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Impact of climate and anthropogenic activities on groundwater quality for domestic and irrigation purposes in Attur region, Tamilnadu, India

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ABSTRACT

In southern India, Attur is a major groundwater province with substantial groundwater quality and quantity deficiencies as a result of increasing population density and urbanization. In the present study, 43 bore well locations are identified in the study area to evaluate the appropriateness of the nature of groundwater for domestic and irrigation uses. The study region majorly covered by charnockite, hornblende biotite gneiss, and porphyroclasts bearing mylonites are exposed in the foothill. The dominant ions in groundwater are as follows K^+, >Na^+, >Mg^{2+}, and >Ca^{2+} for cation and Cl^-, >HCO_3^-, and >SO_4^{2-} for anions. It's revealed that groundwater is mainly alkaline and hard in nature for domestic uses. Various irrigation indices have been calculated for the evaluation of groundwater quality parameters for irrigation suitability. The most efficient methods of statistical analysis are principal component analysis (PCA) and hierarchical cluster analysis (HCA) was carried out in the study. It has also been found that, weathering of host rocks and their minerals, agricultural waste, synthetic fertilizers, and anthropogenic activities are strongly influencing the quality of water in study area. The research concluded that, remedial measures such as primary treatment are immediately needed before use for drinking uses.

Keywords: Groundwater; Groundwater quality; Domestic and irrigation uses; Irrigation indices; PCA; HCA

1. Introduction

Groundwater is an important renewable natural resource, and it plays a vital role in the day-to-day life of living organisms and in the ecosystem. It is an inevitable source of water for domestic and irrigation uses in different parts of the world. Usage of high elevated water contaminated drinking water is a major reason for about 80% of diseases in developing countries [1]. The natural groundwater if generally controlled by the climatic condition, rainfall the other reason for the alteration of the groundwater is by the anthropogenic activities such as land use, agriculture practice, industrial activities, and saline intrusion due to overexploitation [2]. For the past two decades, the quality of groundwater and hydrochemistry studies has been progressively on a global scale to monitor uncontrolled extraction and contamination due to rapid urbanization and industrialization. Assessment of drinking water quality is very important for the sustainable and clean water supply, human health, and integrity of the water environment. It is worth evaluating the quality of groundwater resources in

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India as an important step forward for developing water resource management, meanwhile rural part of the country majorly depends on the groundwater for both purposes. To ensure the quality of groundwater for drinking, periodical monitoring is essential in urban regions [3].

In the past decade, many researchers concentrated more in groundwater monitoring and quality evaluation for drinking and irrigation uses. Nowadays, groundwater quality is declining day by day as a result of over-exploitation and anthropogenic influences such as sewages, agricultural fertilizers and pesticides, untreated industrial effluents. Rajmohan and Elango [4] investigated in the southern part of India and describe the groundwater quality influenced by types of aquifer, rock-water interaction, presence of carbonate, and dissolution of silicate. Li et al. [5] studied groundwater contamination in Tongchuan, Northwest China and reveals that, due to increase in population and over exploration of groundwater are the main factors affects the nature of the groundwater. Singh et al. [6] studied the multivariate statistical and geochemical modeling of groundwater in the Delhi region and found that action of weathering, ion exchange, and anthropogenic activities are the factors that affect the nature of groundwater. Narsimha et al. [7] carried out to assess the groundwater quality by using water quality index in the Telangana region and found that lithological effects, and excessive an amount of fertilizers used for agriculture purposes are the factors that affect the quality of groundwater. Rostami et al. [8] investigate the groundwater quality index using hybrid modeling and geospatial techniques and found that, geographical weightage regression, and hybrid methods of estimation are more practical and useful to decision-makers in water resources management. Eslami et al. [9] studied the hydrochemical characteristics of groundwater using water quality index in Jiroft, Iran. They preferred that; hierarchical cluster analysis of the groundwater samples shows that major ion concentration for pollution. Xu et al. [10] investigated the groundwater pollution in the central-western Guanzhong basin, china and reveals that, rock water interaction and anthropogenic activities are factors plays a vital role of groundwater quality in arid and semi-arid region. Srinivasamoorthy et al. [11] studied the lithological impact on groundwater characterization in Salem district and found that lithological and anthropogenic activities are the major factor that influences the nature of groundwater.

Geographic information system (GIS) is an effective tool to evaluate the potential level of the contamination and graphical representation of geochemical data of groundwater. Spatial distribution maps may be used as an effective tool for decision-makers in local bodies. Groundwater potential and contamination maps are used in earth science in order to assess the level and to predict the variation in groundwater quality [12–19]. Spatial variation of groundwater generally, relies on its geological formation and its anthropological impact on groundwater [20–22]. This study aimed to evaluate the groundwater characteristic in semi-arid region in the Salem district, Tamilnadu, India. Attur is one of the fast-growing areas in the Salem district. There is also a high rate of urbanization and intensive farming, which represents a high demand for quality water in this area. In the study area, an amount of rainfall intensity, geological settings, and presence of minerals in the aquifer are the main factors that can remodify the concentration of chemicals in groundwater. These are the major factors that modify the nature of groundwater chemistry and its quality. The core intention of the research is to evaluate the geochemical properties of groundwater in the hard rock region of Attur and assess its suitability for drinking and agricultural purpose. The outcome of the research is going to be elaborating on the contamination level of groundwater and helpful for decision-makers in the water resource department in the Attur region.

2. Description of the study area

Attur is located in the eastern part of the Salem district, Tamil Nadu, India. It has an area of 611.60 km^2 in between Kalrayan hills and Pachaimalai hills marked with geographical coordinate's 11°26′30″ N – 11°41′30″ N latitude and 78°26′16″ E – 78°49′50″ E longitude (Fig. 1). Attur is the second largest city in the Salem district. Vasishta Nadhi drains the central part of the study area with numerous tributary streams originating from the Kalrayan hills, flowing from west to east. People depend on agricultural and industrial activities for their living. The main crops cultivated are rice, betel leaves, millet, pulses, turmeric, sugarcane, tapioca, cotton, groundnuts, gingelly, and oilseeds. It is also famous for its rainfed and irrigated crops. There are a number of sago factories and rice mills in the study area. Attur Taluk is mainly comprised of crystalline archaean formations with recent alluvium is seen along with the courses of the Vasishta Nadhi River and in the inter-mountain valleys. The rocks are represented by the Gneissic group and charnockite group. The major part of the study region is covered by charnockite, hornblende biotite gneiss, and porphyroclasts bearing mylonites are exposed in the foothill. The study area is charnockites and gneisses form the basement complex which occupies the most of the area. The met sediments, magnetite-quartzite, and amphibolites, are found in the synclinal outliers in the western part (Fig. 2a). Generally, gneisses are highly weathered and display fractures and joints. The maximum elevation is 817 m above MSL and minimum is 140 m above MSL. The climate of the study area is semi-arid and temperature varying from 18.07°C to 44°C. The study area receives rain from both north–eastern and south–western monsoons under the influence. The north–east monsoon predominantly contributes to the rainfall, even though the south–west monsoon rainfall is highly erratic. The average annual rainfall is 777 mm.

A detailed soil investigation was carried out in the Attur taluk of Salem district. Based on variation in physiography and landform, eight soil series were identified in the study area. About 30% of the sample locations are highly eroded, moderately well-drained calcareous associated with clay soils, 20% of the study area covered by moderately deep, well-drained loamy soil with a gentle slope and associated with moderately shallow clayey soils. It shows that non-calcareous soil type covered a partial part of the study area. In the southeast part of the study area covered by hilly terrains with excessively drained gravelly loam soil. A few sample stations are covered by very deep, well-drained loamy soil (Fig. 2b).

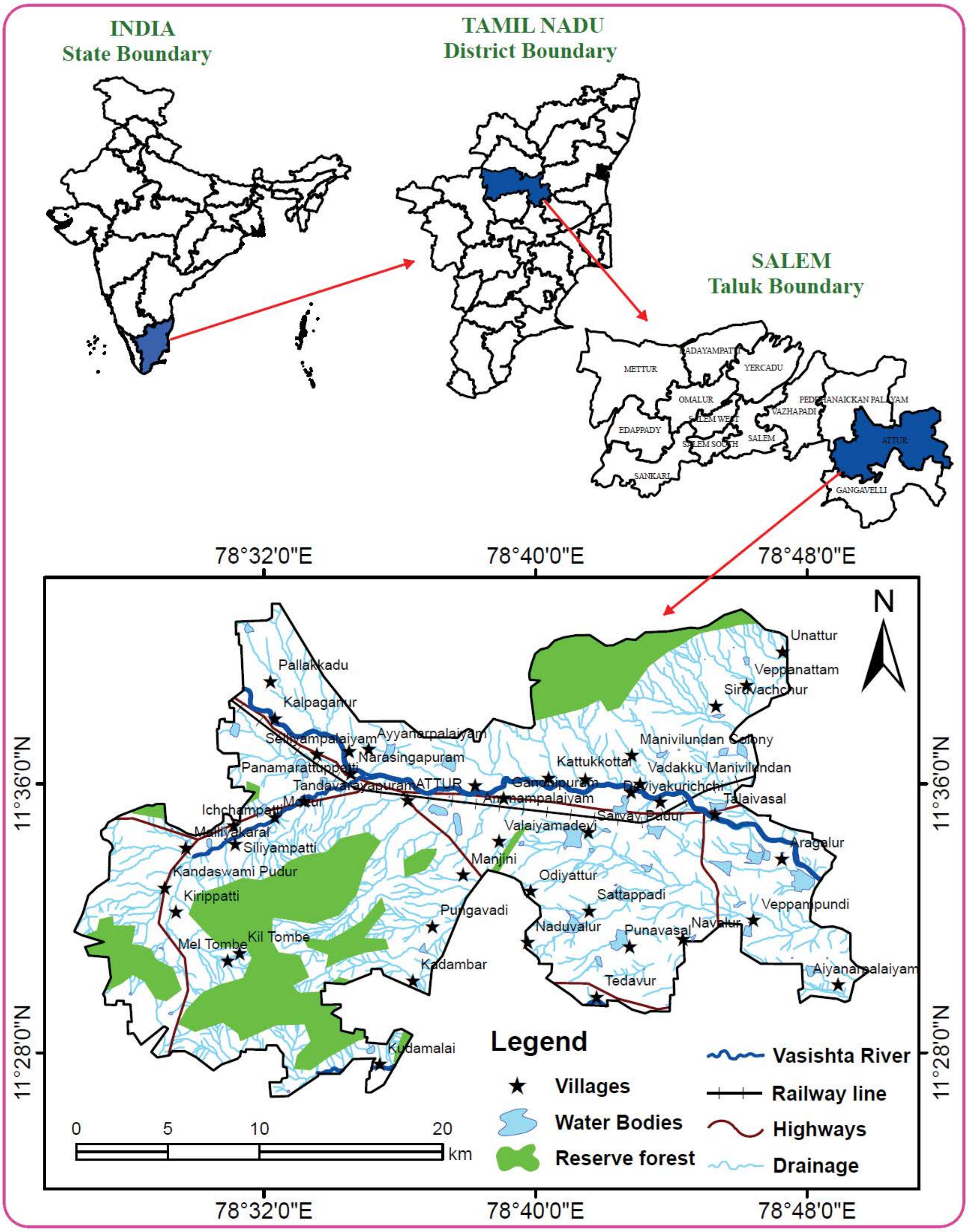


Fig. 1. Location of the study area.

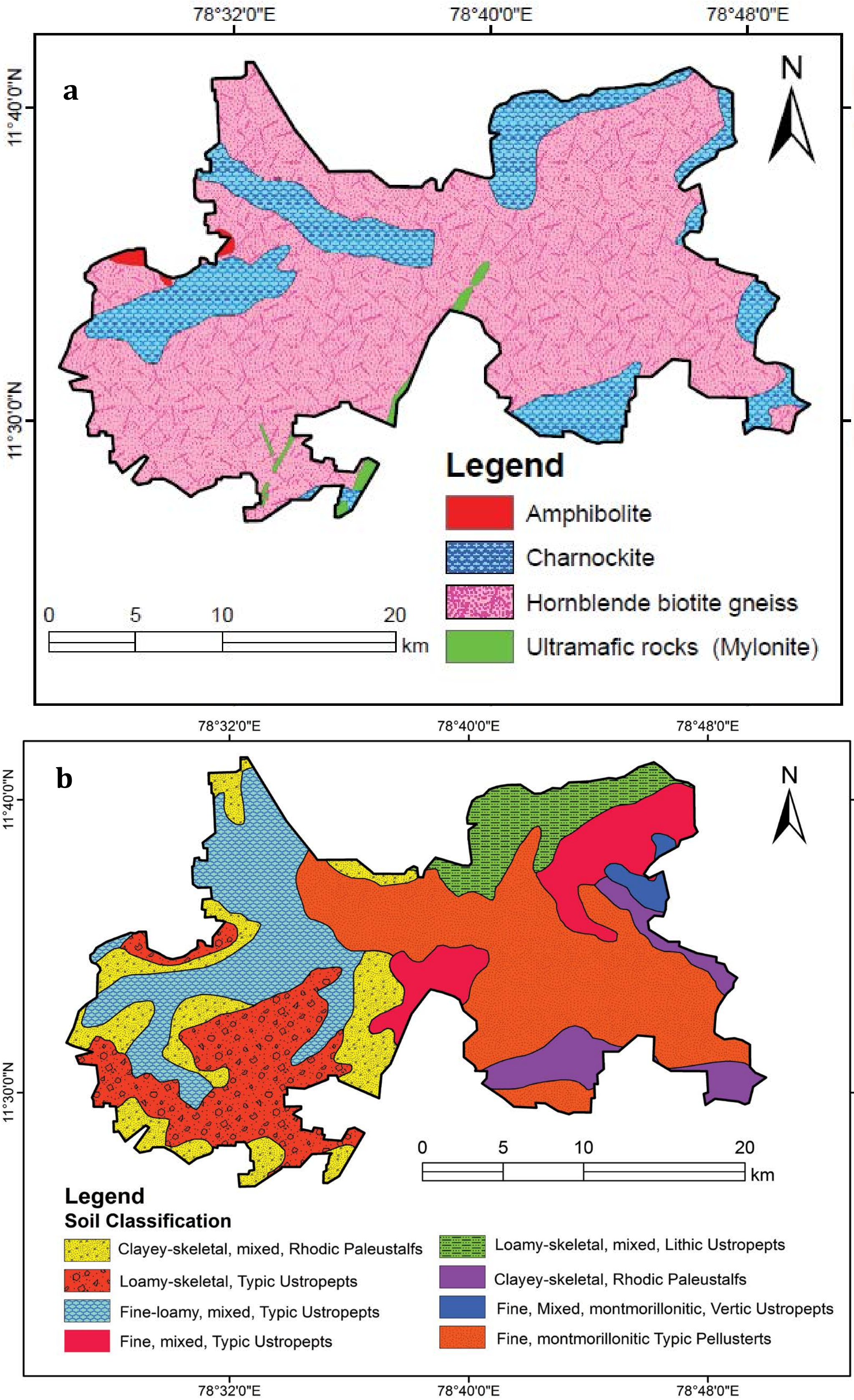


Fig. 2. Geology (a) and soil type (b) of the study area.

