Geospatial approach for assessment of groundwater quality

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Abstract
The increasing population, erratic distribution of rainfall, and their rising demand for water in domestic and irrigation are fulfilled by groundwater resources. Due to overexploitation, there is the deterioration of groundwater quality, and hence to evaluate the groundwater quality, a study was undertaken to understand the water suitability for drinking as well as for irrigation purposes. For this study, five villages, namely Kumulur, Tachankurunchi, Pudurutamanur, Pandaravadai and Poovalur, were selected from Trichy District, Tamil Nadu, India, with an aerial extent of 45.1 km². For the water quality assessment, samples were drawn from 53 locations from the sources like open wells, bore wells and hand pumps, etc. Parameters of pH, EC, TDS, Anions—CO$_3$\(^{2-}\), CO$_3$ \(^{2-}\), HCO$_3$\(^{-}\), Cl$^{-}$, SO$_4$\(^{2-}\), Cations—Ca$^{2+}$, Mg$^{2+}$, B$^{3+}$, Na$^{+}$ and potassium (K$^{+}$) were estimated using the standard analytical procedure in three different seasons, viz., S-I (September 2019), S-II (December 2019) and S-III (March 2020). The WQI was computed for drinking water quality and found that 25% of samples in S-I, 80% samples in S-II and 83% samples in S-III were above the permissible limit for drinking purposes. Indices like Sodium Percentage, Sodium Adsorption Ratio, Permeability Index, Kelly’s Ratio, Magnesium Hazard Ratio, Potential Salinity, USSL Diagram, Wilcox Plot, Piper Diagram and Gibbs plot were evaluated for examining irrigation water quality. The results revealed that in 90% of the area, the water is suitable for irrigation purposes and a few locations (10%) wherein the salt content of water is relatively higher than the entire study area.

Keywords Water Quality Index · Geo-spatial analysis · Groundwater quality · Piper diagram · Gibb plot · Wilcox plot

Abbreviations
% Percentage
mg Milli gram

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1 Introduction

Groundwater is one of the crucial natural resources which meet the requirement of drinking as well for irrigation, and it is limited and a replenishable resource (Salifu et al. 2017). The quality and quantity of groundwater resource are critical due to its dependence on food supplies, public health and transportation, etc., and has a significant impact on society concerning the quality of life (Gupta et al. 2004). As an important of water resources, groundwater has a series of advantages over surface water, i.e. having a wide distribution, good stability, natural regulation, good water quality and not easily contaminating (Gates et al. 2011). In India, around 85% of drinking water requirements and 50% of urban domestic water requirements are fulfilled by groundwater resources. For irrigation, it accounts for approximately 92% of groundwater pumped in the country (Jha et al. 2020).

Due to high dependency on groundwater in arid and semi-arid regions, it becomes necessary to determine the constituents of groundwater and to monitor groundwater constituents periodically to understand the quality of groundwater in a particular area or region (Sakram et al. 2018). The declining quality and quantity of water supply in the area, because of overexploitation and mismanagement of the groundwater resources, need to be intervened at priority (Muthukumar et al. 2011). However, groundwater also has some disadvantages for exploitation, such as being more difficult to be accessed than surface water (Selvaganapathi et al. 2017). Since groundwater is buried underground and requiring a complete understanding of the distribution rules before use, it makes it difficult to estimate the capacity of the aquifer and its exploration of suitable quality aquifers (Janget al. 2016). Hence it is a need for groundwater quality assessment to ensure its suitability in different sectors carefully.

Human activities on the surface and subsurface are influencing the quality of the groundwater. The role of greenhouse-intensive agricultural activities, which includes the application of excessive fertilization and over-irrigation could severely affect the groundwater quality (Khawla and Mohamed 2020). The increasing population and their rising demand for water in domestic and irrigation are fulfilled by groundwater resources as the water infiltrates through the different soil strata, it gets filtrated (Suresh Kumar et al. 2016).
Also, groundwater quality is mainly affected by the geology of the area, land-use practices, rainfall pattern and various climatological factors. In arid and semi-arid regions, where the dependency on groundwater resources is high, the water used for irrigation was of poor quality (Reddy 2013). Overexploitation of groundwater all around the world has resulted in declination of the water table, which has resulted in lower agricultural productivity, sea-water intrusion in a coastal aquifer, groundwater quality degradation, land subsidence, droughts, etc. (Samadder et al. 2011).

