin. The Charnockite Group, which provides for Pyroxene Granulite, Charnockite, Calc-Granulite, and Limestone, is located in small stocks near Karur. The western region of the study area is home to most of the other minor rock types, including granite and garnet granulite located 10 kilometers southwest of Karur town and amphibolites from the Sathyamangalam group located 5 kilometers south of the granite and garnet granulite. Pink migmatite from the Migmatite Group can be found along the northwest edge of the Kadavur basin and another 10–15 kilometers southeast of Karur town.

APPROACH AND TECHNIQUES

Sample collection and analysis

The groundwater quality in the Karur district of Tamil Nadu was evaluated through the collection of 201 samples (Fig. 1). Before analysis, the plastic bottles used for sampling were thoroughly cleaned and washed three times with the sample water. The measuring equipment was calibrated according to the manufacturer's instructions. The laboratory conducted standard chemical examinations of the groundwater samples. Digital pH metres (Genway 3510) and EC metres (Jenway 4510 Conductivity metres) were used to get accurate readings of the solution's pH and EC, respectively. Concentrations of Na^+ and K^+ were determined using a flame photometer. Concentrations of Ca^{2+} and Mg^{2+} were determined using standard EDTA titration. The concentrations of carbonate and bicarbonate were determined through titration with a standard silver nitrate ($AgNO_3$) solution in H_2SO_4. Nitrate, sulphate, and fluoride were analyzed through colorimetric analysis with a spectrophotometer. The C^{++} software WATCLAST was used to create Gibbs diagrams, and Rock works and Piper's diagrams were used to calculate the percentage of each element in the sample. With an analytical precision of 5% to 10%, we were able to convert the principal ion concentrations to meq/L. There is a 5% inaccuracy in the total cation and anion balance, according to calculations made by Freeze and Cherry (1979).

Water quality index (WQI)

A water quality index represents the impact of the composites factors on groundwater quality.

The WQI assesses the quality of groundwater intended for drinking purposes. Water quality criteria (a) are rated according to how dangerous they are using a weighting scheme (w). The concentrations of individual constituents are converted into a single number that combines the effects of the other water quality parameters. The relative weight (W_a) can be calculated using the equation

$$W_a = \frac{w_a}{\sum_{a=1}^{n} w_a} \tag{1}$$

where: W_a – weight of groundwater parameter, n – number of factors.

The quality factors relative importance and involvement of the quality factors in determining drinking water quality by assigning weights (Wa) on a scale from 1 to 5. Due to their importance in assessing drinking water quality, pH and total dissolved solids, each obtains a 5 point weight. While bicarbonate has no effect on water quality in the studied area, its importance in assessing water quality was given a value of 1. Based on their significance in the overall water quality assessment, the remaining characteristics were given weights ranging from 1 to 4 (Ramakrishnaiah et al., 2009; Vasanthavigar et al., 2010; Kalaivanan et al., 2018).

Each parameter's quality assessment (qa) was determined by dividing the corresponding WHO standard into the parameter's concentration in each water sample.

$$q_a = \frac{C_a}{S_a} \times 100 \tag{2}$$

where: C_a – water quality parameter (a) concentration in milligrams per liter, S_a – WHO standard for (a), the WQI was calculated using each parameter's sub-index (SI).

$$SI_a = W_a \times q_a \tag{3}$$

$$WQI = \sum SI_a \tag{4}$$

Table 1. Water quality classification and type of WQI value

Range (mg/l)	Type of water
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
> 300	Water unsuitable for drinking purposes

Water quality indexes were utilized to categorize drinking groundwater (Table 1). Interpolation maps of the WQI were generated using the IDW technique in GIS.