3. Materials and methodology

A total of 43 samples of groundwater were collected from different locations (bore well/hand pumps) in Attur Taluk during the pre-monsoon season. High-density polythene bottles of 1 L capacity were used as sample containers. Bottles for the cation analysis were rinsed with HNO_3 acid and rinsed with distilled water 2–3 times in order to avoid contamination. The wells were pumped for 5–10 min prior to the sample collection, to reduce the influence of accumulated pipe water. Hydrogen concentration (pH) and electrical conductivity (EC) were measured in the filed using handheld devices Elico pH meter and conductivity meter. After the collection, sample bottles were sealed, transported, and stored properly (4°C) till analyzed. The physicochemical parameters such as pH, EC, total dissolved solids (TDS), major cation such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), major anion such as chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^-), and bicarbonate (HCO_3^-) were analyzed using standard methods recommended by American Public Health Association (APHA) [23]. In the laboratory, Ca^{2+}, Mg^{2+}, Cl^-, and HCO_3^- were determined by volumetric titration methods. Na^+ and K^+ were analyzed using a flame photometer. SO_4^{2-} was analyzed using a spectrophotometer. The total hardness (TH) of $CaCO_3$ is computed by $Ca^{2+} + Mg^{2+} \times 50$ (meq). The ionic balance error (IBE) equation is used to obtain the accuracy of the analytical results of all samples between the concentration of the total cation and the anion reported in milliequivalent per litre (meq/L) and calculated using Eq. (1). The value of IBE is expressed in percentage and it was recorded in the range of ±10%.

$$\text{IBE}(\%) = \frac{\sum \text{Cation} - \sum \text{Anion}}{\sum \text{Cation} - \sum \text{Anion}} \times 100 \qquad (1)$$

GIS software package ArcGIS 10.4 using inverse distance weighting (IDW) method were used to create a spatial distribution map for water quality parameters [24,25]. Fig. 3

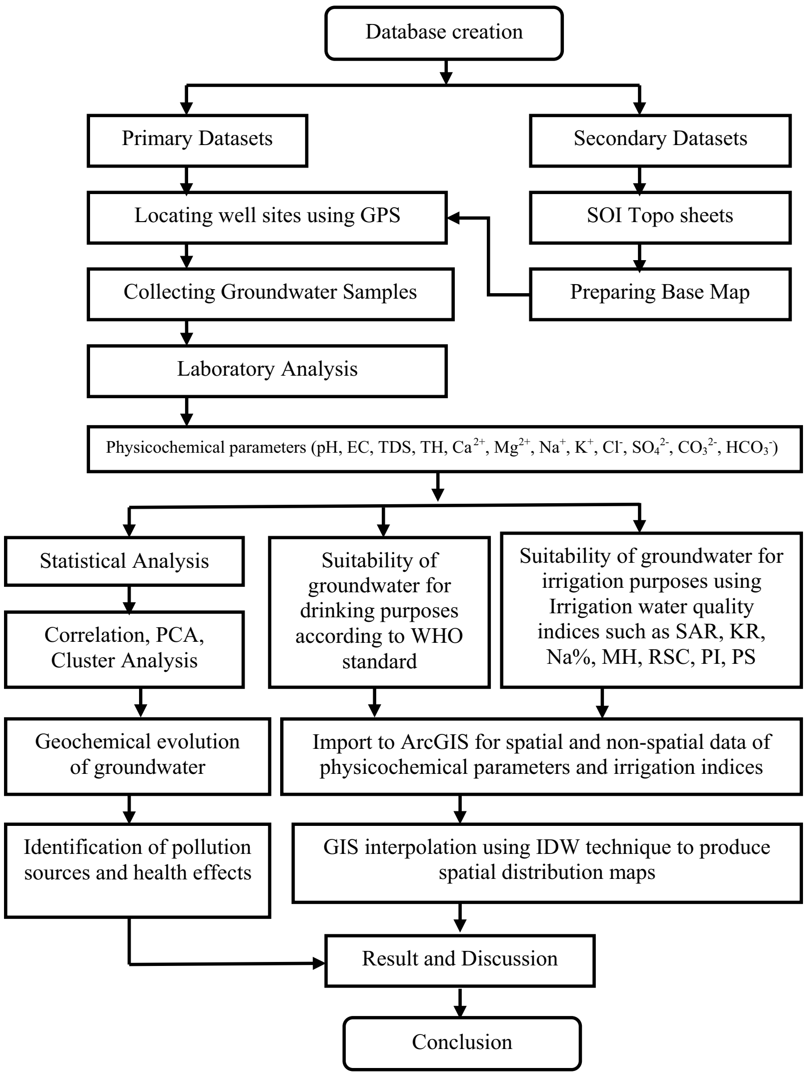


Fig. 3. Methodology followed in the present study.

demonstrates the comprehensive methodology adopted in the present work. In addition, groundwater quality parameters for irrigation suitability was estimated using multiple irrigation water quality indices such as sodium absorption ratio (SAR), Kelly ratio (KR), sodium percentage (Na%), magnesium hazards (MH), residual sodium carbonate (RSC), permeability index (PI), and potential salinity (PS) using Eqs. (2)–(8). All values of the irrigation indices are expressed in meq/L.

Sodium absorption ratio:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\left(\mathrm{Ca}+\mathrm{Mg}\right)/2}} \tag{2}$$

Residual sodium carbonate:

$$\mathrm{RSC} = \left(\mathrm{HCO_3}+\mathrm{CO_3}\right)-\left(\mathrm{Ca}+\mathrm{Mg}\right) \tag{3}$$

Permeability index:

$$\mathrm{PI} = \frac{\sqrt{\mathrm{HCO_3}}+\mathrm{Na}}{\sqrt{\left(\mathrm{Na}+\mathrm{Mg}+\mathrm{Ca}\right)}} \tag{4}$$

Magnesium hazards:

$$\mathrm{MH} = \frac{\mathrm{Mg}\times 100}{\mathrm{Ca}+\mathrm{Mg}} \tag{5}$$

Percentage sodium:

$$\%\mathrm{Na} = \frac{\left(\mathrm{Na}+\mathrm{K}\right)\times 100}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}+\mathrm{K}} \tag{6}$$

Kelly ratio:

$$\mathrm{KR} = \frac{\mathrm{Na^+}}{\mathrm{Ca^{2+}}+\mathrm{Mg^{2+}}} \tag{7}$$

Potential salinity:

$$\mathrm{PS} = \mathrm{Cl^-}+\frac{1}{2}\times \mathrm{SO_4^{2-}} \tag{8}$$

4. Result and discussion

The drinking water quality guidelines were specified by the World Health Organization (WHO) in 2011 [26]. The statistical summary of the different physicochemical parameters in groundwater as along with WHO drinking water guidelines are presented in Table 1.

4.1. Physical characteristics of groundwater

4.1.1. pH

pH is an important parameter to evaluating the acidic or alkaline nature of the water. In case the pH value is not within the desirable range (6.5–8.5) recommended by WHO and BIS [27], it causes effects in humans such as skin to become dry, itchy and irritated, etc., and the results in pipe materials are corrosion, scale formation. The pH levels for groundwater in the study area varied between 7.3 and 8.5, with an average of 7.77, indicating slightly alkaline in nature. Fig. 4a represents that, all samples fall within the acceptable limit as recommended by BIS and WHO standards.

4.1.2. Electrical conductivity

In the study area, the EC value varies from 166 to 3,700 µS/cm, with a mean of 1,510.9 µS/cm (Table 1). As per WHO guidelines, the allowable limit of the EC is 1,500 µS/cm. Fig. 4b shows that, 312.06 and 299.36 km^2 of area are most desirable and not permissible level of EC, respectively. However, an acceptable level of EC is 53.5% of groundwater samples and the remaining 46.5% of groundwater samples are not permissible. Classifications of groundwater based on EC (Handa) [28] are represented in Table 2. Silicate weathering, carbonate dissolution, exchange of ions, oxidation,

Table 1
Descriptive statistical analysis of groundwater quality parameters

Parameters	Minimum	Maximum	Mean	Median	SD	Kurtosis	Skewness	WHO, 2011	
								Most desirable	Not permissible
pH	7.30	8.54	7.77	7.73	0.30	–0.27	0.49	6.5–8.5	<6.5 and >8.5
EC	166.00	3,700.00	1,510.94	1,431.91	796.48	0.77	0.80	<1,500	>1,500
TDS	106.24	2,190.05	892.11	874.00	467.30	0.83	0.86	<500	>1,500
TH	300.00	1,676.75	777.21	712.49	274.50	1.53	0.98	<100	>500
Ca^{2+}	60.00	250.00	126.99	131.00	36.57	2.04	0.74	<75	>200
Mg^{2+}	12.00	174.00	84.23	86.00	40.91	–0.29	0.10	<50	>150
Na^+	13.00	457.00	157.12	135.88	93.10	1.56	0.99	<200	>200
K^+	0.00	94.46	34.29	20.00	31.81	–1.35	0.53	<10	>10
Cl^-	12.50	716.00	239.62	234.26	134.73	2.91	1.44	<200	>600
HCO_3^-	82.00	769.00	237.86	198.65	137.83	4.37	1.90	<300	>600
SO_4^{2-}	7.00	421.00	154.93	153.00	86.50	1.07	0.60	<400	>400

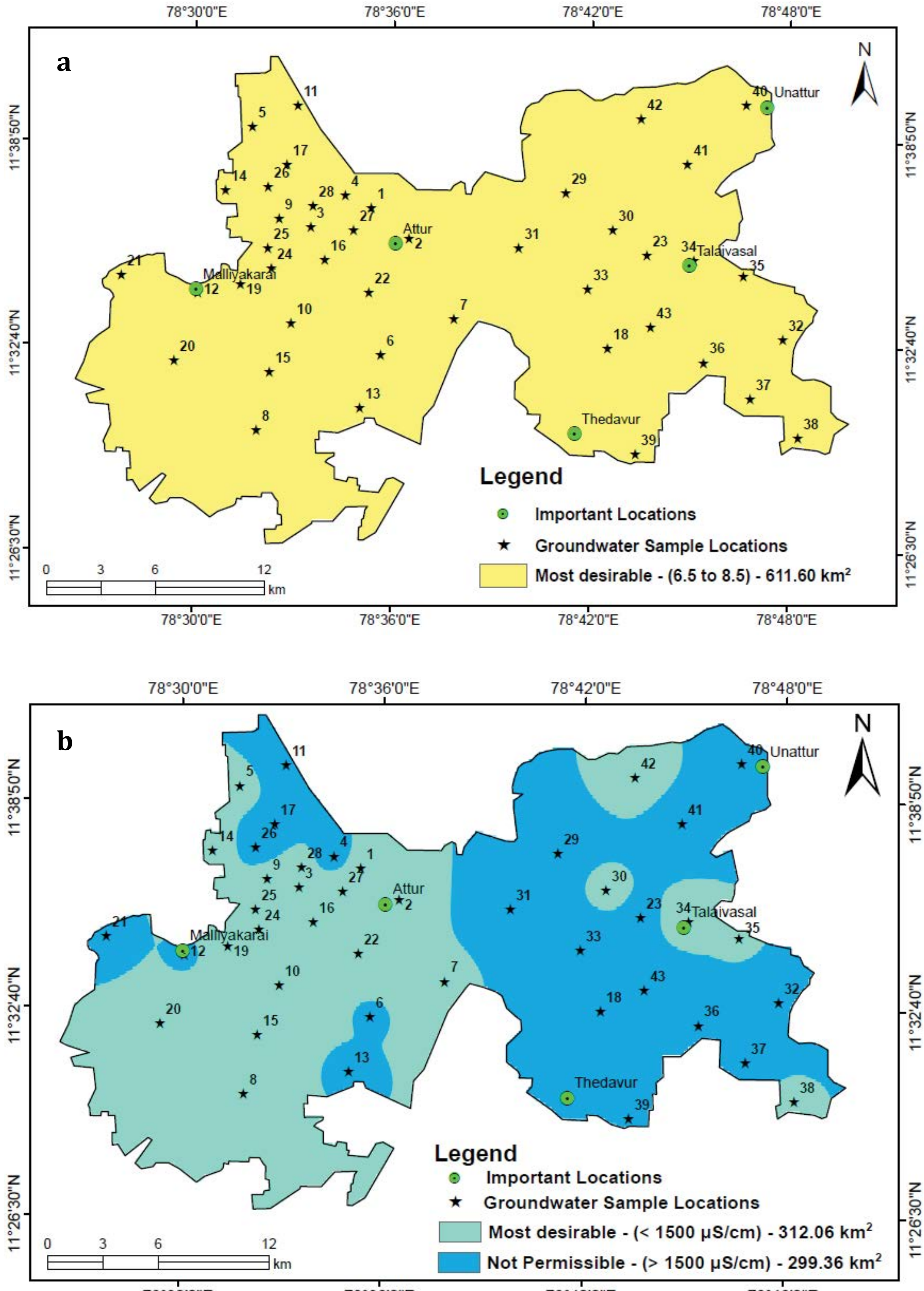


Fig. 4. Spatial distribution (a) pH and (b) EC.

and anthropogenic activities are the main factors for high elevated of EC in groundwater [29,30].

