

Original Research

Assessment of Groundwater Quality and Its Suitability for Drinking and Irrigation Usage in Kanchipuram District of Palar Basin, Tamilnadu, India

Nandini Krishnan^{1*}, Suriya Saravanan²

¹Research Scholar, Department of Civil Engineering, Anna University, Chennai, Tamilnadu, India

²Associate Professor, Department of Civil Engineering, Jerusalem College of Engineering, Chennai, Tamilnadu, India

Received: 26 August 2021

Accepted: 14 December 2021

Abstract

The physicochemical characteristics of groundwater quality are assessed for drinking and irrigation purposes in the Palar sub-basin of the Kanchipuram district. Sixty-four groundwater samples are collected from the deep bore well, and physicochemical parameters are analyzed. Evaluated physicochemical parameters are assessed statistically and compared with WHO and BIS standards. Spatial distribution of physicochemical parameters of the groundwater and Drinking Water Quality Index (DWQI) in the study area is mapped in ArcGIS. The Piper trilinear diagram and Durov plot analysis indicate that the sodium cation and bicarbonates anions are the major ions. According to the Gibbs plot, the chemical weathering of rock-forming minerals is the main driving force which influences water chemistry in this area. The Wilcox diagram and irrigation water quality indices are used to evaluate the groundwater suitability for irrigation. The results reveal that most groundwater samples are suitable for irrigation. The Pearson correlation shows that majority of the parameters are positively correlated with each other. The DWQI in the study area ranges from 51.83 to 384.29 indicating that the groundwater has deteriorated in the western and central regions of the study area, which requires treatment before consumption and protection from geogenic and anthropogenic contamination. Water users can be benefited from the prediction of groundwater quality in the study area.

Keywords: groundwater, physicochemical parameters, water quality index, spatial distribution GIS, Piper and Gibbs diagram

Introduction

Groundwater is a vital renewable source for water supplies around the world. It occurs almost everywhere beneath the earth's surface as a multiple-layer aquifer [1]. Drinking, irrigation, and industrial purposes depend on groundwater resources. Due to rapid population growth, urbanization, industrialization, and agriculture, the groundwater is qualitatively and quantitatively under pressure [2]. As per IPCC synthesis report, higher temperature, pollutant loads due to heavy rainfall, and increased pollutant concentrations during droughts will degrade the quality of fresh water and endanger drinking water [3]. Surface-groundwater interaction may alter bio-geochemical cycles in soils overlying aquifers [4]. For irrigation and drinking purposes, groundwater quality should be monitored continuously to reduce the geochemical contamination risk through appropriate treatment methods [5].

The groundwater quality deterioration is critical due to geogenic and human-induced activities. The knowledge about hydrochemistry of the water is essential to evaluate groundwater quality in any place [6]. In general, indices are created to synthesize water quality information in a format that is simple to communicate. Extensive research has been conducted to measure surface and ground water quality index [7-9]. The groundwater quality monitoring system and policy implementation in the research region are done by characterizing groundwater samples and mapping their water quality index. Irrigation water quality indices are used as an aggregation and communication method for water quality [8]. Many researchers suggest that anomalies in the surface and ground water quality in their study region are caused by human-induced activity [9-13]. The integration of a water quality indicator

with a Geographic Information System (GIS) allows for quick and reliable decision-making [6, 10, 14, 15]. The goals of this research are: (i) to identify the major anions and cations, as well as their physicochemical properties and relationships (ii) to examine the suitability of groundwater in the lower Palar Basin for drinking and agriculture.

Data and Methods

Study Area Description

The study area is a part of the Palar River Basin of Kanchipuram district (Fig. 1), covering 2,111.825 km², and bounded by 12°24' to 12°58' N latitude, 79°33' to 80°9' E longitude. The average annual rainfall is 1,227.7 mm. The minimum and maximum temperatures are around 19.8°C and 36.6°C. The geological formation of the study area is characterized by Quaternary, Tertiary, and Mesozoic Era complex formations, followed by the Archean Age complexity of crystalline rocks. The investigation area is delineated using a 1 arc-second resolution digital elevation model from the Shuttle Radar Topography Mission (SRTM), with a maximum elevation of 231 m above mean sea level. The evaporation rate of 377.08 mm in 2018 is increased to 596.14 mm in 2020 [16]. The average change in temperature for Kanchipuram district is expected to increase by 3.4°C and annual rainfall may reduce to 1% by the end of the century [17]. This shows an alarming situation and the basin needs to be monitored on the local scale.

The basin receives precipitation from the southwest as well as intensified northeast monsoons. The Palar river is seasonal and it flows about 15 days a year.

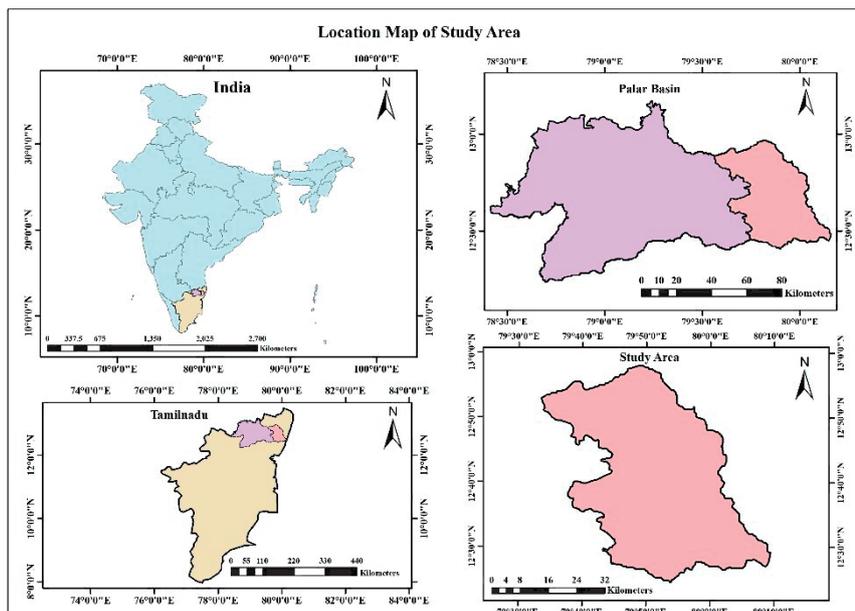


Fig. 1. Location map of the study area.

The study area is located near the coastal region, and stakeholders depend on the groundwater rather than the surface water sources for their survival. Due to urbanization and the overdraft of water, the groundwater quality in the palar basin gets deteriorated. This leads to variation in regional climate change.