RESULTS AND DISCUSSION

Groundwater chemistry

A primary method for determining the nature and type of water is by assessing groundwater quality parameters (Kalaivanan et al., 2018). Table 2 shows the findings of a descriptive analysis based on 201 groundwater samples from the Karur district, which were evaluated for their physicochemical parameters. During post-monsoon seasons, the pH value of the groundwater varies between 6.80 and 8.80, with an average of 7.80. High pH levels may increase the presence of oxidized iron and silicate, which may affect alkalinity. Electrical conductivity (EC), the standard measure of groundwater mineralization, ranges from 154.26 to 4855 µS/cm at 25 °C, with a mean of 1467.5 µS/cm. Increased EC levels in groundwater can cause human gastrointestinal irritation (Singh et al. 2008). TDS values range from 412.11 to 4595.71 mg/L during the post-monsoon season. Water has many uses, and one of the most important factors is its total dissolved solids (TDS). TH concentration values range from 187.77 to 2558.30 mg/L, with an average of 123.97 post-monsoon (POM). TA concentration values range from 12.3 to 387.07 mg/L, with an average of 123.97 post-monsoon (POM). Increases in concentration may occur due to mechanisms, such as the weathering of silicate rocks and the dissolution of carbonate from atmospheric and soil CO_2 (Jeong 2001; Krishna Kumar et al. 2011). The Ca^{2+} concentration values range from 10 to 756 mg/L, averaging 110.99. The sustained consumption of high amounts of calcium over prolonged periods may lead to various health problems, including osteoporosis, defective teeth, kidney stones, rickets, hypertension, stroke, and others (Ansari & Umar, 2019). Mg^{2+} content ranges from 7.70 to 189.53 mg/L, averaging 65.01 mg/L. Ca^{2+} and Mg^{2+} ions are reduced due to a reverse cationic exchange with sodium (Thomson Jacob et al., 1999). Na^+ content ranges from 10.20 to 144.35 mg/L, with an average of 69.96 mg/L. All samples from the region fall within the maximum allowable limit (<

Table 2. Result of physio-chemical parameters

Elements	WHO Standard-2011			Minimum	Maximum	Average
	Most desirable	Maximum allowable	Not permissible			
pH	6.5 to 8.5	-	<6.5 and >8.5	6.80	8.80	7.63
EC	<1500	-	>1500	154.26	4855	1467.50
TDS	<500	500 to 1500	>1500	103.35	3252.85	983.22
Alkalinity	<500		>500	12.30	387.07	123.97
TH	<100	100 to 500	>500	187.77	2558.30	544.03
Ca^{2+}	<75	75 to 200	>200	10	756	110.99
Mg^{2+}	<50	50 to 150	>150	7.70	189.53	65.01
Na^{+}	<200	-	>200	10.20	144.35	69.96
K^{+}	<10	-	>10	2.30	20.95	13.32
NO_3^{-}	<45	-	>45	5.97	94.71	40.48
Cl^{-}	<200	200 to 600	>600	71	1506.54	366.33
SO_4^{2-}	<400	-	>400	25.20	428.15	130.31
F^{-}	<1.5	-	>1.5	0.01	1.54	0.88

Note: *EC* – µS/cm; all parameter – mg/L.

200 mg/L). K^+ content ranges from 2.30 to 20.95 mg/L, with an average of 13.32 mg/L. The concentration of K^+ in groundwater varies with depth, as deeper groundwater tends to have a higher concentration of K^+ than shallow groundwater. HCO_3^- content ranges from 15 to 471.92 mg/L, averaging 151.15 mg/L. According to Elamassi (2012), an alkaline water sample will have a high amount of HCO_3-. Cl- concentrations range from 71 to 1506.54 mg/L, with an average of 366.33 mg/L. High concentrations of Cl- in groundwater indicate pollution (Loizidou and Kapetanios, 1993). Chloride can come from various geologically important sources, such as appetite, sodalite, connate water, and hot springs (Anithamary et al., 2012; Freeze and Cherry, 1979). SO_4^{2-} concentrations range from 25.20 to 428.15 mg/L, averaging 130.31 mg/L. Higher sulfate concentrations may result from leaching and human activities, such as the emission of sulfur gases from industrial and municipal utilities (Saxena 2004). Agricultural operations, septic tank leaks, unlined drainage, sewerage pipelines, home sewage, and leaching from indiscriminate animal waste disposal (Reddy et al., 2013; Datta et al., 1996) can result in variations in F- concentrations, which range from 0.01 to 2.15 mg/l, with an average of 0.91 mg/l. Groundwater fluoride concentration is influenced by various factors such as rock-water interaction, water alkalinity, low calcium, high magnesium, and bicarbonate. Granite rock weathering contributes to the pollution of the area's groundwater with fluoride (Reddy et al. 2019).