4.1.3. Total dissolved solids

TDS is a mixture of organic dissolved matter and inorganic salts in water [31]. In the study area, TDS values varied between 106.24 and 2,190.05 mg/L with a mean value of 892.1 mg/L. The spatial distribution map of TDS is most desirable 21% of groundwater samples, the maximum allowable limit 67.4% of samples and the not permissible limit 11.6% of samples (Fig. 5a). As per Davies and Dewiest [31] classification, all sample locations are fit for both domestic and agriculture uses (Table 3).

Table 2
Classification of groundwater based on EC

EC (µS/cm)	Water type	Classification	No. of samples	% of samples
0–250	Low	Excellent	1	2
251–750	Medium	Good	4	9
751–2,250	High	Permissible	32	75
2,251–6,000	Very high	Doubtful	6	14
6,001–10,000	Extensively high	Poor	–	–
100,001–20,000	Brines weakly concentration	Very poor	–	–

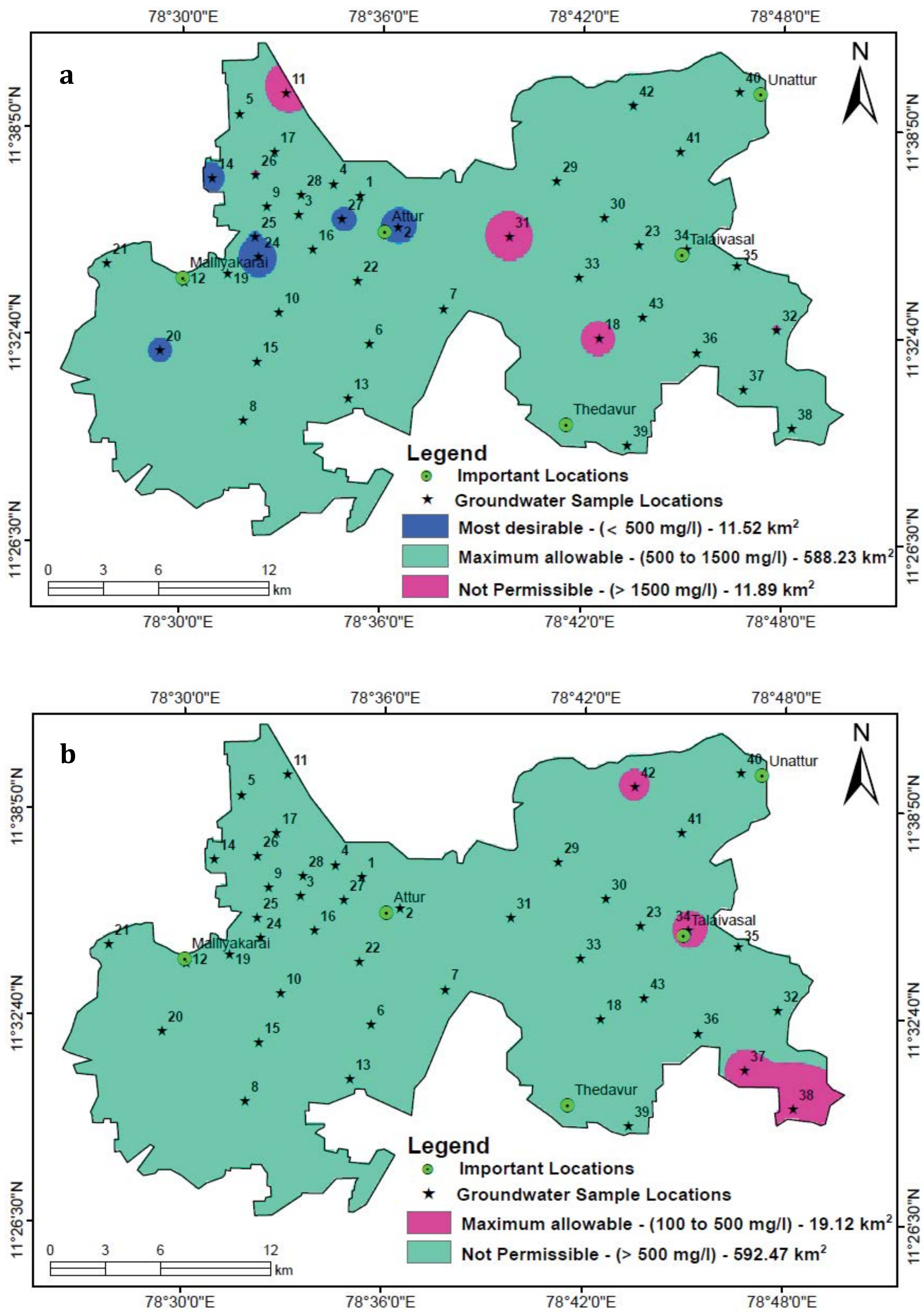


Fig. 5. Spatial distribution (a) TDS and (b) TH.

Table 3
Classification of groundwater of the study area based on TDS and TH

Parameter (mg/L)	Range	Classification	No. of samples	% of Samples
TDS	<500	Desirable for drinking	9	20.93
	500–1,000	Permissible for drinking	18	41.86
	1,000–3,000	Useful for irrigation	16	37.21
	>3,000	Unfit for drinking and irrigation	–	–
TH	<75	Soft	–	–
	75–150	Moderately hard	–	–
	150–300	Hard	1	2.33
	>300	Very hard	42	97.67

4.1.4. Total hardness

A concentration of calcium and magnesium are the major ions influence the presence of hardness in groundwater [32]. TH ranges from 300 to 1,676.75 mg/L with a mean of 777.2 mg/L. About 9.3% of the total hardness of groundwater is within the permissible limit of 400 mg/L and 90.7% of the samples are not permissible for drinking purpose recommended by BIS and WHO. In a study region, 592.47 km^2 of area are not permissible and 19.12 km^2 of area are acceptable level (Fig. 5b). In addition, Sawyer et al. [33] classification of total hardness, all samples belong to a very hard nature (Table 3). A detailed classification of groundwater quality on the basis of TDS and TH is shown in Fig. 6. Around 37% of the samples were categorized as a hard-brackish type and the remaining 63% of samples were classified as hard yet fresh groundwater [34]. High concentrations of hard water might have an adverse effect on the drinking water supply and the consumption of more soap in laundries, as well as on human health.

4.2. Chemical characteristics of groundwater

4.2.1. Calcium

According to WHO guidelines, the permissible and maximum permissible calcium level in drinking water is 75 and 200 mg/L, respectively. Calcium concentration ranges from 60 to 250 mg/L with a mean value of 127 mg/L (Table 1). About 95.34% of the sample locations are fit for drinking uses and two locations such as Attur and Ramanathapuram are observed as not suitable for domestic purposes (Fig. 7a). Some anthropogenic activities like an excessive amount of fertilizer, pesticides may be a major cause of higher concentration of calcium ions. Calcium minerals such as calcite, plagioclase, and hornblende may be a natural source as they are the main source of calcium in groundwater. Charnockite and hornblende-biotite-gneiss are the main rock types in the study area and act as the main source of Ca^{2+} in the groundwater [35].

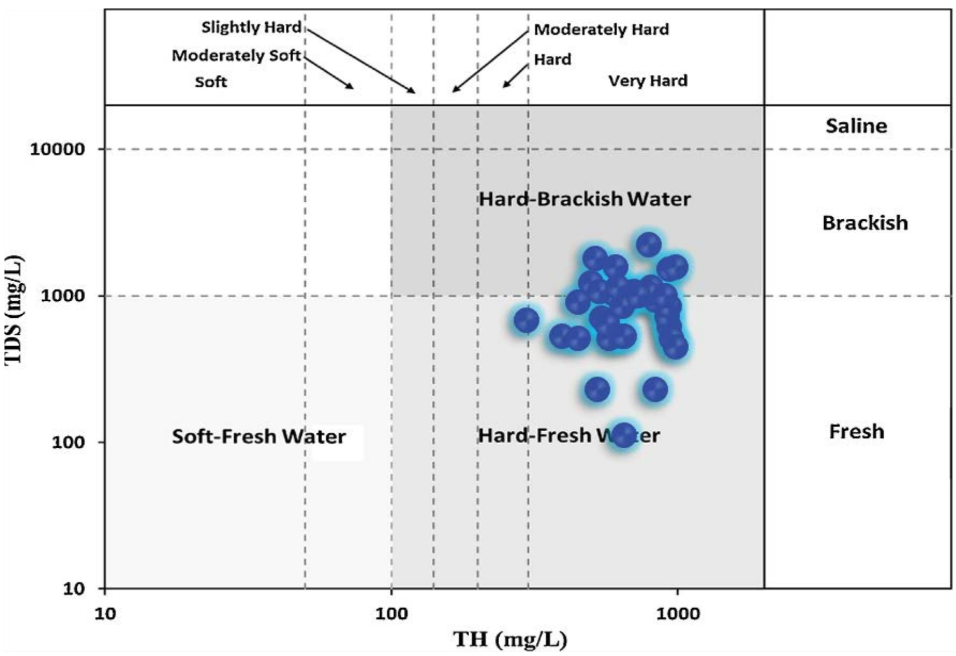


Fig. 6. Groundwater quality in the study area based on TDS and TH.

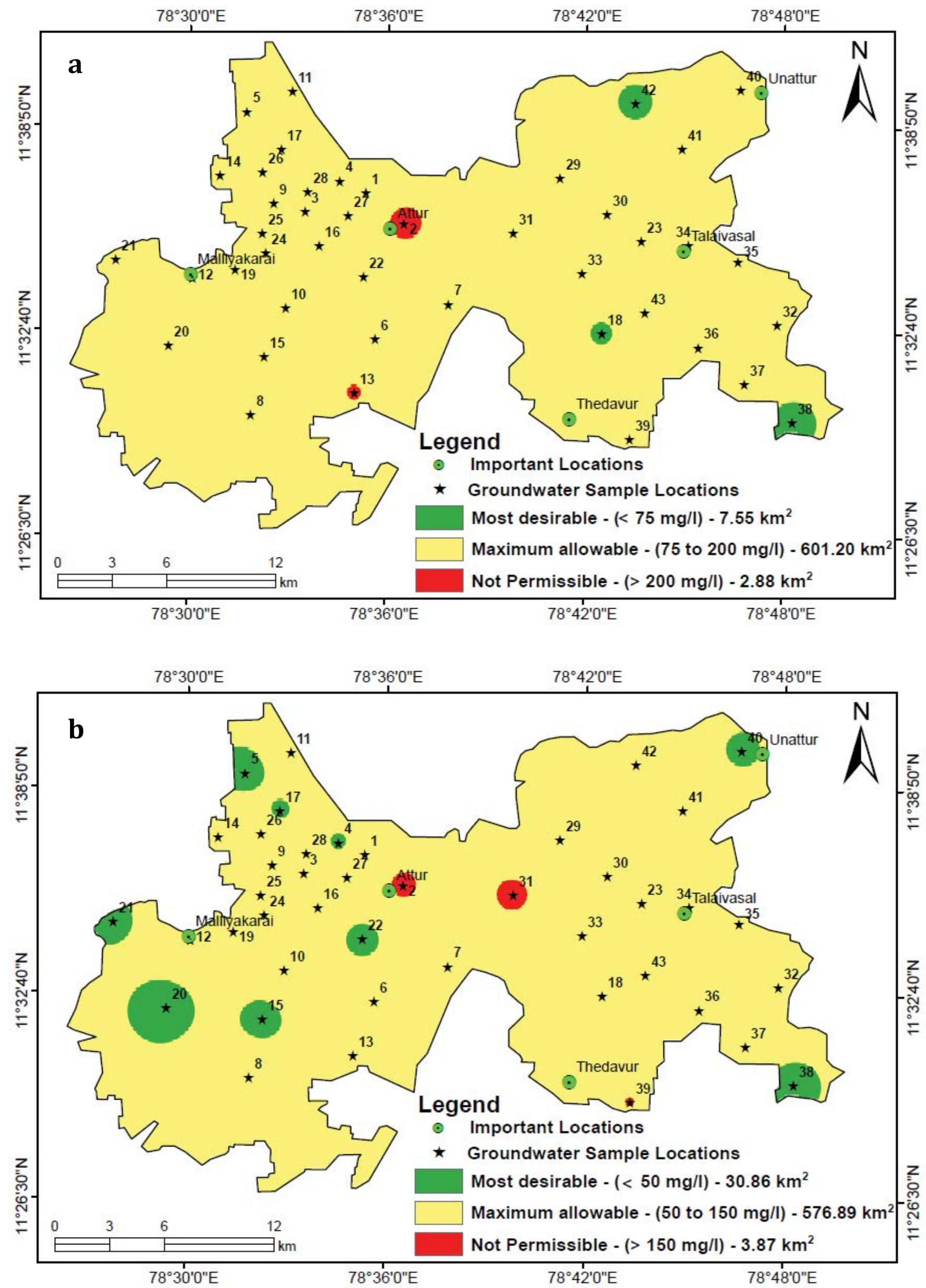


Fig. 7. Spatial distribution (a) Ca^{2+} and (b) Mg^{2+}.