Methodology

Groundwater samples are collected from 64 representative boreholes from the research region in the post-monsoon season (February 2021). As illustrated in Fig. 2, the sampling sites are identified using the Global Positioning System (GPS). The monitoring locations are strategically scattered, with most of them along the riverbed, to detect groundwater quality degradation. The river gets deteriorated by the discharge of partially treated industrial effluent. To minimize unexpected contamination and subsequent changes in the characteristics of the groundwater, the sample collection vials (each with a capacity of one liter) are sterilized under aseptic conditions. The temperature of the collected groundwater samples is about 30 °C to 32 °C at the time of collection. Total Dissolved Solids (TDS) and Electrical Conductivity (EC) of the samples are measured using a TDS meter, and pH is obtained using a pH meter. Calcium (Ca), magnesium (Mg), bicarbonate (HCO₃), chloride (Cl), and Total Hardness (TH) are analyzed by volumetric titration methods, sodium (Na) and potassium (K) are measured with the flame photometer, sulfate (SO₄), and nitrate (NO₃) are estimated using spectrophotometric technique [18]. The quality-controlling mechanism and the dominating hydrogeochemical facies of the study area are examined by plotting physicochemical data in the Piper-trilinear diagram, Durov diagram, Wilcox diagram, and

Gibbs diagram [14, 15, 19-21]. Statistical analysis is executed to find the maximum, minimum, mean, and correlation of physico-chemical parameters [1, 19, 22-24]. The groundwater characteristics of the study area are compared with WHO-recommended standard guide values [25] and BIS [26]. Spatial analysis maps are created using ArcGIS Inverse Distance Weighted (IDW) grid interpolation approach [27-29]. Spatial maps are developed to estimate the groundwater quality in the study area.

Drinking Water Quality Index

Drinking Water Quality Index (DWQI) in the investigation area is estimated, to assess the impact of natural conditions and human-influenced pollution by using twelve physicochemical characteristics (pH, EC, TDS, HCO₃, Cl, SO₄, NO₃, TH, Ca, Mg, Na, K) [6, 8, 30-36]. The DWQI is calculated based on WHO [25] and BIS [26] drinking water standards. The physico-chemical parameters are assigned weight, significant to the relative importance of the parameters [27, 33-36]. The higher weight '5' is given to the parameters that cause severe damage to property and human health and the lower weight '1' is assigned to the significantly less impact parameter. The relative weights ranging from one to five are calculated using a weighting factor shown in Equation (1) and then aggregated with simple averaging.

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \tag{1}$$

where W_i = relative weight; w_i = parameter weight; and n = the number of parameters.

The quality rating (Q_i) for all components is determined using Equation (2) to compute the drinking water quality in the research area:

$$Q_i = \frac{(V_a - V_i)}{(V_s - V_i)} \times 100 \tag{2}$$

where, Q_i = Quality ranking scale of element form a total number of water quality elements, V_a = actual groundwater quality concentration in the research location, V_i = ideal rate of the water quality element can be realized from the standard Tables. V_i for pH = 7, and other parameters, it equals zero. V_s = standard for each chemical parameter. The total DWQI is determined using Equation (3).

$$DWQI = \sum Q_i W_i \tag{3}$$

DWQI spatial variability maps are developed using ArcGIS to evaluate the appropriateness of the drinking water quality in the investigation area.

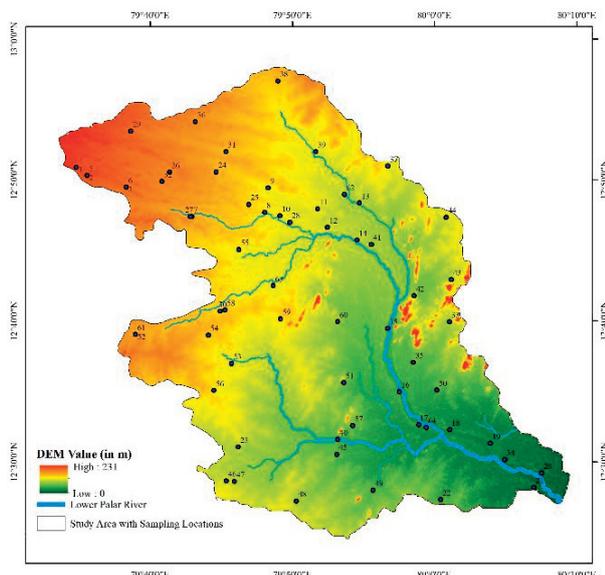


Fig. 2. Study area with sampling location.

Irrigation Water Quality Indices

The effect of mineral water elements on plants and soil determines whether groundwater is suitable for irrigation purposes or not [5, 36]. Total salt concentrations are determined by EC, Sodium Adsorption Ratio (SAR), Kelly Ratio (KR), Soluble Sodium Percentage (SSP), Permeability Index (PI), and Magnesium Adsorption Ratio (MAR). These parameters are used to assess irrigation water quality where the concentration of all the ions is denoted as mg/l.

Sodium Adsorption Ratio

SAR is an essential indicator to identify the suitability of ground water for irrigation [5, 31, 33, 34]. The formula shown in Equation (4) is used to calculate the alkali/sodium threat to crops.

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad (4)$$

Magnesium Adsorption Ratio

MAR [37] value for irrigation water is calculated using the Equation (5).

$$\text{Magnesium Adsorption Ratio (MAR)} = \frac{Mg}{Ca + Mg} \times 100 \quad (5)$$

Soluble Sodium Percentage

The soluble Na% in Equation (6) is used to determine the sodium hardness [38].

$$\text{Soluble Sodium Percentage (SSP)} = \frac{Na + K}{Ca + Mg + Na + K} \times 100 \quad (6)$$

Kelly Ratio

The Kelly ratio [31] is applied to classify irrigation water quality based on the ratio of sodium against Ca and Mg ions are shown in Equation (7).

$$\text{Kelly Ratio (KR)} = \frac{Na}{Ca + Mg} \quad (7)$$

Permeability Index

The permeability index is a critical index to analyze irrigation water quality in connection with soil permeability, influenced by the Na, Ca, Mg, and HCO_3^- . The permeability index is evaluated to determine the water mobility in the soil by Equation (8) [21, 31, 38].

$$\text{Permeability Index (PI)} = \frac{Na + \sqrt{HCO_3^-}}{Na + Mg + Ca} \times 100 \quad (8)$$

Results and Discussion

Evaluation of Drinking Water Quality

The findings from the physico-chemical examination of the groundwater in the study area are summarized. Table 1 shows the water quality standards and the maximum, minimum, and mean values of the physico-chemical parameters. Table 2 lists the number of representative samples that exceed the allowed limit according to the WHO (2017) standards.

Table 1. Drinking waters Standards and statistics of the study area.

Chemical Parameter	WHO (2017)	BIS (2012)	Study Area Samples		
	Acceptable limit	Acceptable limit	Minimum	Maximum	Mean
pH (on scale)	6.5-8.5	6.5-8.5	7.5	9.5	8.10
EC ($\mu\text{s}/\text{cm}$)	-	-	430	4630	1142.37
TDS (mg/l)	500	500	217	2575	652.038
HCO_3^- (mg/l)	-	-	20	695.4	222.05
Cl (mg/l)	250	250	18	1510	182.40
SO_4 (mg/l)	250	200	16	200	64.81
NO_3 (mg/l)	45	45	0.1	50	8.22
TH (mg/l)	100	200	100	1300	288.04
Ca (mg/l)	75	75	8	304	42.68
Mg (mg/l)	50	30	11	131.22	43.24
Na (mg/l)	200	-	7	451	114.79
K (mg/l)	12	-	0.1	86	9.87

Table 2. Relative Weights and number of samples exceeding the permissible limits.