Gibbs plot

Gibbs diagrams examine the chemistry and lithological parameters of an aquifer in groundwater. They are divided into three zones: evaporates, precipitation, and rock. According to Gibbs (1970), these diagrams utilize the relationships between Total Dissolved Solids (TDS) and $(Na^{+}+K^{+})$ / $(Na^{+}+K^{+}+Ca^{2+})$ and TDS and $(C1^{-})/(C1^{-}+HCO_3^{-})$ to determine the origin of the hydrogeochemistry in groundwater systems related to precipitation, rocks, and evaporation. Most of the samples in Figure 3 are located inside the rock dominance zone, demonstrating that the interaction between groundwater and rock chemistry influences post-monsoon groundwater chemistry. The movement of subsurface sampling locations from the rock dominance field to the evaporation dominance field also indicates a significant increase in salt, chloride, and TDS. Contaminated water supplies may contribute to inadequate health procedures. Hydrogeochemical groundwater composition determines rock-water interactions (Elango and Kannan, 2007). The rock water chemistry that saturates the water quality beneath the subsurface reveals the rock water dominance in the study region.

Classification of groundwater

Hydrogeochemical facies help us understand an area's processes and types of water (Piper, 1955). It is possible to identify the quality and

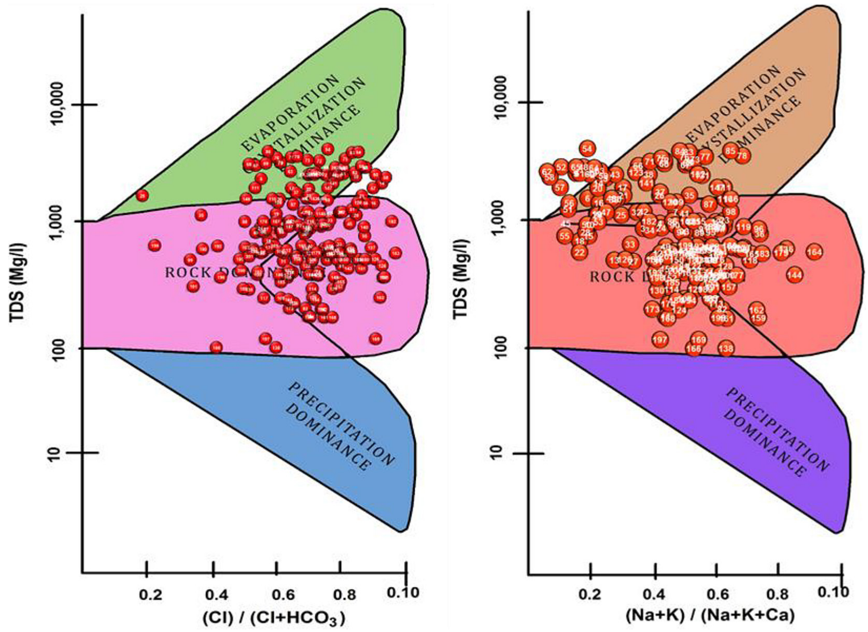

Figure 3. Anions & Cations GIBBS Diagram

source of groundwater and its applicability by studying the facies' correlation with other criteria. In the Piper diagram, the x-axis represents the parameter of been studied, and the y-axis represents the concentration, often shown on a logarithmic scale. This diagram can give insights into groundwater sources, water quality changes, and geochemical issues. The Piper trilinear diagram is another tool that compares water quality. It plots the analytical values of groundwater samples on a trilinear diagram using Rockworks software and helps us understand the area's hydrochemical regime and variations in cation and anion concentrations. The diagram is divided into six subcategories that describe the geochemical evolution of an area: (1) calcium - bicarbonate type, (2) sodium - chloride type, (3) mixed calcium - sodium - bicarbonate type, (4) mixed calcium - magnesium - chloride (Ca-Mg-Cl) type, (5) calcium - chloride type, and (6) sodium - bicarbonate type. According to the Piper plots for the study region, most groundwater samples fall into the Ca-Cl or CaMg-Cl categories during the post-monsoon seasons (Fig. 4). The region shows high levels of Ca^{2+}, Mg^{2+} and HCO_3, which may be due to high levels in host rocks like plagioclase and pyroxene minerals or increased base ionic exchange. Decomposition of organic materials, weathering of silicate minerals, and atmospheric pollution can also contribute to excess HCO_3^-. During both seasons, the concentration of alkali (Na+K) ions is higher than alkaline earth (Ca+Mg) and weak acid (HCO_3) ions, which anthropogenic activities, silicate mineral leaching, and ionic exchange may influence. These factors can impact the groundwater chemistry in the study region."

Water quality index

The Water Quality Index (WQI) was used to distinguish the groundwater quality in this study. Based on the WQI, five categories of drinking water quality have been established: excellent (<50), acceptable (50–100), bad (100–200), extremely poor (200–300), and not appropriate for drinking (>300). The WQI values in this region ranged from 30.8 to 216.91 mg/l, with an average of 64.83 mg/l. According to the WQI, 44 samples were found to be excellent, 143 samples were found to be good, 12 samples were found to be poor, and only two samples were not appropriate for drinking water quality (Fig. 5). The high WQI in the region may be linked to widespread use of irrigation techniques and groundwater extraction. Both natural processes, such as rock weathering and mineral dissolution, as well as human activities, can contribute to high WQI values in this area (Sudharshan Reddy et al. 2020a, b).

Groundwater quality for irrigation purposes

Groundwater is a crucial source of water for irrigation and a valuable natural resource that enables