4.2.2. Magnesium

The concentration of Mg^{2+} ranges from 12 to 174 mg/L with a mean value of 84.2 mg/L (Table 1). Attur and Kattukottai locations covered by charnockite rock, which has Mg-rich pyroxene as the predominant mineral, it may also be a significant source of Mg^{2+} in such areas [36]. The spatial distribution of a magnesium concentration is 30.86 km^2 of area is desirable, 576.89 km^2 is maximum permissible and 3.87 km^2 is not suitable for drinking purposes (Fig. 7b). The possible source of magnesium in the area may be agricultural activities and wastewater discharged from the domestic and sago factories [37].

4.2.3. Sodium

In a study area, the concentration of sodium ion ranges from 13 to 457 mg/L with a mean value of 157.1 mg/L. In 79% of the samples found within the allowable limit and 21% of the samples, Na^+ exceeded the standard permissible level recommended by the WHO drinking water guidelines. The spatial distribution of sodium in the study area is shown in Fig. 8a and it reveals that, 520.82 km^2 of the area observed that permissible limit and the 90.77 km^2 of the area was recorded as not permitted for drinking purposes. The concentration of sodium in groundwater played a significant role in irrigation and triggered both increased hardness and a reduction in the soil permeability [38]. It makes the water in salt tasty. This is attributed to the weathering or degradation of soil salt, which is held as well as the agricultural practices and poor drainage conditions due to the effects of evaporation and anthropogenic activities [39].

4.2.4. Potassium

Potassium concentrations ranged from 0 to 94.46 mg/L with an average value of 34.3 mg/L (Table 1). According to WHO guidelines, the permissible level for drinking water

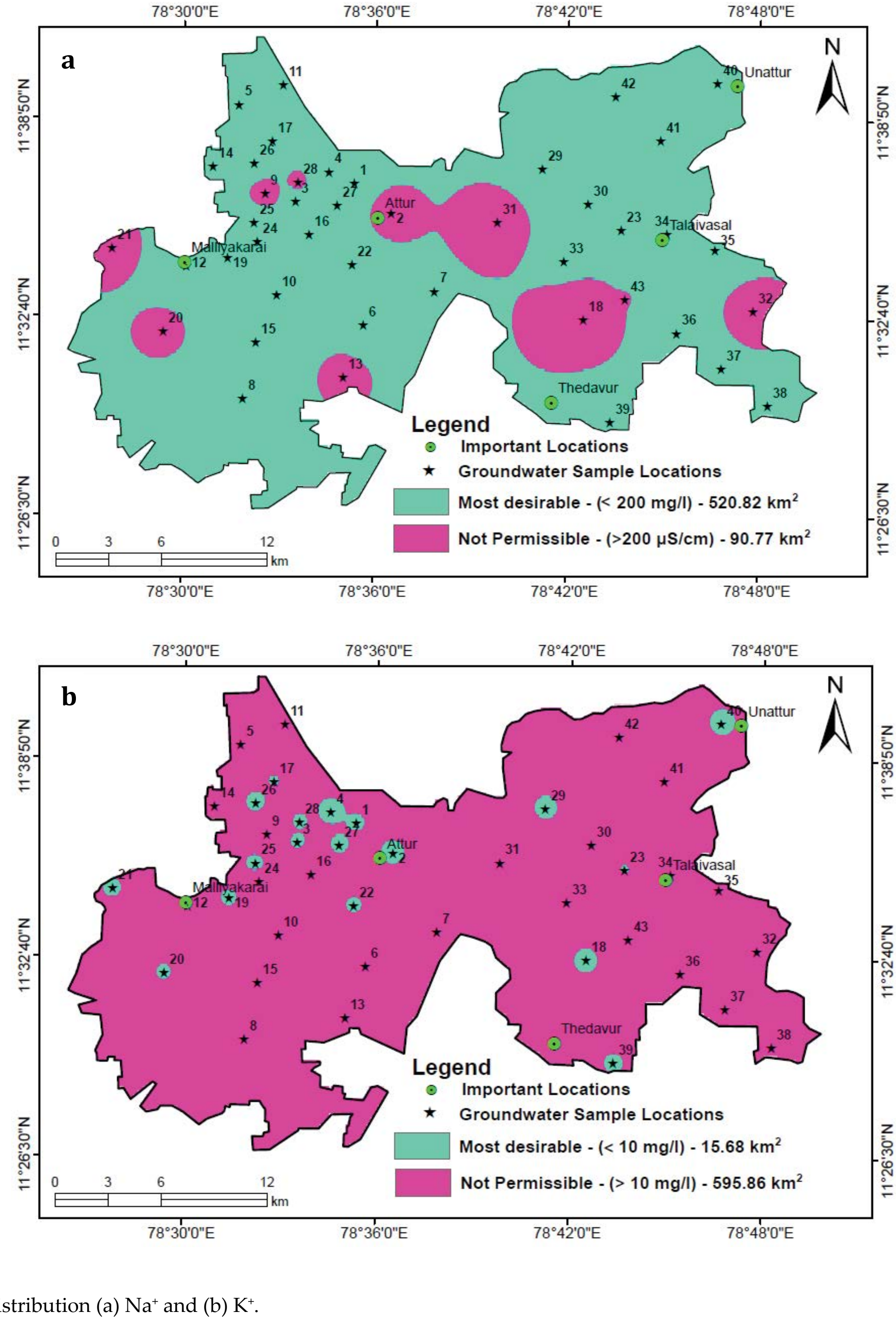


Fig. 8. Spatial distribution (a) Na$^+$ and (b) K$^+$.

in potassium is 10 mg/L. In this study K^+ concentrations, within the permissible limit in 19 (44.2%) samples, and the remaining samples exceed the limit. Spatially most of the area observed at a high potassium concentration of 595.86 km^2 is not permissible and the most desirable limit is 15.68 km^2 (Fig. 8b). High potassium concentrations may originate from K-Feldspar, which is present in the formation of charnockite and hornblende-biotite-gneiss and fertilizer (located in agricultural area), which is strongly retained by the soil of clay particles [40].

4.2.5. Hydrochemical facies of groundwater

Piper trilinear diagram described the water types and identified the major ions influencing the quality of groundwater. Fig. 9 represents the hydrochemical facies of groundwater in the study area. It reveals that, 83.72% of the samples fall in the mixed concentration of Ca^{2+}–Mg^{2+}–Cl^- type, 9.30% of the samples fall in the Ca^{2+}–Cl^- type and 6.98% of the sample locations fall in the Na^+–Cl^- type. It indicates that, the major ions such as calcium, magnesium, sodium, and chloride play a vital role in the quality of groundwater [41]. Inadequate rainfall, evaporation, rock water interaction, ion exchange process are the major factors that influencing the nature of groundwater.

4.2.6. Gibbs plot

Gibbs used to identify major processes controlling the hydrochemistry. It clearly describes the chemistry of the water, which is stored in the lithology of the aquifer and residence time. Three types of separate fields in a plot are evaporation dominance, rock water interaction, and evaporation dominance. Fig. 10 shows that, Gibbs anion and cation of groundwater in a study area. It reveals that, more than partial numbers of sample locations fall in the rock water interaction type and few of the sample locations fall in the evaporation dominance type. It indicates that a poor pattern of rainfall, evaporation, and weathering is the major factor influencing the quality of groundwater.

4.2.7. Chloride

Chloride is one of the essential parameters for the indication of organic matter in water. The excessive chloride content in drinking water can affect the taste, kidney, heart problem, oxidation, and digestibility of the water [42]. The concentration of chloride varies from 12.5 to 716 mg/L with a mean value of 239.6 mg/L (Table 1). Fig. 11a shows that, 19 sample (140 km^2) locations are fall in permissible limit. On the other hand, 23 samples fall within the maximum allowable limit 200–600 mg/L, covering 469.36 km^2 and around the Kattukottai region it is exceeded the limit (716 mg/L) in 2.03 km^2. The main source of chloride at higher concentrations is the influence of percolation, leaching, contamination, dissolution, discharge of domestic, and industrial effluents [43–45]. Weathering of halite rocks, household waste, manures, septic tanks, and waste disposal sites are the main causes of high chloride content in the study area.

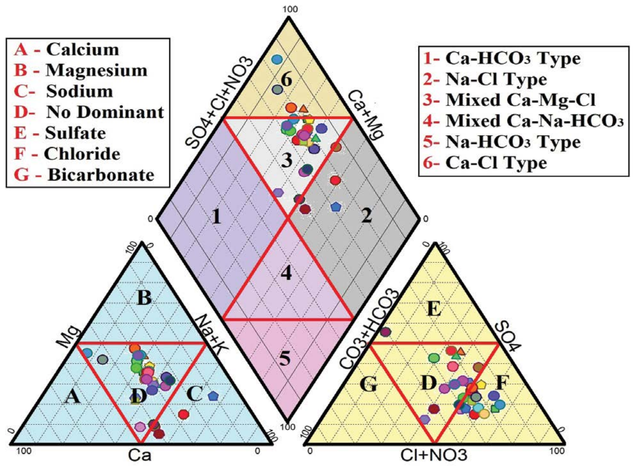


Fig. 9. Piper trilinear diagram of groundwater.

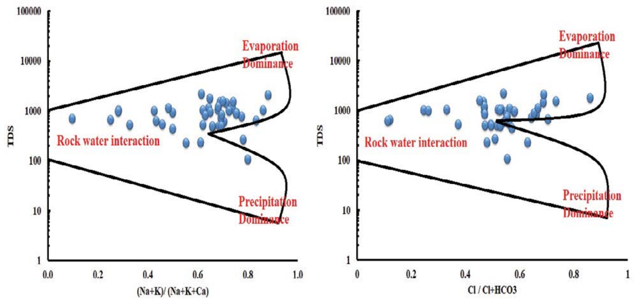


Fig. 10. Mechanisms controlling hydro geochemistry in study area.

4.2.8. Bicarbonate

In this study area, HCO_3^- values varied between 82 and 769 mg/L with a mean value of 237.9 mg/L (Table 1). The bicarbonate distribution map shows the acceptable, maximum allowable, and not permissible limits of drinking water of 521.67, 87.75, and 2.20 km^2, respectively (Fig. 11b). The increase in the concentration of HCO_3^- may be due to the dissolution of CO_2 gas into the water in the air or soil, and the return flow of irrigation containing precipitated carbonate minerals in the soil [46]. The CO_3^{2-} and HCO_3^- may be derived from silicate rock weathering, CO_3^{2-} precipitate dissolution, and CO_2 gas from the atmosphere and soil [47].

4.2.9. Sulfate

Sulfate concentration in the study area varies between 7 and 421 mg/L with an average of 154.9 mg/L (Table 1). The sulfate distribution map shows the acceptable and not permissible limits of drinking water in a 611.44 and 0.16 km^2 of the study area, respectively (Fig. 12). In the area around Thandrayapuram, the percolation of sulfate-rich water from agricultural runoff is high in sulfate concentrations. According to WHO guidelines, a sulfate concentration of surpassed 400 mg/L with sodium or magnesium can cause gastrointestinal irritation.

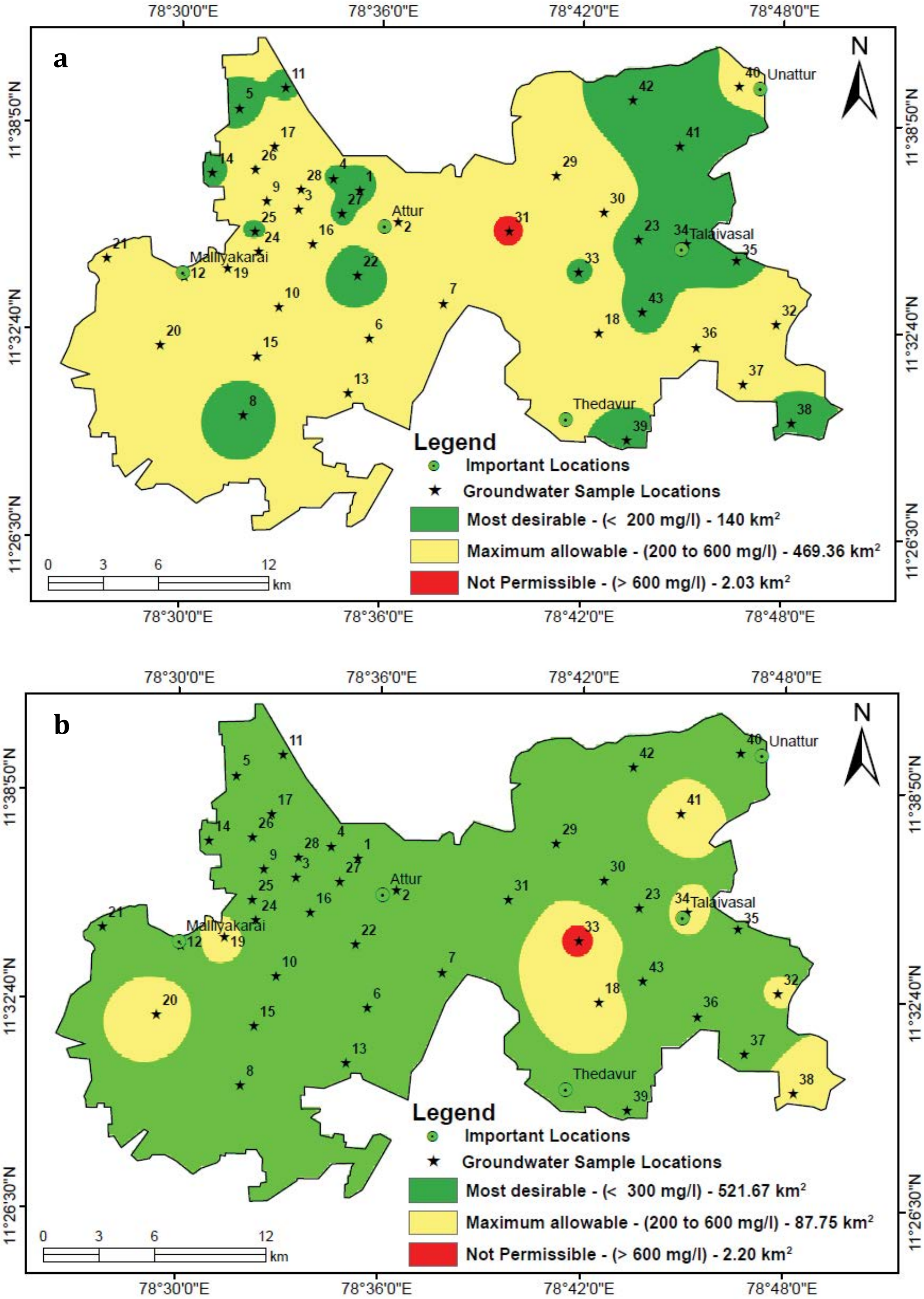


Fig. 11. Spatial distribution (a) Cl^- and (b) HCO_3^-.