Parameters	Weights	Relative Weights(w_i)	Number of samples exceeds the permissible limit
pH (on scale)	4	0.100	1
TDS (mg/l)	5	0.125	46
HCO ₃ (mg/l)	1	0.025	1
Cl (mg/l)	5	0.125	14
SO ₄ (mg/l)	5	0.125	0
NO ₃ (mg/l)	5	0.125	1
TH (mg/l)	3	0.075	62
Ca (mg/l)	3	0.075	6
Mg (mg/l)	3	0.075	18
Na (mg/l)	4	0.100	7
K (mg/l)	2	0.050	14

pH

The pH value measures the hydrogen ion concentration in the groundwater. Majority of the representative groundwater sample (Fig. 3a) has pH value of 7.5 to 9.5. The highest pH value of 9.5 is found at sampling site 21. Except sampling point 21, all other samples are within the permissible range. Although pH has a less direct impact on water users, it is one of the most critical operational water quality indicators. Higher weights are assigned to pH to determine DWQI which is subjected to change chemically and also, the range of pH is an indicator for heavy metal pollution.

Electrical Conductivity

The capacity of water to transport electrical current is measured by electrical conductivity. The most desirable EC limit value in drinking water is given as 1500 $\mu\text{s/cm}$. The value of EC in Fig. 3b) is between 430 and 4630 $\mu\text{s/cm}$ and was found to vary with medium to high values at the central part then increases to the west direction. The EC measures the ability of a material to conduct an electrical current, the higher value of EC indicates an accumulation of salts in the ground water. Type I is for moderate salt accumulations ($\text{EC} < 500 \mu\text{s/cm}$), Type II is for medium salt enrichment ($\text{EC} 500\text{-}750 \mu\text{s/cm}$), Type III is for high salt concentrations ($\text{EC} 750\text{-}2250 \mu\text{s/cm}$), and Type IV is for high salt concentrations ($\text{EC} > 2250 \mu\text{s/cm}$). Samples 1, 2, 4-21, 23, 24, 26, 28-30, 32, 37, 39, 40, 42, 44-47, 49-52, 55-64 are falling in type III, samples 3, 22, 25, 27, 31, 33, 34, 38, 41, 43, 48, 54 are falling in type II, samples 2, 10, 11 falls under type IV and no samples fall under Type I category. Majority of the representative samples fall under the type III category.

Total Dissolved Solids

Spatial distribution mapping of TDS in the investigation area (Fig. 3 c) has a maximum value of 2575 mg/l and a minimum value of 217 mg/l. The samples (24, 28, 30, 35, 53, 64) with a TDS value between 1000 and 3000 mg/l are suitable for irrigation. Except for the samples mentioned above, all groundwater sampling points are appropriate for drinking. About 43.75% of samples palatability of water with total TDS less than 600 mg/l is considered good as per WHO guidelines.

Bicarbonates

Bicarbonate concentration spatial distribution mapping (Fig. 3d) has a maximum value of 20 mg/l to 695 mg/l. Except for sample 53, all other samples are within the allowable limit and acceptable for drinking purposes.

Chloride

Spatial distribution of chloride (Fig. 3 e) has minimum and maximum values and is between 18 and 1510 mg/l. In the investigation area, samples 8, 12, 15, 23, 24, 28, 30, 35, 36, 44, 46, 47, 53, 64 have exceeded the maximum acceptable limit due to over-exploitation and less groundwater recharge rate in the basin. The chloride ion level in the groundwater at sampling point 36 of the investigation area exceeds the maximum permitted value of 600 mg/l due to the lack of underground drainage systems and poor maintenance.

Sulfate

Sulfate contamination in groundwater can cause human health issues and material damage implications, making the hydrochemical parameter relatively

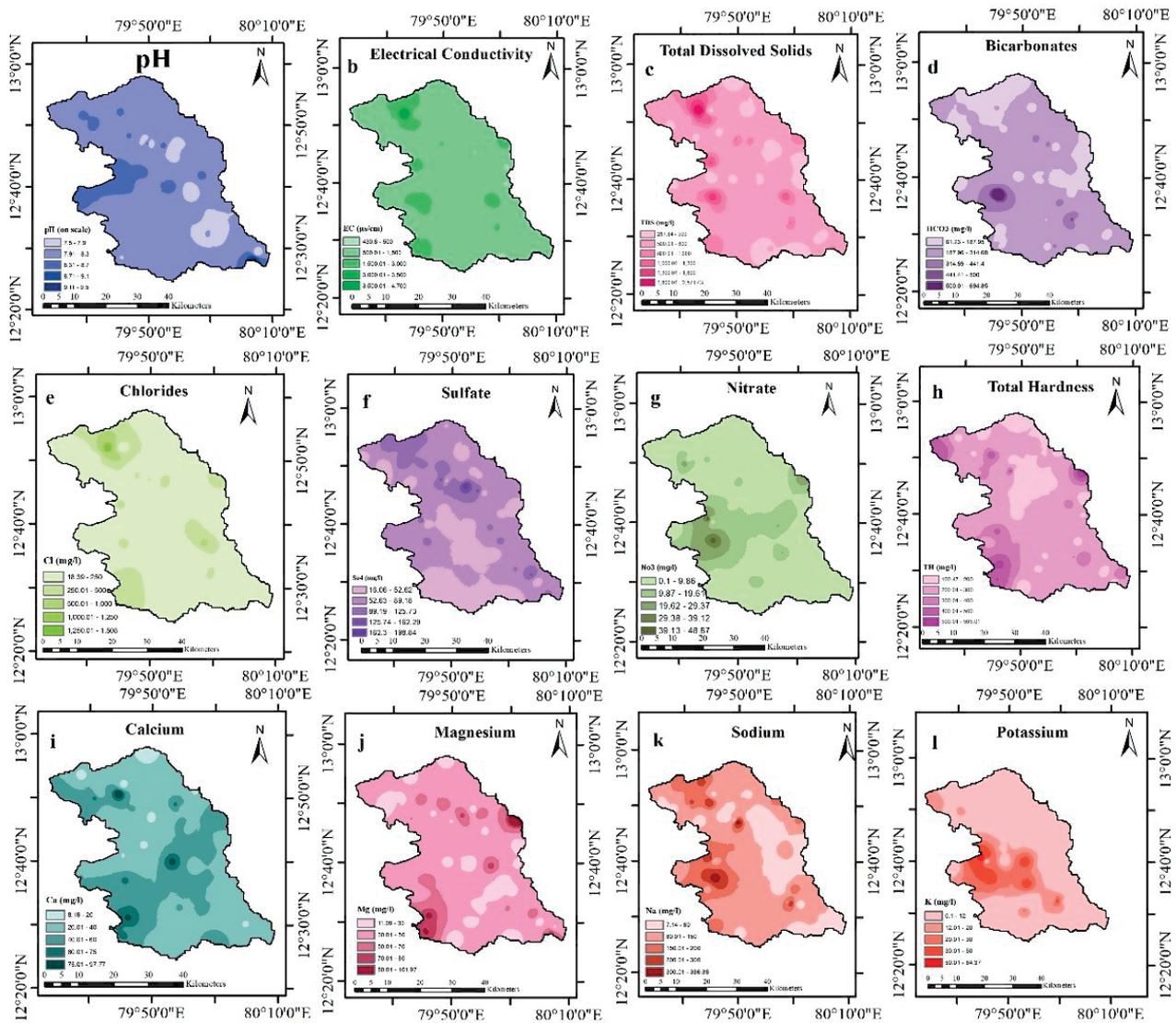


Fig. 3. Spatial distribution of the physico- chemical parameters in the study area a) pH b) Electrical Conductivity c) Total Dissolved Solids d) Bicarbonates e) Chlorides f) Sulfate g) Nitrate h) Total Hardness i) Calcium j) Magnesium k) Sodium l) Potassium

important and are assigned with higher weights. Spatial distribution of sulfate (Fig. 3f) has the minimum and maximum value for groundwater samples and is between 15 and 200 mg/l. All samples are within the threshold limits according to international and national standards.