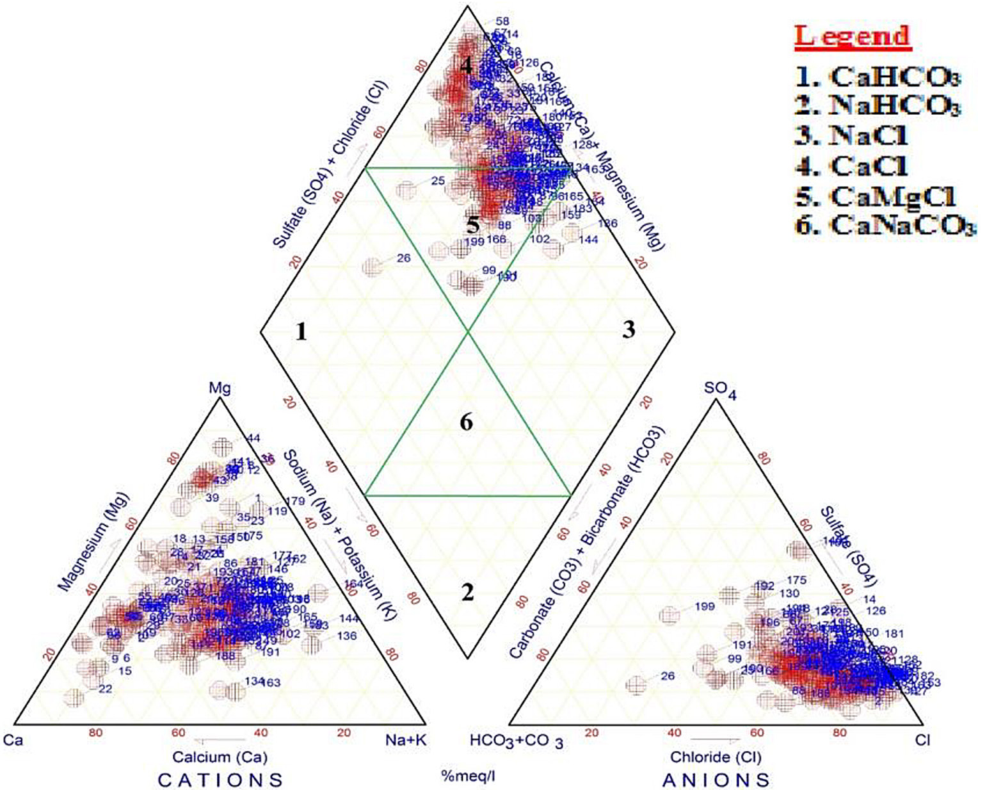

Figure 4. Piper's tri-linear diagram

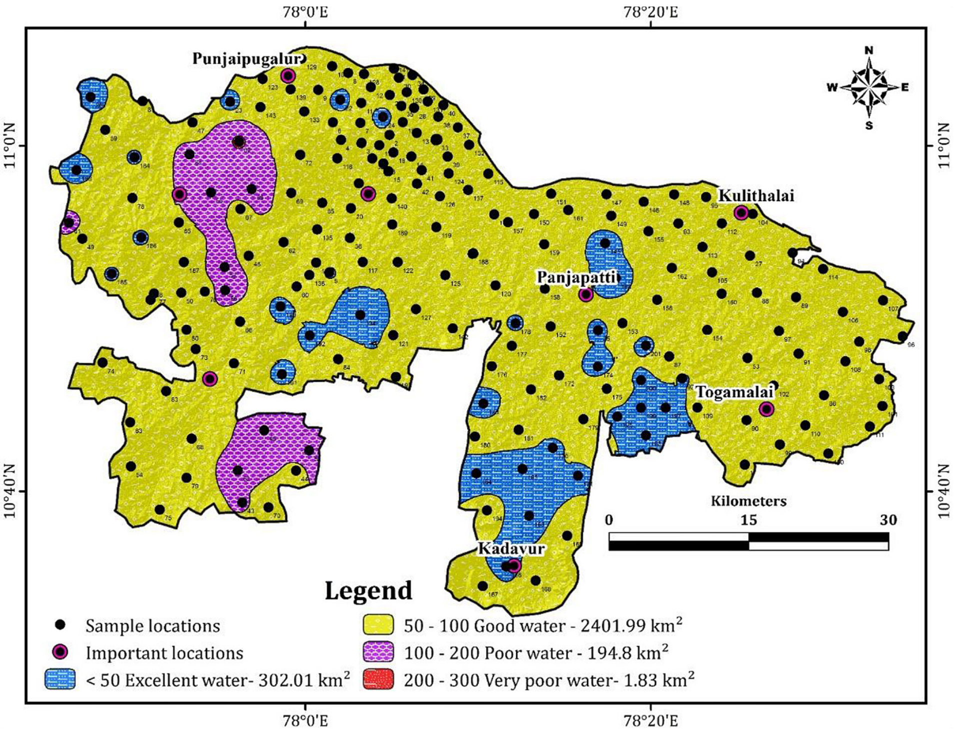

Figure 5. Spatial distribution map of WQI

farmers to produce crops and sustain their livelihoods (Meena and Bisht, 2021; Shah et al., 2019). Irrigation accounts for a large portion of total water usage in many countries and is a critical factor in food production. Thus, it is vital to maintain high-quality groundwater for irrigation purposes.

USSL diagram

The United States Salinity Laboratory (USSL) diagram of groundwater quality is useful in understanding the different aspects of groundwater quality. It can be used to identify potential sources of contamination from surface runoff, such as from agricultural or urban activities. The diagram determines the salinity of the water by measuring its electrical conductivity (EC) and evaluating the groundwater quality for different uses. According to Richard (1954), the United State Soil Laboratory Staff (USSL) identifies 16 zones of water suitability for irrigation within the United States. High sodium concentrations in water can affect soil permeability and characteristics (Adimalla et al., 2018). The USSL diagram determines the salinity and sodium hazard of water usability for agriculture. The diagram indicates that 59% of the samples fall into the C3S1 class with high salinity and low alkalinity during the post-monsoon (POM) season, while 21% fall into the C2S1 class, 18% into the C4S1 class, and only 2% into the C1S1 class, indicating medium to high salinity and low alkalinity (Fig. 6). In the study area, this type of water can have adverse effects on fine-textured soils, but applying gypsum in agricultural fields can help mitigate these effects.