4.3. Irrigation indices

To assess the suitability of groundwater for irrigation purposes different indices such as SAR, RSC, PI, PS, MH, (%Na), and KR were calculated and the statistical summary of the results is presented in Tables 4 and 5.

4.3.1. Sodium absorption ratio

The exchangeable Ca^{2+} and Mg^{2+} ions are replaced by Na^+, the high Na^+ content of irrigation water changes the soil characteristics and reduce the crop yield [48]. In the present work, the SAR values ranged from 0.21 to 8.70 meq/L with a mean value of 2.74 meq/L (Table. 4). The spatial distribution of SAR in the study area is shown in Fig. 13a. The SAR classification shows that all groundwater samples are excellent for irrigation purposes (Table 5). In addition, Fig. 14a shows that, USSL classification of groundwater to assess its suitability for irrigation uses. About 32 sample locations fall in the high conductivity and low salinity (C3–S1), each 2 sample locations fall in the C3–S2 and C4–S1 category, the remaining one sample is C4–S3 category. It

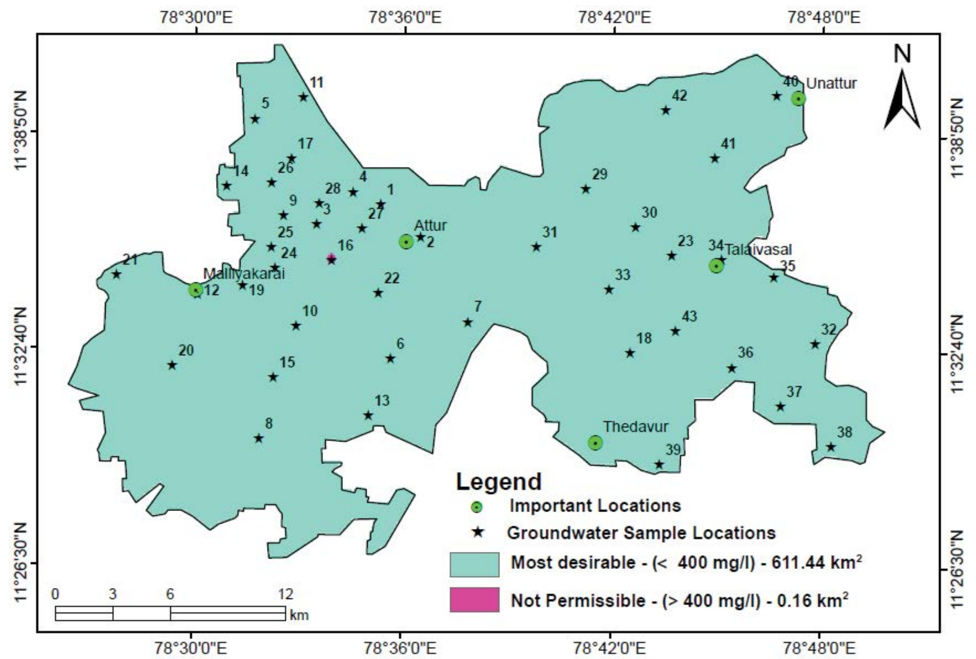


Fig. 12. Spatial distribution of SO_4^{2-}.

Table 4
Statistical summary of computed water quality parameters for irrigation

Irrigation indices	Minimum	Maximum	Average	Median	Standard deviation	Kurtosis	Skewness
SAR (meq/L)	0.21	8.70	2.74	2.55	1.63	3.22	1.20
%Na (%)	6.45	65.58	36.15	35.98	13.35	0.15	–0.26
RSC (meq/L)	–22.84	2.54	–9.30	–9.23	5.08	0.20	–0.18
MH (%)	11.19	69.92	49.62	52.32	14.02	1.16	–1.16
PI (%)	11.06	75.61	43.39	44.77	15.22	–0.12	0.07
PS (meq/L)	1.09	21.05	7.31	7.13	3.88	2.91	1.43
KR	0.04	1.90	0.57	0.53	0.38	2.79	1.31

indicates that the more than partial number of sample locations is suitable for irrigation in almost all soil and crop type.

4.3.2. Residual sodium carbonate

Residual sodium carbonate value is used to evaluate the suitability of groundwater for irrigation in clay soils with high cation exchange capacity [49]. In general, the high concentration of carbonate and bicarbonate is due to the alkaline nature of the soil, which is unfavorable for agricultural use. In a study area, RSC ranged from –22.84 to 2.54 meq/L with an average of –9.30 meq/L (Table 4). The RSC value less than 1.25 indicates that groundwater is safe for irrigation purposes, 42 samples (98%) were safe for irrigation in the study area, and 1 sample (2%) were marginal to unsuitable for irrigation purposes (Table 5, Fig. 13b).

4.3.3. Percentage of sodium

Excess sodium in irrigation water, deteriorate the soil structure, and reduces crop yield. When the sodium ion concentration in the irrigation water is high, Na^+ tends to be absorbed by clay particles, replacing magnesium and calcium ions. This process of sodium exchange in water for Ca^{2+} and Mg^{2+} in soil reduces permeability and ultimately leads to poor internal drainage of soil. In the study area, %Na ranged from 6.45% to 65.58% with an average of 36.15% (Table 4). It is observed that 35 samples were classified as excellent and good for irrigation, followed by 15 samples and 1 sample were categorized as moderate and doubtful for irrigation (Table 5, Fig. 15a). In addition, the Wilcox classification [50] of groundwater was carried out in the study area. Fig. 14b represents that, 81% of sample locations fall in good, 5% of sample locations fall in moderate and 14% sample locations fall in doubtful for irrigation uses.

4.3.4. Magnesium hazards

Magnesium hazards is an important index value to assess the suitability of water for irrigation purposes. Calcium and magnesium generally retain a stable form in groundwater [51–53]. In some cases, more magnesium

Table 5
Irrigation water quality of groundwater based on various irrigation indices

Irrigation indices parameters	Range	Water class	Pre-monsoon	
			No. of Samples	% of samples
Sodium absorption ratio (SAR)	0–10	Excellent	43	100
	10–18	Good	0	0
	18–26	Doubtful	0	0
	>26	Unfit	0	0
Residual sodium carbonate (RSC)	<1.25	Good	42	98
	1.25–2.5	Doubtful	0	0
	>2.5	Unfit	1	2
Permeability index (PI)	>75	Class-I	1	2
	25–75	Class-II	37	86
	<25	Class-III	5	12
Magnesium hazards (MH)	<50	Suitable	18	42
	>50	Unsuitable	25	58
Percentage sodium (% Na)	<20	Excellent	0	0
	20–40	Good	35	81
	40–60	Moderate	2	5
	60–80	Doubtful	6	14
	>80	Unfit	0	0
Kelly ratio (KR)	<1	Suitable	38	88
	>1	Unsuitable	5	12
Potential salinity (PS)	<5	Excellent to good	12	28
	5–10	Good to injurious	22	51
	>10	Injurious to un-satisfactory	9	21

present in water affects the soil quality and converts it to alkaline, which reduces the yield of the crop. If the magnesium hazard exceeds 50, then the water is hazardous to agriculture and unsuitable for irrigation. Magnesium hazards range from 11.19 to 69.92 at an average value of 49.62 in the study area (Table 4). The magnesium hazards in 58% of the bore well water samples exceed 50 and are not suitable for irrigation purposes (Table 5, Fig. 15b). In the study area, mainly charnockite rock, with Mg-rich pyroxene as the predominant mineral and the origin of excess magnesium in groundwater [54].

4.3.5. Permeability index

Permeability is mainly controlled by ions Na, Ca, Mg, Cl, and HCO_{32}^- of the soil and is influenced by long-term use of high salt content irrigation. In the agricultural perspective, a high permeability index, combined with geological characteristics, would facilitate the widespread pollution of underground water. According to Doneen classification [55], class I (>75%), class II (25%–75%), and class III (<25%). The PI value ranges from 11.06% to 75.61%, with an average of 43.39% (Table 4). The Doneen classification shows that 2% and 86% of the samples in class I and II mean that the water is suitable for irrigation and that the remaining 12% of the samples in class III are not suitable for irrigation purposes (Table 5, Fig. 16a).

4.3.6. Potential salinity

PS is determined as the chloride concentration of almost half of the sulfate concentration, which might also imply the suitability of groundwater for agriculture. The PS values ranged from 1.09 to 21.05 meq/L, with a mean of 7.31 meq/L. Classifications for groundwater quality on the basis of PS are shown in Table 5. About 28% and 51% of samples were classified as excellent to good and good to injurious class, respectively (Table 5). The remaining 21% of the samples classified as injurious to unsatisfactory indicate that, not suitable for irrigation [21,56,57]. The spatial distribution of PS classification of irrigation water quality is shown in Fig. 16b.

4.3.7. Kelly ratio

The concentration of sodium calculated against calcium and magnesium ion is known as Kelly ratio [58,59]. It is an important factor to assess the suitability of groundwater for irrigation uses in a study area. The value of Kelly ratio, less than one is suitable and greater than one is unsuitable for irrigation uses. In the study area, the Kelly ratio ranged from 0.04 to 1.90 with an average of 0.57 (Table 4). In that regard, 88% of the samples fell within the allowable limit of less than 1 and were categorized as suitable and safe for irrigation purposes, while the remaining 12%

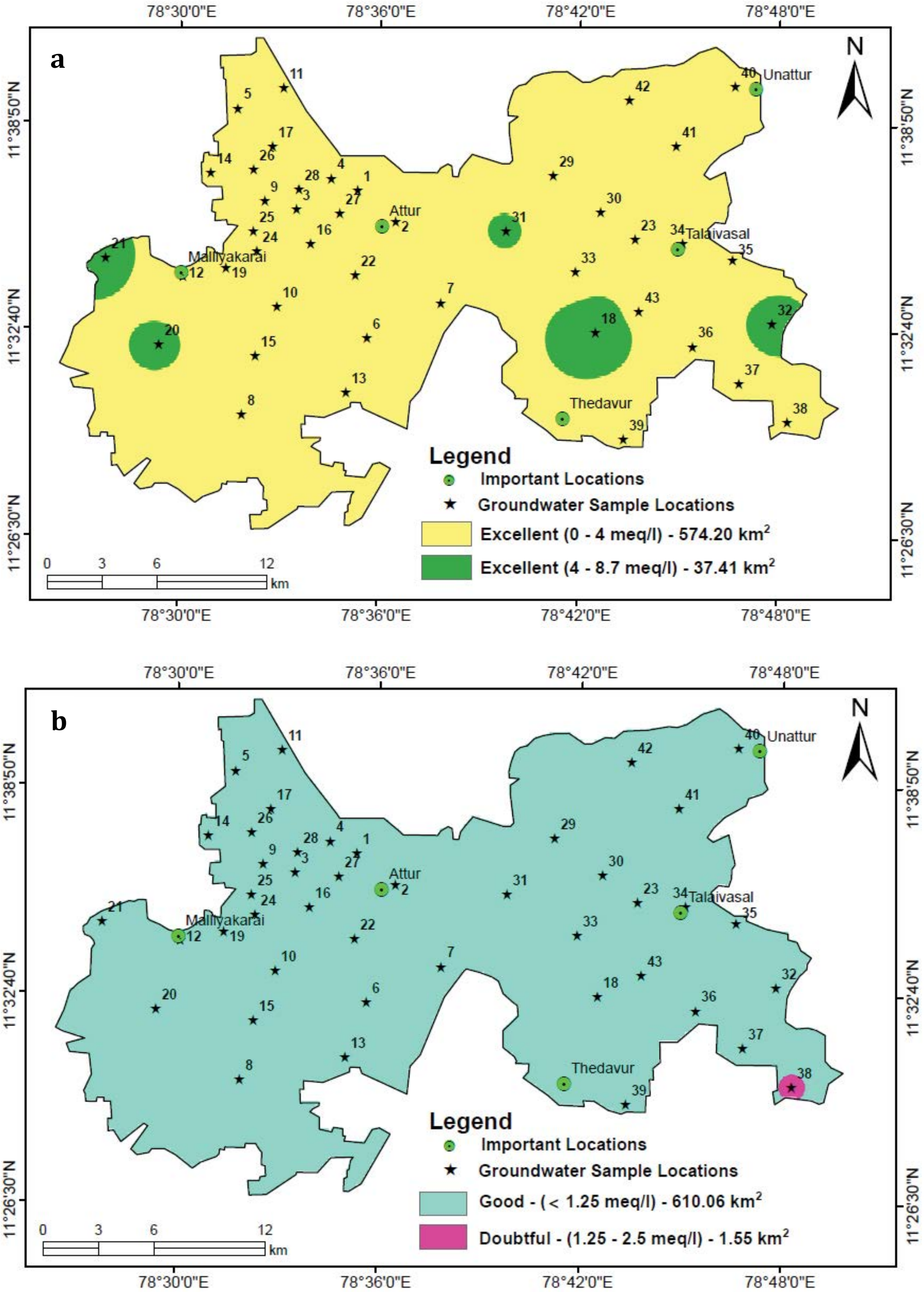


Fig. 13. Spatial distribution (a) SAR and (b) RSC.

of the samples exceeded the allowable limit of more than 1 and were categorized as unsuitable for irrigation purposes (Table 5, Fig. 17).