Nitrate

Nitrogen compounds are the most widespread pollutants in subterranean environments, derived mainly from agricultural non-point sources. Therefore, an increase in nitrogen pollution causes a severe threat to public drinking water supplies and human health. The NO₃⁻ concentration varies from 0.1 to 50 mg/l, with a mean of 8.22 mg/l (Fig. 3g). Except the sampling point 30, all other representative samples do not exceed the permissible limit of 45 mg/l.

Total Hardness, Calcium, and Magnesium

Spatial distribution of TH, calcium, and magnesium are mapped in Fig. 3 h), i), and j). Ca and Mg are directly related to water hardness and abundant elements in surface and ground water. Ca concentration is between 8 and 304 mg/l, and Mg concentration varies from 11 to 131.22 mg/l. Hardness in water is caused by various dissolved metallic ions, predominantly in the form of Ca and Mg cations. The TH content is observed with a minimum value of 100 mg/l and 1300 mg/l. The calcium concentration is permissible in 90% of the samples, but 65% of the samples surpass the permissible magnesium limit. This indicates that the hardness in groundwater is in the form of Mg than Ca. Magnesium is considered as an alkali earth metal and is washed from all the rocks and found to be abundant in water bodies [27]. Magnesium is also used

Table 3. Classification of groundwater in the study area based on Drinking Water Quality Index.

Range	Type of water	Sample Numbers
<50	Excellent water	Nil
50-100	Good water	1, 2, 4, 5, 7, 8, 12, 21, 23, 24, 28, 30, 32, 42, 44, 46, 47, 52, 53, 56, 58, 60, 64
100-200	Poor water	3, 6, 9-11, 13-20, 22, 25-27, 29, 31, 33, 34, 37-41, 43, 45, 48-51, 54, 55, 57, 59, 61-63
200-300	Very poor water	35
>300	Water unsuitable for drinking purpose	36

in industry for several purposes and as a fertilizer in agriculture.

Sodium and Potassium

Spatial distribution mapping of sodium and potassium are illustrated in Fig. 3 (k, l). Na concentration varies from 7 to 451 mg/l, and 89% of the representative sampling points are within the permissible range. Na is the dominant ion among the cations and occurs in most of the natural waters. Na contributes about 53 to 69% of the total cations, this is primarily due to silicate weathering and dissolution of soil salts stored by the influence of evaporation, human activities, agricultural activities, and poor drainage conditions. The sampling point locations 24, 26, 28, 30, 36, 53, and 64 indicate that a higher Na concentration is expected than the contribution of Ca to the total cations due to the influence of ion exchange. K is a naturally occurring element, but its concentration remains lower than Ca, Mg and Na. The maximum value is found to be 86 mg/l and 75% of the sampling points are within

the permissible limit, indicating potassium complexes under the conditions investigated. Although 25% of the sampling points exceed the allowable limit, the total contribution of K in the cation is determined as 2.22%.

The DWQI used to evaluate water quality for drinking water purposes is listed in Table 3. The maximum DWQI value is 384.29 in sampling point 36, and the minimum DWQI value is 51.83 in sampling point 48. DWQI spatial distribution maps (Fig. 4) revealed that groundwater samples in the southern and north-eastern regions of the study area are suitable for drinking. The central, northern, and southwestern parts of our study area are unsuitable for drinking purpose and must be treated appropriately before use.

Evaluation of Irrigation Water Quality Indices

Irrigation water suitability is also influenced by the mineral on the soil and water [6]. Soil drainage is an important factor that links plant growth with water quality. If the soil is well-drained, plants can grow on it even if it has abundant saltwater. A reasonable yield is impossible to achieve in a poorly drained location with good quality water. The Water quality indices EC, SAR, PI, KR, SSP, and MAR and the classification are shown in Table 4. Based on these indices, farmers can select the appropriate management practice to overcome potential salinity hazards.

SAR values in this area range from 1.65 to 127, with an average of 25. In such circumstances, irrigation water causes permeability issues in clayey soils, which shrink and swell [35, 39, 40]. The higher Na concentration in water has a detrimental effect on the salt content of the soil and has a direct impact on plant growth.

Based on PI, the groundwater samples can be categorized into suitable, good, and unsuitable. Groundwater from all other sampling sites in the research area, except for sampling point 15, is acceptable and good for irrigation.

Wilcox diagram is plotted using Diagrammes Version 6.75 shown in Fig. 5. It relates % of sodium with EC and a higher ratio of it indicates that it is unfavorable to plant growth [41, 42]. It is found that 50% of the samples fall in good to an acceptable range, 21.88 % of the representative samples fall in excellent to good range, 15.63% of the groundwater

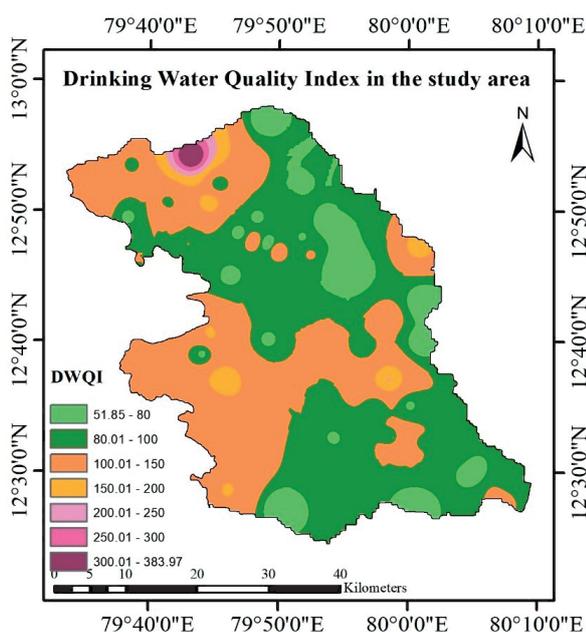


Fig. 4. Drinking Water Quality Index in the study area.

Table 4. Classification of groundwater in the study area based on Irrigation Water Quality Indices