The use of poor quality of water not just affects the growth of the crop, but there are many adverse effects, affecting the physical condition of the soil, crop health, and yield (Khawla and Mohamed 2020). In the regions where agriculture is the primary activity, there is a need to monitor the groundwater quality for contamination due to the usage of chemical fertilizer (Iqbal et al. 2020). Quality of water is essential to determine the success of the crops with different water requirements, and hence it is necessary to understand the hydro-geochemical nature of the groundwater regarding irrigation, which can contribute to the effective management of the crop and avoid negative crop growth and its production (Abbasnia et al. 2018; Reddy 2013; Soleiman et al. 2018).

Human life is also under threat when contaminated water is to be used for consumption. The presence of contaminants in water along with elements beyond their permissible limits can adversely affect human health (Brhane 2018). Due to intense agricultural practices, leading to the intensive usage of chemical fertilizers and increased groundwater pumping has not just affected the water quality resulting in quality degradation (Reddy 2013). Therefore, water quality monitoring should be emphasized in an area at the highest preference as it indirectly affects human health in the form of different problems (WHO 2006).

Water quality evaluation is of prime importance for the protection and sustainable management of groundwater resources, to meet the demands, and for climate change. A practical method for determining water quality is by using different indices (Adimalla et al. 2020). Water Quality Index (WQI) is a widely used tool in evaluating water quality (Selvaganapathi et al. 2017; Iqbal et al. 2020; Brhane 2018). It summarizes different water quality parameters in a single number, which is simple to understand, easy to interpret, and acts as a key in forming a decision about the water quality and based on it, the possible use of the water body (Adimalla and Qian 2019; Khanoranga and Khalid 2019; Khatri et al. 2020). It also facilitates the comparison between samples collected from different regions.

WQI helps in the understanding of issues regarding water quality, which is integrated by large complex data and based on which value is provided on which management plans can be implemented (Rawat and Singh 2018). The estimation of water quality the following approaches four different methods present across the globe are the National Sanitation Foundation Water Quality Index (NSFWQI), the Canadian Council of Ministries of the Environment Water Quality Index (CCMEWQI), the Oregon Water Quality Index (OWQI) and Weighted Arithmetic Water Quality Index Method (WAWQI) (Dendukuri et al. 2017).

To determine the water quality for irrigation, different indices, viz. Sodium Absorption Ratio (SAR), Permeability Index (PI), Residual Sodium Carbonate (RSC), Percentage Sodium (%Na), Kelly Ratio (KR) and Magnesium Hazards (MH), are index value that elaborates the fitness of groundwater for agriculture use (Jafar et al. 2018; Khanoranga and Khalid 2019; Khatri et al. 2020).

GIS can be defined as a technique for capturing, storing, retrieving, interpreting analyses and predicting (Rawat and Singh 2018). GIS is also used as a database system to store and prepare 2D, 3D for water quality status maps according to the concentration values of different chemical constituents (Jha et al. 2020). Geographical information system (GIS) is used for various applications from micro-level planning to macro-level planning,
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evaluation, implementation and regular monitoring (Patele et al. 2013). The GIS applications are a rapidly growing field of research with the integration of different subjects like atmosphere, ocean, land, sea, water resources, health, defence, agriculture, demography, forestry to economics and many more (Khare et al. 2015; Sakram et al. 2018; Asadi et al. 2020). Integration of GIS and WQI provides detailed, quick and reliable information, which can be used further for the interpolation of WQI data spatially by interpolation and also formulate decision support system to adopt strategy related to water quality (Singh et al. 2020).

2 Materials and methods

The groundwater samples were analysed to find their suitability for drinking and irrigation purposes.