4.4. Box plot of the groundwater

Box plot one of the efficient methods to identify the anion and cation dominance. It used to represent time-based concentration and influence of major ions. The plot estimated the mean, median, and standard deviation of groundwater [60]. The top and bottom of the rectangular box represent the upper and lower quartiles of the parameters. The middle line represents the median and the size of the box indicates the spores of the central value. In a study area, the box plot of groundwater reveals that influencing by the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cations and $Cl^- > HCO_3^- > SO_4^{2-}$ for anions (Fig. 18). It represents that, the chemical composition of groundwater highly dominated by

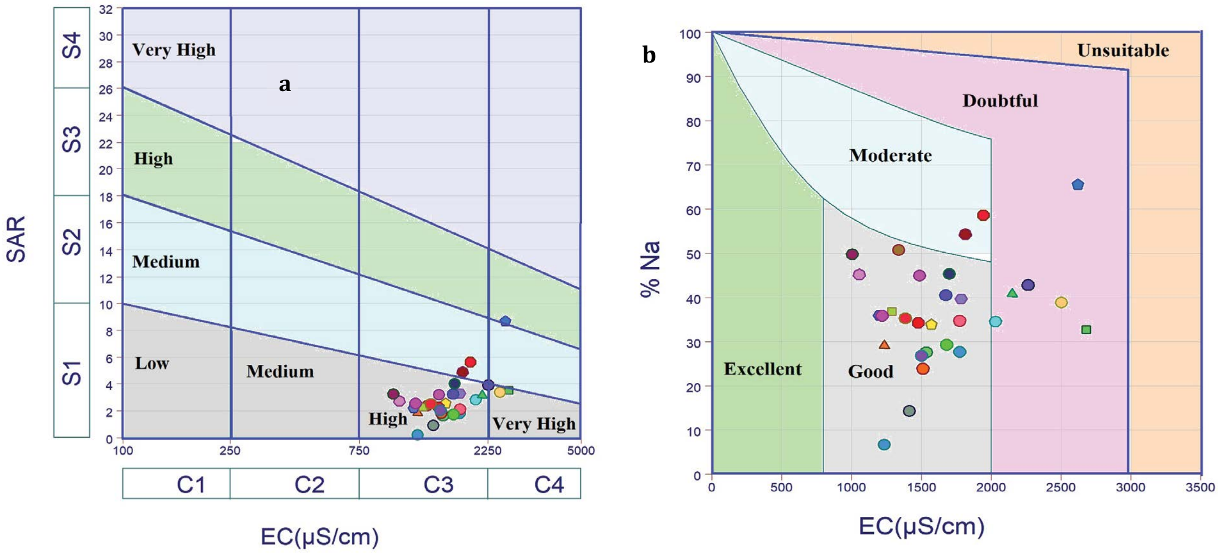


Fig. 14. (a) USSL diagram and (b) Wilcox diagram of groundwater in study area.

the processes of weathering of minerals, rock water interaction, ion exchange process, and anthropogenic activities.

4.5. Principal component analysis

PCA has been carried out on the groundwater parameters to identify and describe the geochemical processes and sources of pollution dominating the nature of groundwater in the study area. Fig. 19 shows that, scree plot of the principal component of the variable and five components have an eigenvalue of greater than 1. In the present study, principal components corresponding to loading values of greater than 0.65 (bold), five principal components were extracted by the varimax rotation method and total variance is 77.28 % are presented in Table 6 and Fig. 20. PC1 reveals that TDS, EC, Na^+, Cl^-, and SO_4^{2-} are positively weighted (strong correlation) with 18.92% of the total variance and it described that, rock weathering and anthropogenic activities are major sources of contamination in the study area. PC2 shows that TDS and EC are positively correlated and Ca^{2+} and Mg^{2+} are negatively correlated. A variance of PC2 is 18.61% and a cumulative variance of 37.54%. The negative values indicate weathering of parent rock minerals are dominated by the quality of groundwater. PC3 illustrates 16.63% of the variance with positive weight on K^+ ion is high among all the major ions and 54.17% of cumulative variance. It shows that groundwater quality influenced by weathering of potassium-rich minerals like feldspar and potash rock. PC4 has 11.78% and 65.96% of the total and cumulative variance. It indicates that SO_4^{2-} rich

Table 6
Loading factors of groundwater parameters

Variable	PC1	PC2	PC3	PC4	PC5
pH	0.088	0.462	0.522	0.438	0.177
TDS	**0.670**	**0.647**	–0.046	–0.061	–0.246
TH	0.584	–0.521	0.032	0.319	–0.040
EC	**0.635**	**0.668**	–0.039	–0.163	–0.239
Ca^{2+}	0.429	–0.622	0.462	–0.003	0.074
Mg^{2+}	0.555	–0.365	0.292	–0.287	–0.245
Na^+	**0.688**	0.019	–0.378	–0.099	0.539
K^+	0.322	0.066	0.569	–0.265	–0.301
Cl^-	**0.805**	–0.182	–0.205	–0.145	0.176
CO_3^{2-}	–0.101	0.256	0.435	0.364	0.397
HCO_3^-	0.028	0.176	0.270	–0.576	0.636
SO_4^{2-}	**0.665**	0.011	–0.135	0.606	0.053
Eigen value	2.271	2.234	1.996	1.414	1.358
% Variance	18.928	18.618	16.632	11.784	11.320
Cumulative variance	18.928	37.545	54.177	65.962	77.282

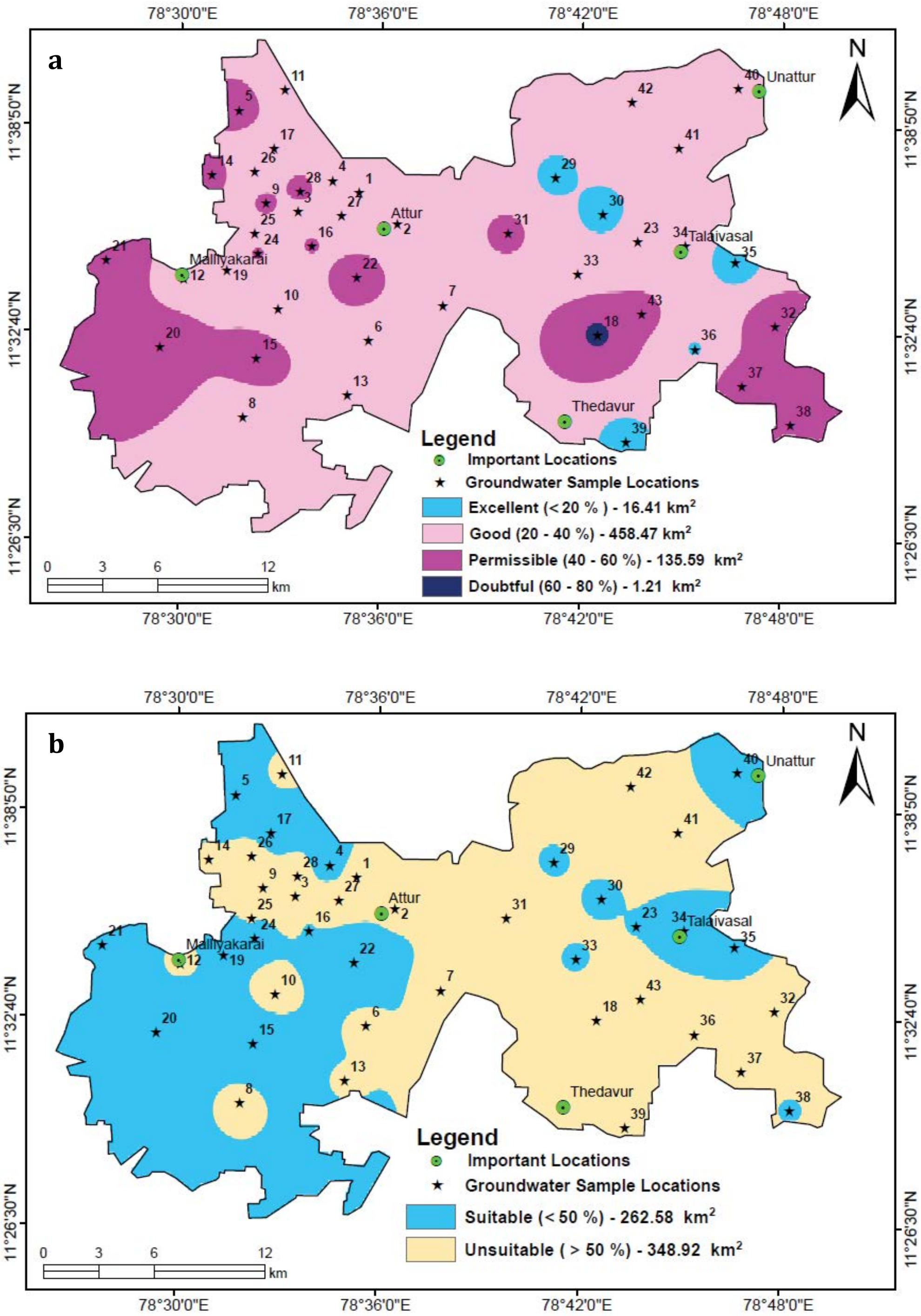
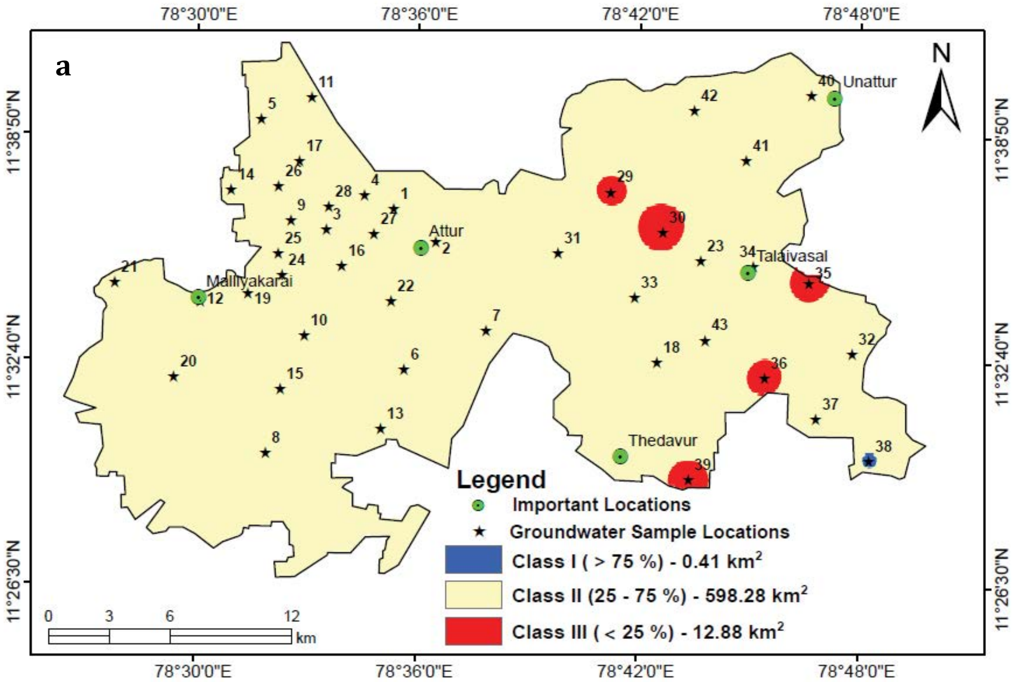


Fig. 15. Spatial distribution (a) %Na and (b) MH.

minerals are dominated. PC5 has 11.32% and 77.28% of total and cumulative variance [61].

4.6. Hierarchical cluster analysis

HCA is widely used to represent the cluster group of each parameter and sample locations in the study area. This linkage method used to determine the distance between the group of samples as a function of the pair-wise distance between observation. In a study area, HCA was achieved for water quality parameters and sample locations were carried out. Fig. 21a represents, the chemical parameters are classified into three clusters. Cluster 1 comprises of pH, CO_3^{2-}, K^+, Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, Cl^-, and HCO_3^-. The second cluster comprises, TDS and TH. Cluster 3 measures EC. Cluster 1 represents the total dissolution



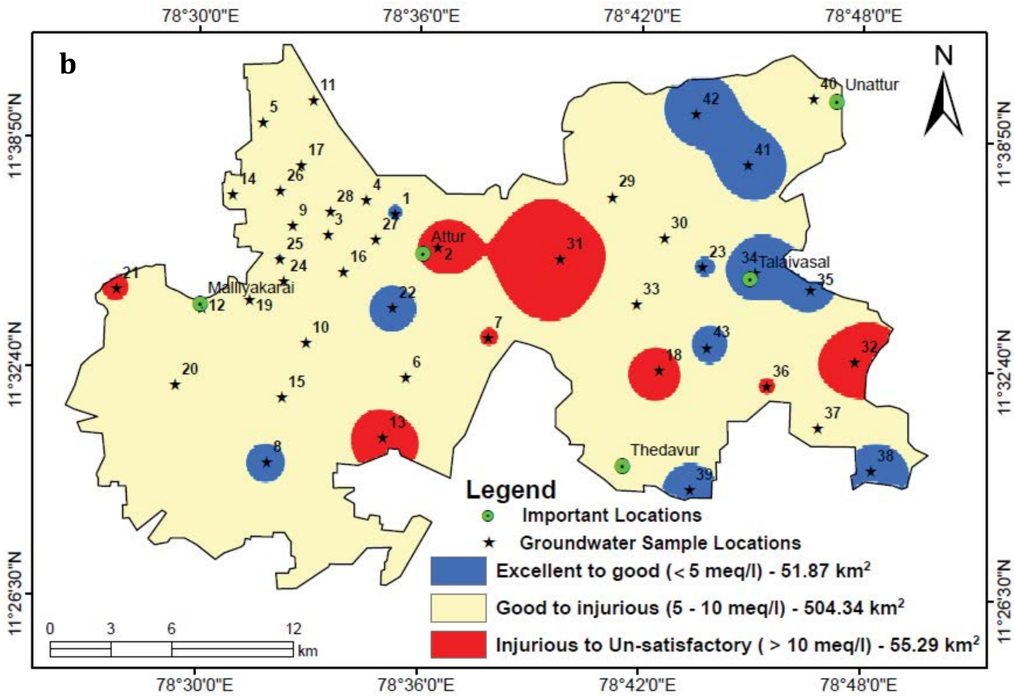


Fig. 16. Spatial distribution (a) PI and (b) PS.

of all ions and reveals that weathering and anthropogenic activities (domestic waste, quality of irrigation water, and excess utilization of chemical fertilizers) are the factors that influence the nature of groundwater. Fig. 21b represent the linkage of sample locations in the study area. The sample locations are classified into eight different groups using linkage methods. The group 1 comprise (4,21,26, and 32) 9.30% of the sample locations, group II measures (3,6,8,12 ,13,16,17,23,29,33,36,37,39,40,41, and 43) 37.20% of sample locations, 1,5,22,30,34,35,38, and 42 sample locations are group III, group IV comprises 9,15, and 28, group V comprise 7,10,19,20, and 25, group IV comprise 2,14,17, and 24, and group VII measures 11,18, and 31.The result of HCA reveals that, geogenic process, weathering of parent rocks, reverse ion exchange process and anthropogenic activities are highly influencing the nature of groundwater quality.