Irrigation Water Quality Indices	Range	Class	Sample Numbers	Total number of Ssamples	Percentage of samples
EC ($\mu\text{s/cm}$)	<250	Low	Nil	Nil	-
	250-750	Medium	3, 22, 25, 27, 31, 33, 34, 38, 41, 43, 48, 54	12	18.8
	750-2250	High	1,2, 4-21, 23, 24, 26, 28-30, 32, 37, 39, 40, 42, 44-47, 49-52, 55-64	49	76.6
	>2250	Very High	35,36,53	3	4.6
SAR (mg/l)	<10	Excellent	2, 9, 11, 13-16, 18,20 -22, 25, 33, 35 ,41	15	23.4
	10-18	Good	1, 6-8, 10, 12, 23, 27, 31, 43, 48 ,62	12	18.8
	18-26	Doubtful	3, 5, 34, 39, 44, 47,51, 52, 54, 60,61	11	17.2
	>26	Unsuitable	2, 9, 11, 13-16, 18, 20-22, 25, 33, 35, 41	26	40.6
MAR (mg/l)	>50	Harmful and unsuitable	7-13, 15, 18, 19, 21, 23, 28-31, 34 -40, 44, 46,47, 52-55, 58, 59, 63, 64	34	53.1
	<50	Suitable	1-6, 14,16, 17, 20, 22, 32, 33, 41-43, 45, 48-51, 56, 57, 60-52	30	46.9
SSP (mg/l)	<20	Excellent	22, 33	2	3.1
	20-40	Good	2, 9, 11, 13-16, 18, 20, 21, 23, 25, 27, 35, 41	15	23.4
	40-60	Permissible	1, 3, 5-8, 10, 12, 31, 39,42-44, 47, 48, 52, 54, 60-62	20	31.3
	60-80	Doubtful	17, 19, 24, 32, 34, 36-38, 40, 45, 46, 49-51, 53, 55-9, 63, 64	22	34.4
	>80	Unsuitable	4, 26,28-30	5	7.8
TH (mg/l)	<75	Soft	Nil	Nil	0
	75-150	Moderately hard	9, 10, 12, 21, 28, 34, 38, 48, 55	9	14.1
	150-300	Hard	3, 6, 11, 13- 17, 19, 22, 25-27, 29-33, 37, 39-41, 45, 46, 49-52, 54, 56-63	39	60.9
	>300	Very Hard	1, 2, 4, 5, 7, 8, 18, 20, 23, 24, 35, 36, 42, 47, 53, 64	16	25
KR (mg/l)	<1	Suitable	1, 2, 6-16, 18, 20-23, 25, 27, 33, 35, 47, 62	26	40.6
	>1	Unsuitable	3-5, 17, 19, 24, 26, 28-32, 34, 36-40, 42, 44-46, 48-61, 63, 64	38	59.4
PI (mg/l)	>75%	Suitable	26, 28-30, 34, 37, 38, 45, 50, 53, 55, 57-59, 63, 64	16	25
	25%-75%	Good	1-14,16-25,27,31-33,39-44,46-49, 51, 52, 54, 56, 60-62	47	73.4
	<25%	Unsuitable	15	1	1.6

fall in the zone of acceptable to uncertain, and 9.38% of the samples fall in the category of uncertain and not suitable range. Majority of samples in the investigation area are viable for irrigation. The salt concentration in the soil water will increase due to human activities, agricultural activities, and evaporation.

KR calculated for all groundwater samples range between 0.10 and 10.36 mg/l. According to KR classification, around 40 percent of the groundwater samples are suitable for irrigation [5, 41]. KR indicates a balance among Na^+ , Ca^{2+} , and Mg^{2+} ions in water. The significance of KR greater than 1 suggests that there is an overabundance of Na in the water. MAR values >50

are considered harmful and unsuitable for irrigation purposes. MAR ranges from 17.27 to 86.12, with an average of 53.06 is found in the sampling points. This infers about 50% of the sampling points are unsuitable for irrigation.

Hydrochemical Facies

The evolution of hydrochemical facies in the groundwater is understood by plotting the trilinear Piper diagram using Diagrammes Version 6.75. Hydrochemical facies help to determine the origin and classification of different types of water [42, 43].

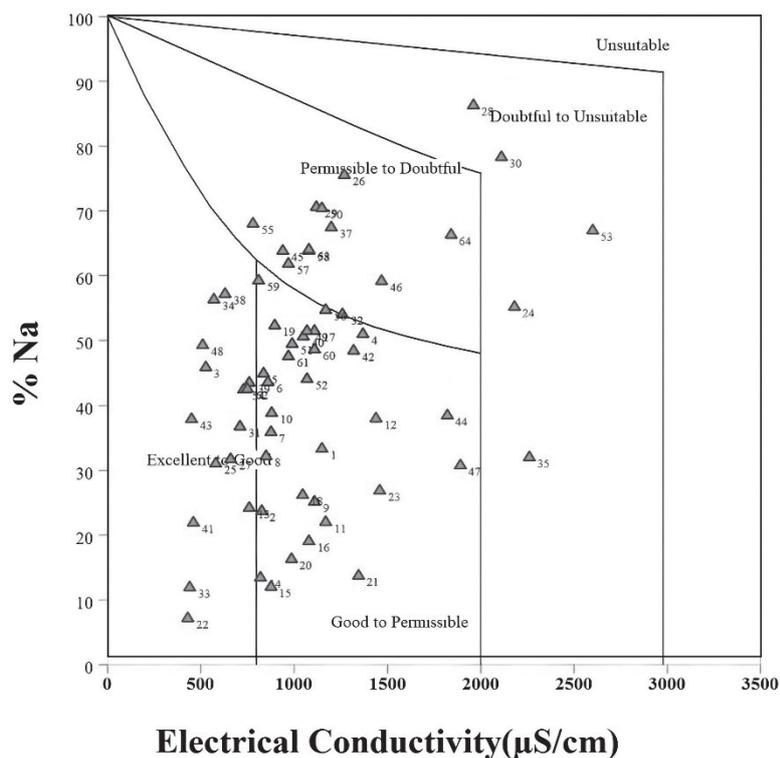


Fig. 5. Wilcox diagram showing the suitability of groundwater for irrigation in the study area.

Hydrochemical facies of groundwater explains the relationship between main anions and cations and their behavior. The hydrochemical facies of the groundwater using the concentration of the major anions (Cl, SO₄ and HCO₃) and cations (Ca, Mg, Na, and K) in mg/l plotted in Piper-trilinear diagram (Fig. 6). The mechanism

for geochemical evolution is represented into six different water types as Type I (Ca-HCO₃ type), Type II (Na-Cl type), Type III (mixed Ca- Na-HCO₃ type), Type IV (mixed Ca-Mg-Cl type), Type V (Ca-Cl type) and Type VI (Na-HCO₃ type). The percentage distribution of samples of each type of water is as follows: 43.75%

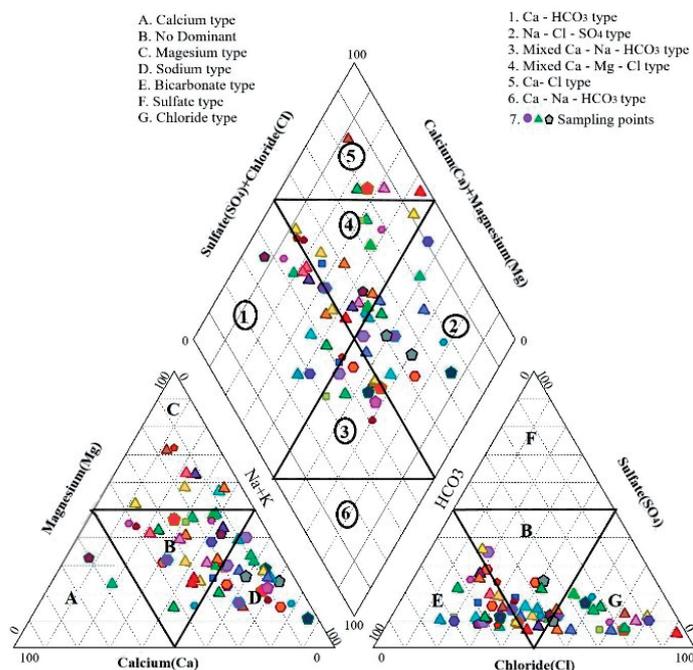


Fig. 6. Piper Trilinear Diagram for the major cation and anions of the groundwater samples in the study area.