Wilcox's diagram

Electrical conductivity (EC) and sodium percent (Na%) were the criteria that Wilcox (1955) used to categorise different types of water for use in irrigation. Using a Wilcox diagram to illustrate EC and Na results, the researchers determined that the groundwater samples fell into one of five categories: (1) excellent to good, (2)

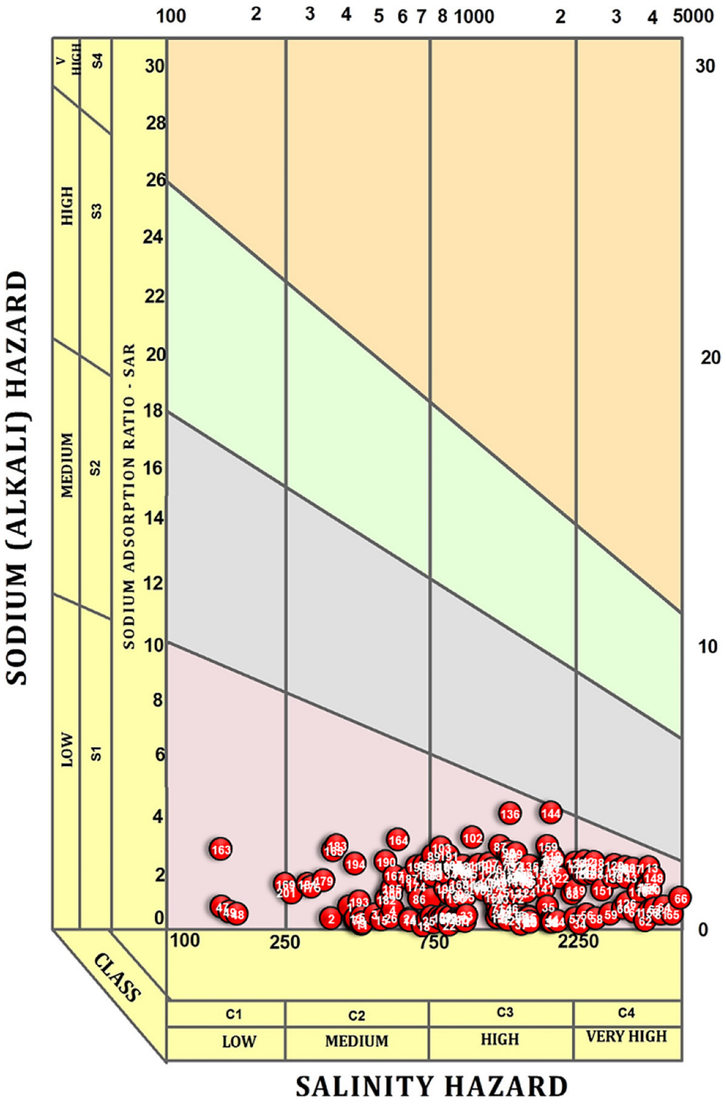

Figure 6. USSL diagram for irrigation classes

good to permissible, (3) permissible to doubtful, (4) doubtful to unsuitable, and (5) unsuitable. The Wilcox representation shows that 23% of the groundwater samples in the study region were evaluated as excellent to good, and 56% of the samples were classed as good to permissible. The remaining samples had a percentage of 1% that was permitted to questionable, 10% that was uncertain to unsuitable, and 10% that was unacceptable (unsuitable) (Fig. 7). Most samples are suitable for irrigation purposes, indicating that groundwater upstream is suitable for agriculture. At the same time, the highest pollution levels are found downstream. Wastewater from factories and sewerage from homes being dumped into the waterway may be responsible for this.