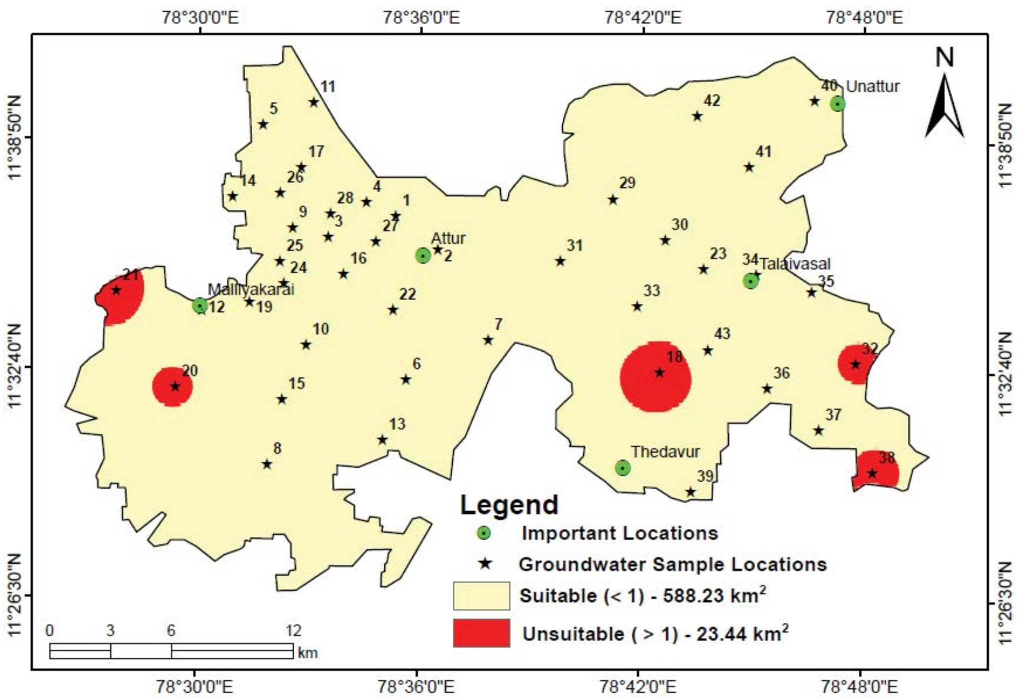


Fig. 17. Spatial distribution of Kelly ratio.

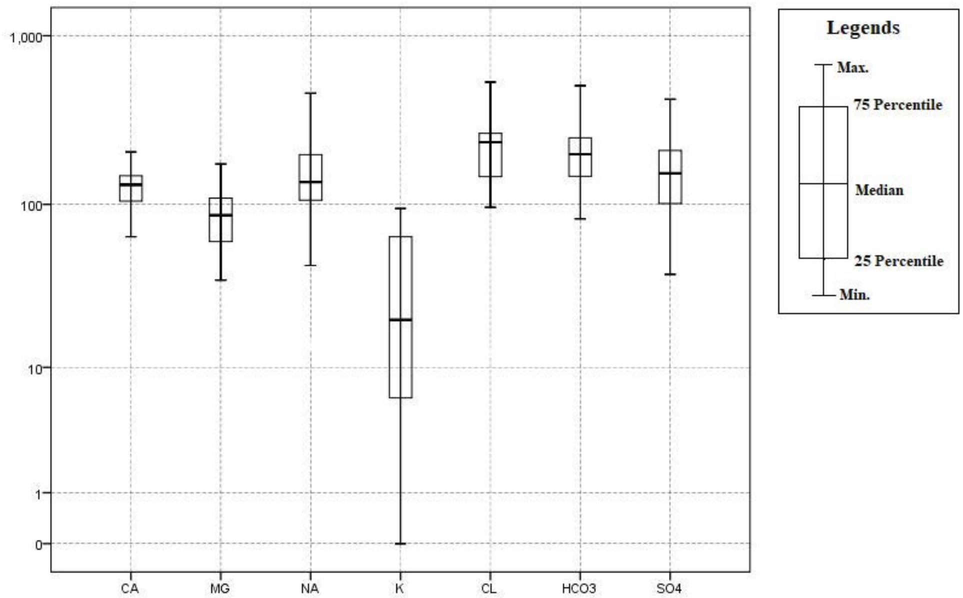


Fig. 18. Box plot for the major cations and anions.

5. Conclusion

In the present study, the assessment of groundwater quality for drinking and irrigation purposes in Attur Taluk was evaluated in accordance with the suggested standard guidelines. The study draws the following conclusions.

- Groundwater is predominantly alkaline in nature from the study area. The EC (46.5% of samples) and TDS (11.6% of samples) values were found to be greater than the acceptable limit as per WHO guidelines. As per Davies and Dewiest classification of TDS, all groundwater samples are suitable for drinking as well as for irrigation purposes.
- Total hardness 9.3% of the samples within the permissible limit of 500 mg/L and 90.7% of samples surpasses the limit which causes groundwater that is not suitable for drinking purposes according to WHO guidelines. This indicates that the study area is very hard in nature.

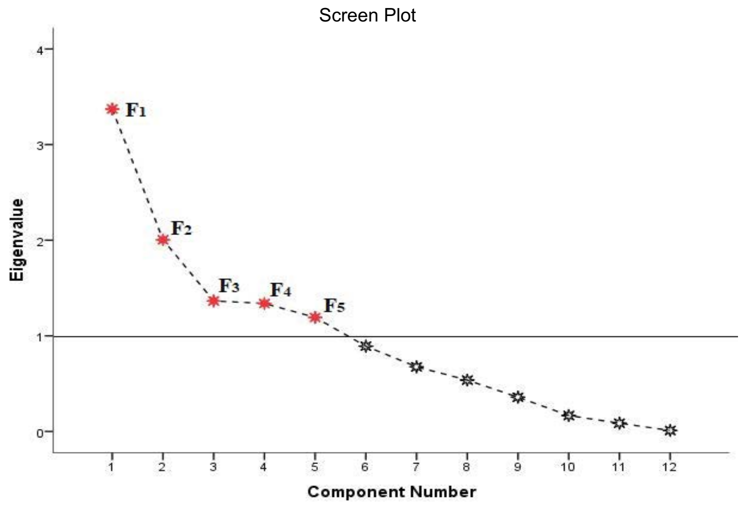


Fig. 19. Screen plot.

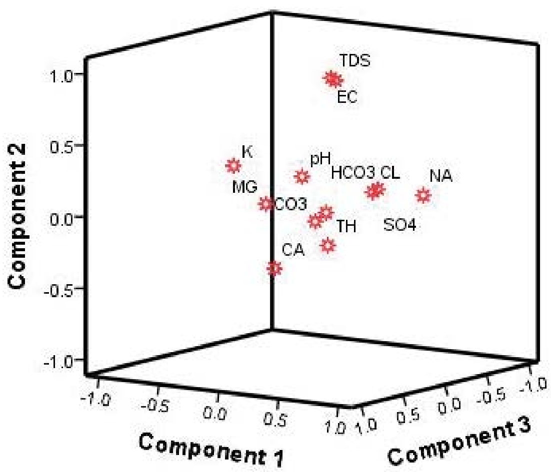


Fig. 20. Principal component of groundwater parameters.

- The dominant constituents of water are as follows $K^+ > Na^+ > Mg^{2+} > Ca^{2+}$ for cation and $Cl^- > HCO_3^- > SO_4^{2-}$ for anions. The primary sources of weathering of rocks (Charnockite and hornblende-biotite-gneiss) and their minerals, with secondary sources of agricultural waste, manures used, and anthropogenic activities are strongly reflected in the study area.
- SAR values were less than 10, indicates that the area's groundwater is suitable for irrigation in almost all soil and crop type. About partial number of sample locations fall in the high conductivity and low salinity (C3–S1). The RSC value, 42 samples (98%) were safe for irrigation in the study area, and only one sample in the south–eastern part of Puliankurichi (2%) were marginal to unsuitable for irrigation purposes.
- The %Na is 98% of the samples fall in excellent to permissible, and only one sample in the southern part of Sellampatty was dubious for irrigation. Wilcox classification reveals, 81% of sample locations fall in good, 5% of sample locations fall in moderate, and 14% sample locations fall in doubtful for irrigation uses. The magnesium hazards of 58% of the bore well water samples exceed 50 and are not suitable for irrigation purposes. The PI shows that 2% and 86% of the samples in class I and II, respectively, that the water is suitable for irrigation and 12% of the samples in class III indicates that, not suitable for irrigation purposes.
- Classifications for groundwater quality on the basis of PS were shown in 21% of the samples classified as injurious to unsatisfactory, indicating that the groundwater is not suitable for irrigation. Kelly ratio values indicate that 12% of the samples surpassed the allowable limit of more than 1 and were categorized as unsuitable for irrigation purposes in the south, south–east and west of the study area.
- Statistical analysis reveals that, major ions such as sodium, calcium, chloride, and sulfate are highly influencing the nature of groundwater.
- Further the water is used for agriculture; the crop yield, a soil structure, will be affected. The effects of agricultural runoff, anthropogenic practices, ion exchange, and weathering of rocks and their minerals are the major factors that affect the nature of groundwater in study area.

The following recommendations are required in the present situation to manage the water quality in the study area. Farmers are aware that they are using organic fertilizers instead of chemical fertilizers. The Government of the State may pursue a program of awareness-raising on the high use of fertilizers and rainwater harvesting. Farmers should be in control of anthropogenic activities, and the government should transfer water resources to manage contamination. The future scope of the research is to improve the water quality index. This work will be very much helpful to future researchers in the field of water quality can be improved in the study area by establishing an artificial recharge management plan that ensures sustainable and non-hazardous groundwater quality resources for a different purpose.

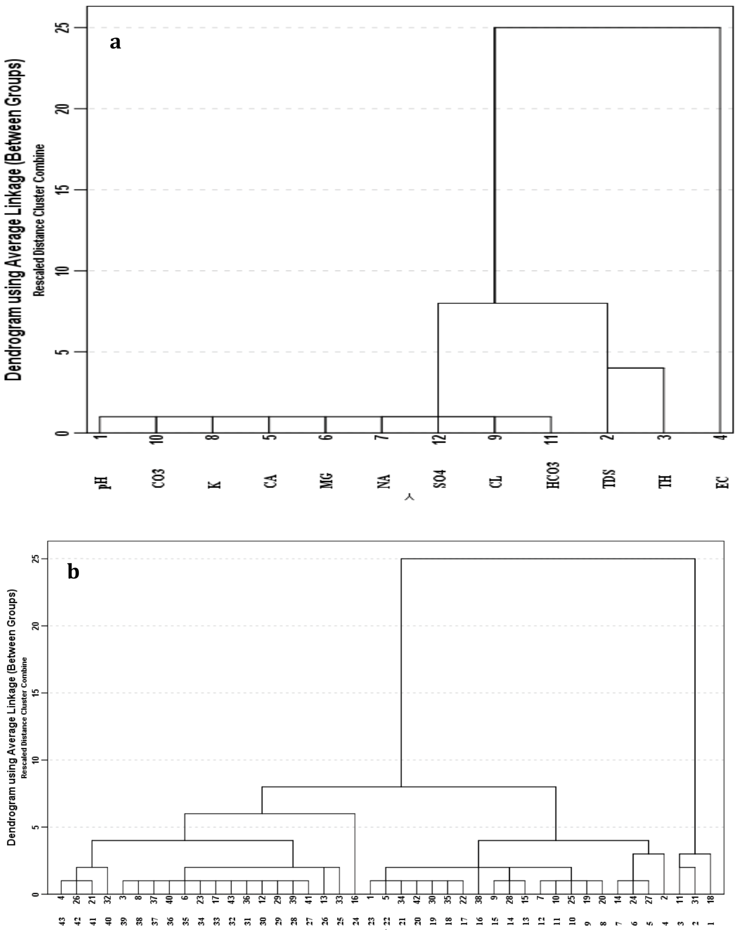


Fig. 21. Dendrogram diagram of groundwater (a) chemical parameter (b) sample locations.

References

[1] P.S. Kumar, P. Balamurugan, Evaluation of groundwater quality for irrigation purpose in attur taluk, Salem, Tamilnadu, India, Water Energy Int., 61 (2018) 59–64.

[2] P.S. Kumar, P. Balamurugan, Suitability of ground water for irrigation purpose in. Omalur Taluk, Salem, Tamil Nadu, India, Indian J. Ecol., 46 (2019) 1–6.