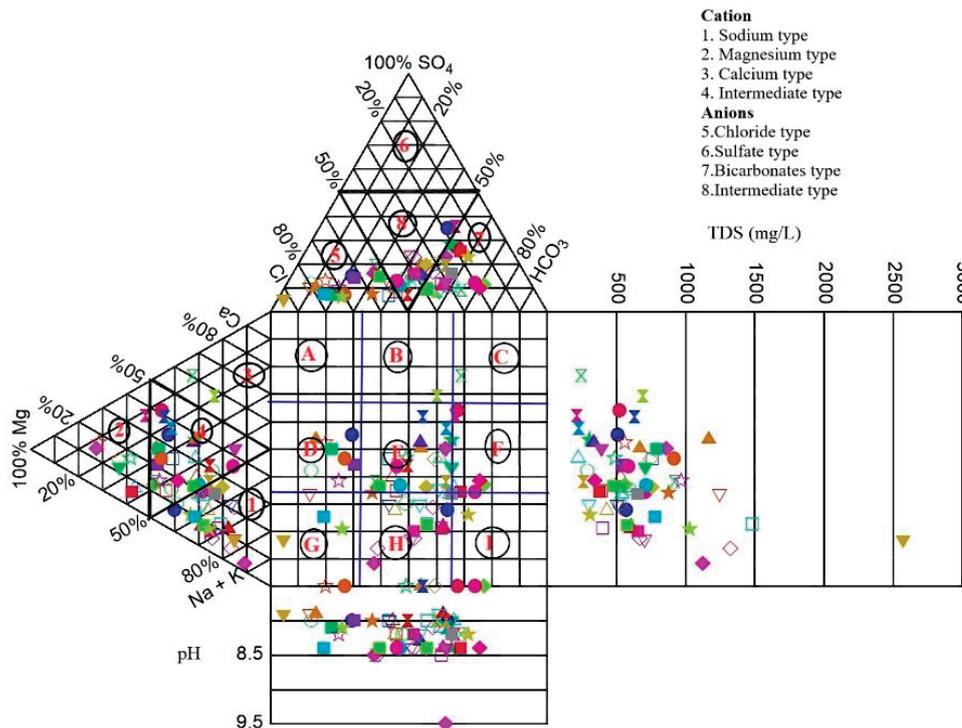


Fig. 7. Durov plot for the major ions of the groundwater samples in the study area.

for mixed Ca-Na-HCO₃ type, 23.44% for Ca-HCO₃ type and Na-Cl type, 7.81% for mixed Ca-Mg-Cl type, 1.56% for Ca-Cl type, and no sample fall in Na-HCO₃ type. From the results, it is clear that there is a dominance of the primary groundwater salinity over the secondary salinity released in weathering the bedrock.

The bicarbonate is the highest dominant ion from the anions triangle with 32.81%, followed by chloride with 29.68%, and 37.5% of the samples have no dominance. On the other hand, for cations, the highest dominant ion is sodium with 34.34%, magnesium with 14.06%

calcium with 3.12 %, and 48.43% of the samples with no dominance. These triangle fields represent the values of alkaline earth cations (Ca, Mg), alkali cations (Na, K), weak acids (HCO₃), and strong acids (Cl and SO₄). The cation-anion relationship in the piper diagram shows the sodium and bicarbonates are highly concentrated in the study area due to the weathering and dissolution of silicate in soils or rock salts through evaporation and human-induced activities.

The Durov chart plotted using AqQA is another popular graphic representation of hydrochemical data

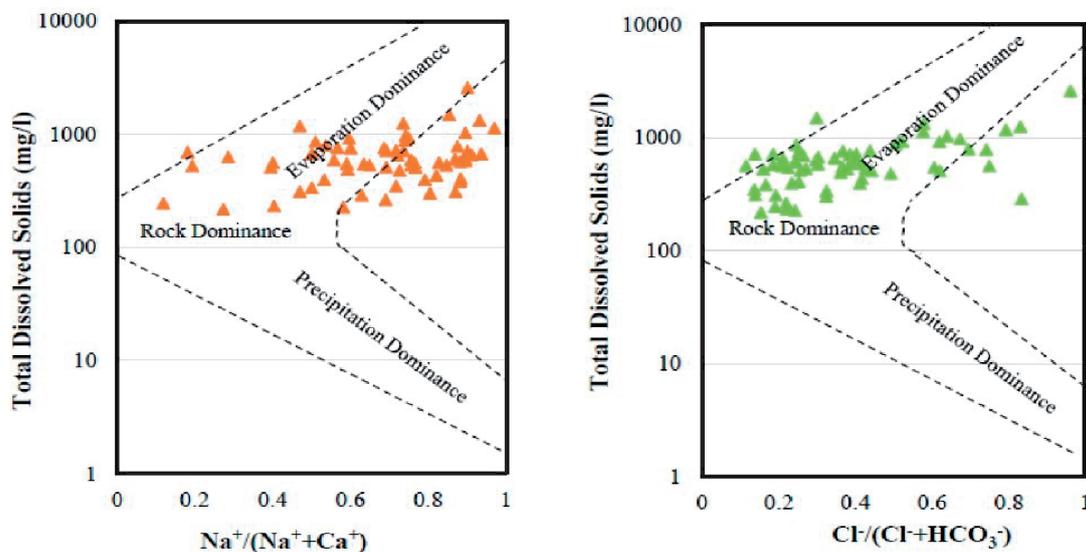


Fig. 8. Mechanism controlling the chemistry of groundwater.

Table 5. Groundwater physicochemical parameter correlation matrix of the study area.

Parameters	pH	EC	TDS	HCO ₃	Cl	SO ₄	NO ₃	TH	Ca	Mg	Na	K
pH	1											
EC	-0.022	1										
TDS	-0.044	0.987	1									
HCO ₃	-0.175	0.143	0.191	1								
Cl	-0.126	0.877	0.858	-0.117	1							
SO ₄	0.063	0.447	0.509	0.285	0.407	1						
NO ₃	0.200	0.315	0.339	0.226	0.077	0.177	1					
TH	-0.252	0.737	0.710	-0.077	0.821	0.172	0.024	1				
Ca	-0.188	0.749	0.708	-0.177	0.815	0.138	-0.006	0.839	1			
Mg	-0.195	0.680	0.665	0.044	0.675	0.343	0.033	0.681	0.536	1		
Na	0.140	0.813	0.783	0.187	0.622	0.366	0.441	0.394	0.426	0.326	1	
K	0.026	0.393	0.441	0.275	0.200	0.191	0.620	0.146	0.144	0.072	0.434	1

similar to the Piper-trilinear plot, used to classify natural waters and identify their composition along with total dissolved solids and alkalinity. As shown in the Durov diagram (Fig. 7), most water elements are plotted within the HCO₃-Na zone. The samples analyzed in region E show 45.31% and indicate that there is no dominance of cations or anions, and the probability of new formation of freshwater is possible. In the diagram, regions A, D, and G illustrate ion-exchange processes that influence groundwater chemistry, while regions C, F, and I depict the reverse ion-exchange process in the research area.