Doneen's permeability index

Water used for irrigation over an extended period can reduce soil permeability. The concentrations of sodium, calcium, magnesium, and bicarbonate in the soil are all relevant factors. Doneen (1964) developed the Permeability Index (PI) to determine whether the water is suitable for irrigation. The PI measures the effect of water on soil permeability and provides a useful tool for evaluating water quality for irrigation. With the help of the Permeability Index, farmers and water resource managers can make informed decisions about the most appropriate water sources for irrigation and ensure that soil permeability is not negatively impacted.

$$\text{Permeability Index Na} + \sqrt{\text{HCO}_3 / \text{Ca} + \text{Mg} + \text{Na}^+} \times 100 \qquad (5)$$

The structure and texture of the soil are represented in Doneen's (1964) Permeability Index (Figure.8), a metric used to estimate the quality of water utilised for irrigation purposes. During the post-monsoon season, the PI measurements in the study region indicated that 43% of the groundwater samples fell under class I. Class I groundwater is considered suitable for

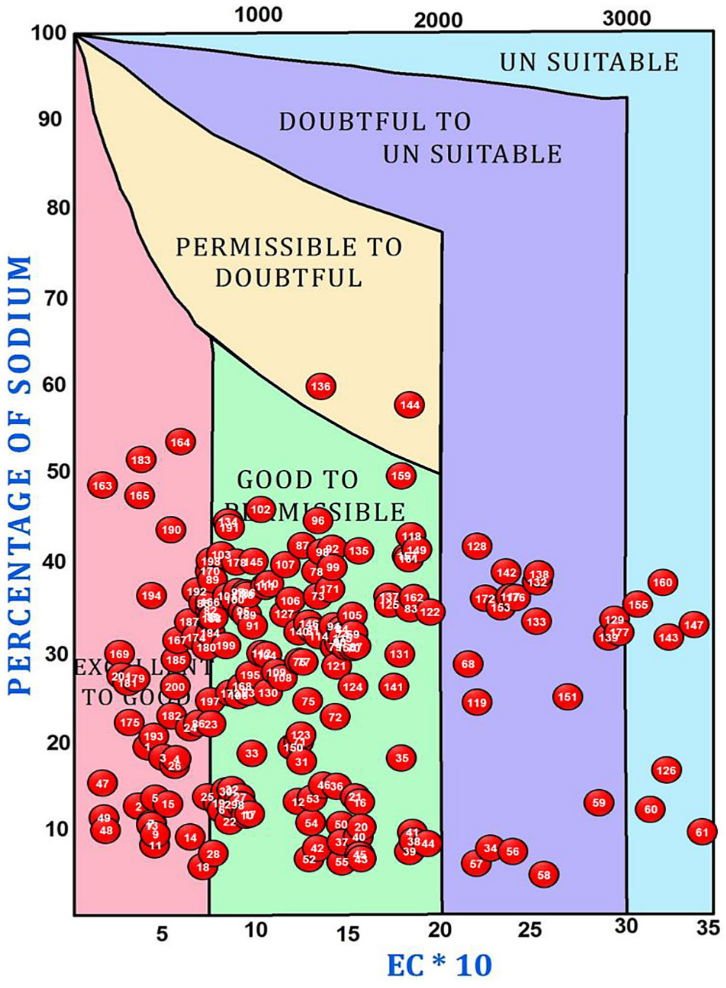

Figure 7. Wilcox's diagram for irrigation classes

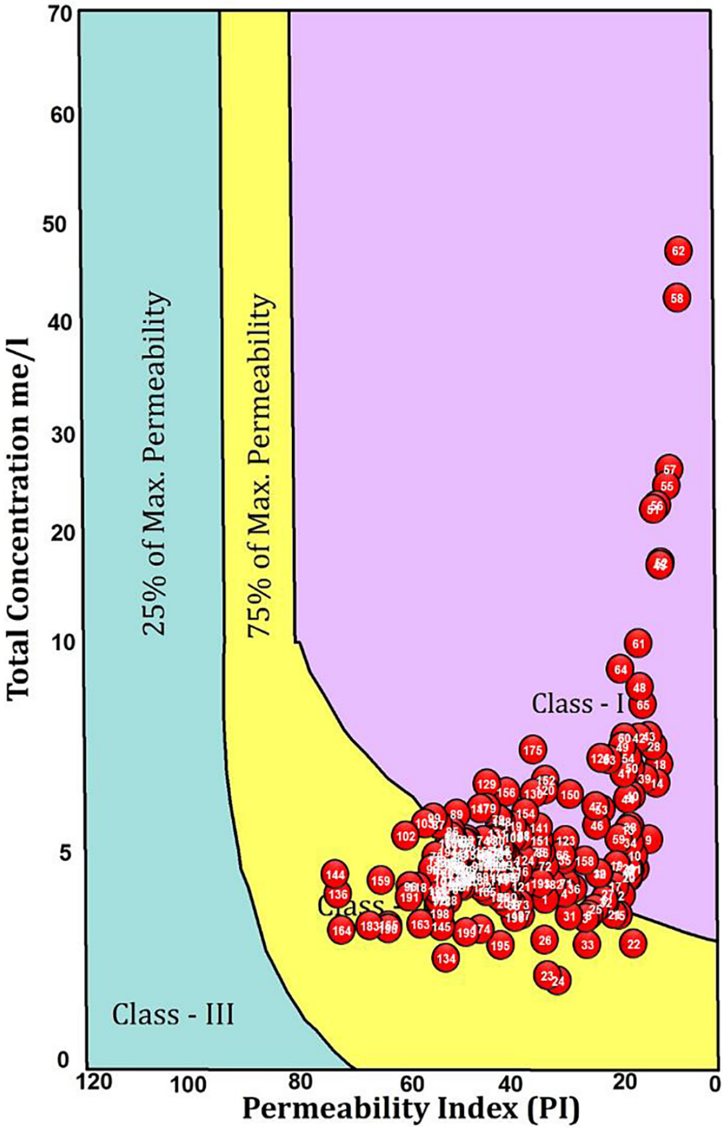

Figure 8. Doneen's diagram for irrigation classes

irrigation and permits 100% percolation to the ground below. 57% of the samples, on the other hand, fell into class II, which is regarded to be reasonably acceptable for irrigation, with 75% of the water being able to percolate into the ground. The findings of the research indicated that each of the samples may be used successfully in agricultural settings.