[3] M.K. Jha, A. Chowdhury, V.M. Chowdary, S. Peiffer, Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints, Water Resour. Manage., 21 (2007) 427–467.

[4] N. Rajmohan, L. Elango, Identification and evolution of hydrogeochemical processes in the groundwater environment in an area of the Palar and Cheyyar River Basins, Southern India, Environ. Geol., 46 (2004) 47–61.

[5] P. Li, X. He, Y. Li, G. Xiang, Occurrence and health implication of fluoride in groundwater of loess aquifer in the Chinese loess plateau: a case study of Tongchuan, Northwest China, Exposure Health, 11 (2019) 95–107.

[6] C.K. Singh, A. Kumar, S. Shashtri, A. Kumar, P. Kumar, J. Mallick, Multivariate statistical analysis and geochemical modeling for geochemical assessment of groundwater of Delhi, India, J. Geochem. Explor., 175 (2017) 59–71.

[7] A. Narsimha, Groundwater quality for drinking and irrigation purposes and potential health risks assessment: a case study from semi-arid region of South India, Exposure Health, 11 (2019) 109–123.

[8] A.A. Rostami, M. Isazadeh, M. Shahabi, H. Nozari, Evaluation of geostatistical techniques and their hybrid in modelling of groundwater quality index in the Marand Plain in Iran, Environ. Sci. Pollut. Res., 26 (2019) 34993–35009.

[9] F. Eslami, K. Yaghmaeian, A. Mohammadi, M. Salari, M. Faraji, An integrated evaluation of groundwater quality using drinking water quality indices and hydrochemical characteristics: a case study in Jiroft, Iran, Environ. Earth Sci., 78 (2019) 1–10, doi: 10.1007/s12665-019-8321-1.

[10] P. Xu, W. Feng, H. Qian, Q. Zhang, Hydrogeochemical characterization and irrigation quality assessment of shallow groundwater in the Central-Western Guanzhong Basin, China, Int. J. Environ. Res. Public Health, 16 (2019) 1–18, doi: 10.3390/ijerph16091492.

[11] K. Srinivasamoorthy, C. Nanthakumar, M. Vasanthavigar, K. Vijayaraghavan, R. Rajivgandhi, S. Chidambaram, S. Vasudevan, Groundwater quality assessment from a hard rock terrain, Salem district of Tamilnadu, India, Arabian J. Geosci., 4 (2011) 91–102.

[12] S. Aravindan, K. Shankar, P. Ganesh, K.D. Rajan, Groundwater geochemical mapping in hard rock area of Gadilam river basin using GIS technique, Tamil Nadu, India, Indian J. Appl. Geochem., 12 (2010) 209–216.

[13] S. Aravindan, K. Shankar, Ground water quality maps of Paravanar River sub basin, Cuddalore District, Tamil Nadu, India, J. Indian Soc. Remote Sens., 39 (2011) 565–581.

[14] K. Shankar, S. Aravindan, S. Rajendran, Hydro geochemistry of the Paravanar River Sub-Basin, Cuddalore District, Tamilnadu, India, J. Chem., 8 (2011) 835–845.

[15] S. Venkateswaran, S. Karuppannan, K. Shankar, Groundwater quality in Pambar sub-basin, Tamil Nadu, India Using GIS, Int. J. Recent Sci. Res., 3 (2012) 782–787.

[16] S. Duraisamy, V. Govindhaswamy, K. Duraisamy, S. Krishinaraj, A. Balasubramanian, S. Thirumalaisamy, Hydrogeochemical characterization and evaluation of groundwater quality in Kangayam taluk, Tirupur district, Tamil Nadu, India, using GIS techniques, Environ. Geochem. Health, 41 (2019) 851–873.
[17] N.S. Kawo, K. Shankar, Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia, J. Afr. Earth Sci., 147 (2018) 300–311.
[18] T. Mohanakavitha, K. Shankar, R. Divahar, T. Meenambal, R. Saravanan, Impact of industrial wastewater disposal on surface water bodies in Kalingarayan canal, Erode district, Tamil Nadu, India, Arch. Agric. Environ. Sci., 4 (2019) 379–387.
[19] B.S. Kamble, P.R Saxena, R.M. Kurakalva, K. Shankar, Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar municipal solid waste dumpsite of Hyderabad city, India, SN Appl. Sci., 2 (2020) 1–22.
[20] S. Aravindan, K. Shankar, S.S. Mini, Integrated geohydrological studies in the sedimentary part of Gadilam River Basin, Cuddalore District, Tamil Nadu, Asian J. Earth Sci., 43 (2011) 183–192.
[21] K. Srinivasamoorthy, S. Chidambaram, M.V. Prasanna, M. Vasanthavihar, J. Peter, P. Anandhan, Identification of major sources controlling groundwater chemistry from a hard rock terrain—a case study from Mettur taluk, Salem district, Tamil Nadu, India, J. Earth Syst. Sci., 117 (2008) 49–58, doi: 10.1007/s12040-008-0012-3.
[22] T. Mohanakavitha, R. Divahar, T. Meenambal, K. Shankar, V.S. Rawat, T.D. Haile C. Gadafa, Dataset on the assessment of water quality of surface water in Kalingarayan Canal for heavy metal pollution, Tamil Nadu, Data Brief, 22 (2019) 878–884.
[23] APHA, Standard Methods for the Examination of Water and Wastewater, 17th ed., American Public Health Association, Washington, DC, 1989.
[24] K. Shankar, N.S. Kawo, Groundwater quality assessment using geospatial techniques and WQI in north east of Adama Town, Oromia Region, Ethiopia, Hydrospatial Anal., 3 (2019) 22–36.
[25] P. Balamurugan, P.S. Kumar, K. Shankar, R. Nagavinothini, K. Vijayasurya, Non-carcinogenic risk assessment of groundwater in southern part of Salem District in Tamilnadu, India, J. Chil. Chem. Soc., 65 (2020) 4697–4707.
[26] WHO, Guidelines for Drinking-Water Quality, World Health Organization, Geneva, 2011, pp. 303–304.
[27] BIS Standard, Draft Indian, Bureau of Indian Standards, 2019, pp. 1–5.
[28] B.K. Handa, Description and Classification of Media for Hydro-Geochemical Investigations, Symposium on Ground Water Studies in Arid and Semiarid Regions, Roorkee, 1969.
[29] K. Ramesh, L. Elango, Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India, Environ. Monit. Assess., 184 (2012) 3887–3899.
[30] S. Mohd, A. Hussain, G. Mahmood, Analysis of groundwater quality using water quality index: a case study of greater Noida (Region), Uttar Pradesh (UP), India, Cogent Eng., 3 (2016) 1–11.
[31] S.N. Davis, R.J. Dewiest, Hydrogeology, Wiley, New York, NY, 1966
[32] P. Balamurugan, P.S. Kumar, Quality of ground water assessment in Salem District using GIS Techniques, Adv. Nat. Appl. Sci., 10 (2016) 22–32.
[33] C.N. Sawyer, L. McCarty, G. Parkin, Chemistry for environmental engineers, Environ. Manage.,1978.
[34] P.J. Sajil Kumar, Evolution of groundwater chemistry in and around Vaniyambadi industrial area: differentiating the natural and anthropogenic sources of contamination, Geochemistry, 74 (2014) 641–651.
[35] C. Thivya, S. Chidambaram, R. Thilagavathi, M.V. Prasanna, C. Singaraja, V.S. Adithya, M. Nepolian, A multivariate statistical approach to identify the spatio-temporal variation of geochemical process in a hard rock aquifer, Environ. Monit. Assess., 187 (2015) 1–19, doi: 10.1007/s10661-015-4738-5.
[36] B.R. Panda, S. Chidambaram, N. Ganesh, V.S. Adithya, M.V. Prasanna, K. Pradeep, U. Vasudevan, A hydrochemical approach to estimate mountain front recharge in an aquifer system in Tamilnadu, India, Acta Geochim., 37 (2018) 465–488.
[37] P. Li, S. He, X. He, R. Tian, Seasonal hydrochemical characterization and groundwater quality delineation based on matter element extension analysis in a paper wastewater irrigation area, northwest China, Exposure Health, 10 (2018) 241–258.
[38] S. Venkatramanan, S.Y. Chung, T. Ramkumar, R. Rajesh, G. Gnanachandrasamy, Assessment of groundwater quality using GIS and CCME WQI techniques: a case study of Thiruthuraipoondi city in Cauvery deltaic region, Tamil Nadu, India, Desal. Water Treat., 57 (2016) 12058–12073.
[39] S.Andrew, Occurrence of high bicarbonate groundwater in Victoria, Australia, W. Balderer, A. Porowski, H. Idris, J. LaMoreaux, Eds., Thermal and Mineral Waters: Environmental Earth Sciences, Springer, Berlin, Heidelberg, 2014, pp. 97–110.
[40] P.J. Sajil Kumar, E.J. James, Identification of hydrogeochemical processes in the Coimbatore district, Tamil Nadu, India, Hydrol. Sci. J., 61 (2016) 719–731.
[41] K. Shankar, S. Aravindan, S. Rajendran, Hydrochemical profile for assessing the groundwater quality of Paravanar River sub-basin, Cuddalore District, Tamil Nadu, India, Curr. World Environ., 6 (2011) 45–52.
[42] V.M. Wagh, S.V. Mukate, D.B. Panaskar, A.A. Muley, U.L. Sahu, Study of groundwater hydrochemistry and drinking suitability through Water Quality Index (WQI) modelling in Kadava river basin, India, SN Appl. Sci., 1 (2019) 1–16, doi: 10.1007/s42452-019-1268-8.
[43] V.M. Wagh, D.B. Panaskar, J.A Jacobs, S.V. Mukate, A.A. Muley, A.K. Kadam, Influence of hydro-geochemical processes on groundwater quality through geostatistical techniques in Kadava River basin, Western India, Arabian J. Geosci., 12 (2019) 1–25, doi: 10.1007/s12517-018-4136-8.
[44] S. Mukate, V. Wagh, D. Panaskar, J.A. Jacobs, A. Sawant, Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water, Ecol. Indic., 101 (2019) 348–354.
[45] J. Chan Ho, Effect of land use and urbanization on hydrochemistry and contamination of groundwater from Taejon area, Korea, J. Hydrol., 253 (2001) 194–210.
[46] V.M. Wagh, D.B. Panaskar, A.M. Varade, S.V. Mukate, S.K. Gaikwad, R.S. Pawar, M.L. Aamalawar, Major ion chemistry and quality assessment of the groundwater resources of Nanded tehsil, a part of southeast Deccan Volcanic Province, Maharashtra, India, Environ. Earth Sci., 75 (2016) 1–26, doi: 10.1007/s12665-016-6212-2.
[47] M. Zilberbrand, E. Rosenthal, E. Shachnai, Impact of urbanization on hydrochemical evolution of groundwater and on unsaturated-zone gas composition in the coastal city of Tel Aviv, Israel, J. Contam. Hydrol., 50 (2001) 175–208.
[48] L.A. Richards, Diagnosis and improvement of saline and alkali soils, Agric. Handb., 60 (1968) 210–220.
[49] H.M. Raghunath, Ground water, New Age International(P) Ltd., Publishers, New Delhi, 1987.
[50] Wilcox, Classification and Use of Irrigation Waters, US Department of Agriculture, Washington, 1955.
[51] H. Yuzhen, Y. Deng, A hybrid intelligent model for assessment of critical success factors in high-risk emergency system, J. Ambient Intell. Humaniz. Comput., 9 (2018) 1933–1953.
[52] P. Balamurugan, P.S. Kumar, K. Shankar, Dataset on the suitability of groundwater for drinking and irrigation purposes in the Sarabanga River region, Tamil Nadu, India, Data Brief, 29 (2020) 1–13, doi: 10.1016/j.dib.2020.105255.
[53] J.A. Al-Tabbal, K.K. Al-Zboon, Suitability assessment of groundwater for irrigation and drinking purpose in the northern region of Jordan, J. Environ. Sci. Technol., 5 (2012) 274–290.
[54] M. Ameur, F. Hamzaoui-Azaza, L.B. Cheikha, T. Ahmed, M. Gueddari, A GIS mapping assessment of the suitability of the Oued Rmel aquifer for irrigation in the Zaghouan district (north-eastern Tunisia), Environ. Earth Sci., 77 (2018) 1–15, doi: 10.1007/s12665-018-7472-9.
[55] L.D. Doneen, Notes on Water Quality in Agriculture Published as a Water Science and Engineering Paper 4001, Department of Water Science and Engineering, University of California, 1964.

[56] G. Siamak, S. Srikantaswamy, Analysis of agricultural impact on the Cauvery river water around KRS dam, World Appl. Sci. J., 6 (2009) 1157–1169.
[57] P. Tahmasebi, M.H. Mahmudy-Gharaie, F. Ghassemzadeh, A.K. Karouyeh, Assessment of groundwater suitability for irrigation in a gold mine surrounding area, NE Iran, Environ. Earth Sci., 77 (2018) 1–12, doi: 10.1007/s12665-018-7941-1.
[58] W.P. Kelly, Permissible composition and concentration of irrigated waters, Proc. ASCF, 607 (1940) 607–613.
[59] W.P. Kelley, Use of saline irrigation water, Soil Sci., 95 (1963) 385–391.
[60] K. Srinivasamoorthy, M. Gopinath, S. Chidambaram, M. Vasanthavigar, V.S. Sarma, Hydrochemical characterization and quality appraisal of groundwater from Pungar sub basin, Tamilnadu, India, J. King Saud Univ. Sci., 26 (2014) 37–52.
[61] S. Deepa, S. Venkateswaran, Appraisal of groundwater quality in upper Manimuktha sub basin, Vellar river, Tamil Nadu, India by using Water Quality Index (WQI) and multivariate statistical techniques, Model. Earth Syst. Environ., 4 (2018) 1165–1180.