Mechanism of Groundwater

Gibbs plot are often used to assess dissolved chemical constituent sources, such as precipitation dominance, rock dominance, and evaporation dominance. The ratio of dominant anions and cations is plotted against the value of TDS (Fig. 8). The Gibbs plot suggests that most samples fall in the rock dominance zone, indicating the groundwater interaction between rock chemistry. Gibb's plot shows that the chemical weathering of the rock forms minerals. The Gibbs ratio I (cation) value in the present study varies from 0.11 to 0.96 with a mean value of 0.38, and the Gibbs ratio II (anion) values range from 0.11 to 0.97 with a mean value of 0.66. Anthropological induced activity and urbanization have increased the TDS value and tend the samples to fall into the rock and evaporation dominance zone.

The Pearson Correlation matrix of the physicochemical parameters of the groundwater is analyzed using Microsoft Excel in the investigation area (Table 5). The majority of the parameters are positively correlated with each other. The parameters TDS, Cl, Na vs. EC; Cl vs. TDS; TH, Ca vs. Cl, and Ca vs. TH indicates a positive correlation of more than 0.8 and

significantly influence the groundwater quality than other parameters. The parameters TH, Ca, Mg vs EC; TH, Na, Ca, Mg, SO₄ vs TDS; TH, Ca, Mg vs Cl, and Ca vs TH indicate a positive correlation of more than 0.5. The hardness present in the groundwater is in the form of CaCl₂, MgCl₂, and NaCl. The bicarbonates in groundwater show a negative correlation with calcium and chloride.

Conclusions

The study area is stressed due to urbanization, global warming, and more demand for water resources. The outcome of the study reveals that integration of physicochemical analysis with GIS interpolation methods would help to investigate the mechanisms behind groundwater salinization, visualize groundwater spatial variation, and assess groundwater quality for drinking and irrigation purposes. The results of the study reveal that 1209.27 km² area of lower palmar basin of the Kanchipuram district has good drinking water. Northwestern, southwestern and central part of the study area of about 902.55 km² has poor drinking water. The principal cation and anion abundance in the study area are listed in the following order: Na = HCO₃ = Cl > Mg > Ca > SO₄ > K > CO₃. Na and Cl ions are dominant ions among the studied cations and anions. Calcium is found to be prevalent in groundwater because of its presence in bedrock and has higher solubility. The high EC, chloride, sodium, calcium, and magnesium concentrations in the research area demonstrate that the rock-water interaction mechanism is the primary source of water quality degradation. EC has higher salinity of range greater than 750 µs/cm in the area of about 1714.8 km², SAR has a range of greater than 18 in the area of about 1220.9 km², SSP has a range

greater than 60 in the area of about 890.9 km² and total hardness is of higher range greater than 150 mg/l in the area of about 1814.05 km². The high salt content in irrigation water causes osmotic pressure in soil solution. The salts also affect soil structure, soil permeability, aeration, texture, and make soil hard. Though the study area has high salinity and hardness, PI is found to be excellent and has good soil drainage.

The plotting results from the Durov diagram and the Piper-trilinear diagram conclude that most of the elements of water are plotted within the HCO₃-Na zone. The Gibbs plot shows that the predominant samples fall into the evaporation dominance zones and dominance zones of the rock-water interaction. The Piper trilinear diagram authenticates that the groundwater follows the mixed water types Ca- Na-HCO₃, Ca- Na-HCO₃, Ca-HCO₃, Na-Cl, mixed Ca-Mg-Cl, Ca-Cl water type. It also shows that sodium is the principal cation, and bicarbonate is the dominant anion. Weathering and dissolving of silicate in soils and rock salts through evaporation and anthropogenic causes are responsible for the elevated sodium ion concentration in the research area. The spatial distribution mapping of DWQI values at the unobserved locations of the study area can also be utilized. DWQI spatial distribution maps at the regional level for the present and future help to improve groundwater quality. The groundwater quality is influenced by increased temperature, reduced annual rainfall in the hydrological cycle, and groundwater recharge rate. The climate influencing variables such as precipitation and temperature, as well as their variability effect on the hydrological cycle and groundwater quality, must be anticipated for the future climate scenario at the regional level. Climate change adaptation requires strategic knowledge in climate science for water users in sustainable habitats and sustainable agriculture. Hence, a better understanding of climate drivers, impacts, and challenges, with support from government and non-governmental organizations would fetch fruitful results to the water users.

Acknowledgments

The authors are thankful to the Principal and the Head of the Department of Civil Engineering, Jerusalem College of Engineering, Chennai for the Laboratory facilities.

Conflict of Interest

The authors declare no conflict of interest.

References

1. SHAHAB A., SHIHUA Q., RASHID A., HASAN FU., SOHAIL, M. T. Evaluation of Water Quality for Drinking

- and Agricultural Suitability in the Lower Indus Plain in Sindh Province, Pakistan. Polish Journal of Environmental Studies, **25** (6), 2563, **2016**.
2. NANDINI K., SURIYA S. A Review of Potential Impact of Climate Change on Global Water Resources. Journal of Seybold Report, **15** (7), 495, **2020**.
3. JARRAUD M., STEINER A. Climate Change 2014 Synthesis Report IPCC Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change. Volume 9781107025, **2012**.
4. RIEDEL T. Temperature-associated changes in groundwater quality. Journal of Hydrology, **572** (2), 206, **2019**.
5. ACHARYA S., SHARMA S.K., KHANDEGAR V. Assessment of groundwater quality by water quality indices for irrigation and drinking in South West Delhi, India. Data in Brief, **18**, 2019, **2018**.
6. SRINIVAS Y., HUDSON OLIVER D., STANLEY RAJ A., CHANDRASEKAR N. Evaluation of groundwater quality in and around Nagercoil town, Tamilnadu, India : an integrated geochemical and GIS approach. Applied Water Science, **3**, 631, **2013**.
7. ROBERT M., BROWN NINA, MCCLELLAND I., DEININGER R.A., RONALD G.T. A-Water Quality Index - do we dare? Water & Sewage Works, 117, 339, **1970**.
8. SAEEDI M., ABESSI O., SHARIFI F., MERAJI H. Development of groundwater quality index. Environmental Monitoring and Assessment, **163** (1-4), 327, **2010**.
9. DHIVIYAA PRANAVAM T.S., VENKATESA RAO T., PUNITHAVATHI L., KARUNANITHI S., BHASKARAN A. Groundwater pollution in the Palar Riverbed near Vellore, Tamil Nadu, India. Indian Journal of Science and Technology, **4** (1), 19, **2011**.
10. RAWAT K.S., SINGH S.K. Water Quality Indices and GIS-based evaluation of a decadal groundwater quality. Geology, Ecology, and Landscapes, **2** (4), 240, **2018**.
11. SELVAKUMAR S., RAMKUMAR K., CHANDRASEKAR N., MAGESH N.S., KALIRAJ S. Groundwater quality and its suitability for drinking and irrigational use in the Southern Tiruchirappalli district, Tamil Nadu, India. Applied Water Science, **7** (1), 411, **2017**.
12. ZEREG S., BOUDOUKHA A., BENAABIDATE L. Impacts of natural conditions and anthropogenic activities on groundwater quality in Tebessa plain, Algeria. Sustainable Environment Research, **28** (6), 340, **2018**.
13. ALIKHAN H.A., HUSSEIN A.K., ALSHUKRI A.S. Groundwater quality assessment using water quality index: A case study of Al Najaf City, Iraq. Periodicals of Engineering and Natural Sciences, **8** (3), 1482, **2020**.
14. ARJUN RAM, TIWARI S.K., PANDEY H.K., ABHISHEK KUMAR CHAURASIA, SUPRIYA SINGH, SINGH Y.V. Groundwater quality assessment using water quality index (WQI) under GIS framework. Applied Water Science, **11** (2), 1, **2021**.
15. VAIPHEI S.P., KURAKALVA R.M., SAHADEVAN D.K. Water quality index and GIS-based technique for assessment of groundwater quality in Wanaparthy watershed, Telangana, India. Environmental Science and Pollution Research, **27** (36), 45041, **2020**.
16. CGWB. Groundwater quality in shallow aquifers of India. Central Ground Water Board, Ministry of Water Resources, Government of India, Faridabad, **2018**.
17. CCC&AR and TNSCCC DISTRICT WISE CLIMATE CHANGE INFORMATION FOR THE STATE OF