The long-term use of groundwater for irrigation may raise the concentration of ions like sodium, calcium, magnesium, and bicarbonate in the soil and decrease its permeability. Since the water used for irrigation evaporates and returns to the ground, the concentration of ions there increases. This emphasises the need to prudently manage and monitor groundwater consumption for irrigation to guarantee its long-term viability.

CONCLUSIONS

For the purpose of determining whether or not the groundwater in the Karur area is suitable for human consumption, 201 samples were taken and examined. The results of the research are described this way.

Most of the groundwater samples in the research region had significant concentrations of Ca^{2+}, Mg^{2+}, and HCO_3, as shown in Piper plots. According to Gibbs diagrams, most samples fall inside the rock dominance zone, suggesting that groundwater chemistry is affected by the interactions with freshwater and rock weathering. The Water Quality Index (WQI) showed that 44 of the samples were excellent (WQI <50), 143 were good (WQI 50–100), 12 were poor (WQI

100–200), and only two were very poor for drinking water quality. The majority of the groundwater samples were suitable for drinking purposes.

According to the USSL diagram, 59% of the samples have a high salinity and low alkalinity, whereas 21% have a medium salinity (C2S1), 18% have a high salinity (C4S1), and just 2% have a low salinity (C1S1). According to Doneen's diagrams, 43% (POM) of the samples are in class I (ideal for irrigation purposes) with 100% percolation to the ground, and 57% (POM) of the samples are in class II (moderately acceptable for irrigation) with 75% percolation to the ground. The GIS geographical distribution of the groundwater quality study in this region reveals that most of the groundwater samples meet the standards for drinking water. Nevertheless, groundwater needs to be continuously monitored and effectively managed.

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