- TAMIL NADU TEMPERATURE PROJECTIONS FOR KANCHIPURAM, **2015**.
18. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater, 23rd Edition, **2017**.
 19. KRISHNA KUMAR S., LOGESHKUMARAN A., MAGESH N.S., GODSON P.S., CHANDRASEKAR N. Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India. *Applied Water Science*, **5**, 335, **2015**.
 20. ELUBID B.A., HUANG T., AHMED E.H., ZHAO J., ELHAG K.M., ABBASS W., BABIKER M.M Geospatial Distributions of Groundwater Quality in Gedaref State Using Geographic Information System (GIS) and Drinking Water Quality Index (DWQI). *International Journal of Environmental Research and Public Health*, **16** (5), 731, **2019**.
 21. NAGARAJU A., THEJASWI A., SHARIFI Z. Assessment of groundwater quality and its suitability for agricultural usage in and around Rangampeta area, Andhra Pradesh, South India. *Journal of Water Chemistry and Technology*, **38** (6), 358, **2016**.
 22. SARANYA A., SASHIKKUMAR M.C. Hydrochemical Analysis of Groundwater Quality in Virudhunagar district, Tamil Nadu, India. *Indian Journal of Ecology*, **46** (1), 39, **2019**.
 23. VOZA D., VUKOVIC M., TAKIC L., NIKOLIC D. Application of multivariate statistical techniques in the water quality assessment of Danube river, Serbia. *Archives of Environmental Protection*, **41** (4), 96, **2015**.
 24. BOJARCZUK A., JELONKIEWICZ E., JELONKIEWICZ L., LENART-BORO A. Changes in the quality of shallow groundwater in agriculturally used catchment in the Wiśnickie Foothills (Southern Poland). *Archives of Environmental Protection*, **45** (1), 19, **2019**.
 25. WORLD HEALTH ORGANIZATION (WHO). Guidelines for drinking water quality, 4th ed., 1, 631, **2017**.
 26. BUREAU OF INDIAN STANDARDS (BIS) 10500. Indian standard drinking water- specification, 2nd ed., 1, 16, **2012**.
 27. SHANMUKHA S.G., PRADEEP KUMAR G.N. Spatial distribution of groundwater quality indices using decision support system in Cheyyeru Watershed, YSR District, India. *Spatial Information Research*, **29**, 297, **2020**.
 28. CHAITANYA B.P., KANAK M.P. Spatial analysis of groundwater quality mapping in hard rock area in the Akola and Buldhana districts of Maharashtra, India. *Applied Water Science*, **8** (4), 1, **2018**.
 29. MAJKIC-DURŠUN B., OROS I., OPARUSIC I., PETKOVIC A. Assessing groundwater quality for multiuse and geochemical evolution in the South Banat area of Serbia, Pannonia Basin. *Polish Journal of Environmental Studies*, **28** (5), 3269, **2019**.
 30. PONSADAILAKSHMI S., GANAPATHY SANKARI S., MYTHILI P.S., MADHURAMBAL G. Evaluation of Water Quality Suitability for Drinking using Drinking Water Quality Index in Nagapattinam district, Tamil Nadu in Southern India. *Groundwater for Sustainable Development*, **6**, 43, **2018**.
 31. RAMESH K., ELANGO L. Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. *Environmental Monitoring and Assessment*, 184, 3887, **2012**.
 32. SUSAIAPPAN S., SOMANATHAN A., SULTHAN M. T. Suitability of Water sources for Domestic and Irrigation Purpose around Corporate Dumpsite. *Polish Journal of Environmental Studies*, **30** (4), 3803, **2021**.
 33. ABDULRASOUL AL-OMRAN, FAHAD AL-BARAKAH, ABDULLAH ALTUQUQ, ANWAR ALY, MAHMOUD NADEEM Drinking water quality assessment and water quality index of Riyadh , Saudi Arabia. *Water Quality Research Journal of Canada*, **50** (3), 287, **2015**.
 34. DINKA M.O. Groundwater quality composition and its suitability for drinking in long-term irrigated area. *Journal of water and land development*, **44** (I-III), 43, **2020**.
 35. ARIVARASI R., GANESAN M. Seasonal variation in ground water quality and its suitability for drinking and agriculture – a case study in Kancheepuram region, Tamil Nadu, India. *Global NEST Journal*, **19** (1), 131, **2017**.
 36. DALILA ZIANI, ABDERRAHMANE BOUDOUKHA, ABDERRAHMANE BOUMAZBEUR, LAHCEN BENAABIDATE. Water Quality Assessment for Drinking and Irrigation using Major Ions Chemistry in the Semiarid Region: Case of Djacer Spring, Algeria. *Asian Journal of Earth Science*, **10** (1), 9, **2017**.
 37. SZABOLCS I., DARAB C. The influence of irrigation water of high sodium carbonate content on soils. In I. Szabolcs (Ed.), *Proc 8th International Congress Soil Science Sodic Soils, Res Inst Soil Sci Agric Chem Hungarian Acad Sci, ISSS Trans II*, 802, **1964**.
 38. DONEEN L.D. Salination of soil b y salts in the irrigation water. *Transactions, American Geophysical Union*, **35** (6), 943, **1954**.
 39. RAWAT K.S., KUMAR S., SANDEEP S., GAUTAM K. Assessment of groundwater quality for irrigation use: a peninsular case study. *Applied Water Science*, **8**, 1, **2018**.
 40. VASANTHAVIGAR M., SRINIVASAMOORTHY K., VIJAYARAGAVAN K., RAJIV GANTHI R., CHIDAMBARAM S., ANANDHAN P., MANIVANNAN R., VASUDEVAN S. Application of water quality index for groundwater quality assessment : Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment*, **171**, 595, **2010**.
 41. NAGARAJU A., KUMAR K.S., THEJASWI A. Assessment of groundwater quality for irrigation: a case study from Bandalamottu lead mining area, Guntur District, Andhra Pradesh, South India. *Applied Water Science*, **4**, 385, **2014**.
 42. PIPER A.M. A Graphical Procedure in the Geochemical Interpretation of Water- Analysis. *TRANSACTIONS, AMERICAN GEOPHYSICAL UNION*, 914, **1944**.
 43. KADA H., DEMDOUM A. Assessment of the Hauterivian groundwater quality in zinc mining area for drinking and irrigation uses : Case of Chaabet el Hamra, Algeria. *Journal of water and land development*, **46** (VII-IX), 131, **2020**.