2.1 Study area

Agricultural Engineering College and Research Institute, Kumulur, is a state-owned institution, constituted with Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. The institute is spread across an area of 1.14 sq. km and is located 30 km away from Trichy city. Agriculture is the major source of livelihood for the people living in the vicinity. Paddy is the major crop in this region. The area falls in the Lalugudi and Pullambadi block of Trichy district with an aerial extent of 45.1 sq. km. The average annual rainfall of this region is 881.412 mm. The sampling was collected with three different periods. In Tamil Nadu region, the rainfall is concentrated in June to September (Southwest monsoon) and October to December (Northeast monsoon), which has a significant contribution to annual rainfall (Vaidheki and Arulanandhu 2017). Due to which understanding the water quality before and after the rainfall the postmonsoon period (March 2020) is considered which would be able to analyse in this study. Due to which understanding the water quality before and after the rainfall the postmonsoon period (March 2020) was considered which would be able to analyse in this study. The Pullambadi canal (distributaries of the Cauvery River) also acts as a source of irrigation. Besides, during postmonsoon periods, groundwater is the main source of irrigation.

Hence it is necessary to assess the groundwater quality in the study area. For assessment of groundwater quality, 53 samples were collected across the 5 villages, falling in the proximity of the Agricultural Engineering College and Research Institute, Kumulur campus, namely Kumulur, Tachankurunchi, Pudurutamanur, Pandaravadai and Poovalur (shown in Fig. 1). The geographical extent of the study area is spread across the east longitude of 78° 78' and 78° 85' and the northern latitude of 11° 00' and 10° 89'. The water sampling was done in September 2019, December 2019 and March 2020 in 100-day intervals. Groundwater samples were collected along with coordinates (using hand-held GPS instrument of 5 m accuracy) from the different sources of groundwater like open dug wells, hand pumps and bore wells. Out of 53 collected water samples, there are 14 nos. of samples collected from open dug wells, 8 nos. of samples from hand-operated pumps, 31 nos. of samples from bore wells. It is observed that the depth of an open well ranges from 12 to 15 m, whereas the bore depth having in the ranges of 60 to 100 m and the hand-operated pump is found to be 7 to 10 m. The collected groundwater sample’s locations are depicted in Fig. 1.
2.2 Soil

The study area consists of soil like black cotton soils, red sandy to loamy soils and alluvial soils. A thin layer of red sandy soils overlies the western and southern parts. The alluvial soils occur in the central part, near Poovalur. Black cotton soils are observed in the northern part, whereas red loamy soils occur in the hilly regions (Suresh 2008).

2.3 Geology

A large part of the Lalgudi block was covered by formations like the hard rock of granite, gneisses and charnockite. At certain parts of the Lalgudi block, presence of sedimentary formations is Gondwana, Cretaceous and Quaternary formations. The study area exists thin fringes of Gondwana formation which were the ancient sedimentary formation. The cretaceous formations are the lowest and lie on the western charnockites in the major areas. In the study area, on exists gneiss and granite at northern and southern ends. There is heavy weathering near the junction with the cretaceous rocks, and the charnockite is also tremendously weathered with tufaceous limestone (Kankary matter) (Suresh 2008).

2.4 Hydro-chemical analysis of water

Water sampling for the water quality assessment was done for understanding the chemical constituents. Therefore, utmost care was exercised to avoid the possibility of any external
contamination (Brhane 2018). The samples were collected in a glass and plastic bottle thoroughly with 1% nitric acid. On field, the container was cleaned and rinsed 3–4 times with the sample water (Sakram et al. 2018). The bottle should not be washed with detergent or soaps.

2.4.1 Preliminary survey

The preliminary survey of the area was done for the location of the groundwater sources in and around the study area. The geospatial data of the corresponding sampling point were noted along with a landmark near the source for identification. The coordinates were obtained from the handheld GPS device (accuracy of 5 m). Some data points were also collected for use while generating the training file for running the maximum likelihood classification for land use and land cover. The interaction with locals was done for understanding the groundwater situation in particular areas. The rainfall data were obtained for AEC & RI Kumulur Meteorological Laboratory for the sampling period.

2.5 Water sampling and analysis

For the collection of the water samples, the following methods have been adopted.

I. The tube well or hand pump water was pumped for about 15 to 20 min to drain out the water retained in the pipe.
II. The bottle was washed repeatedly with the water before taking the sample of about 1 L.
III. The water should be collected as such, without bothering about the turbidity, as it does not affect the test results.
IV. From the well, the sample was drawn either during irrigation, just before the water falling into the irrigation channel or by drawing it with the help of a bucket or any clean container using a rope. The water surface should not be disturbed for the removal of floating impurities. Place the cap on the bottle tightly.
V. On a piece of paper of suitable size, the name, address, sample number, identification mark, etc., were written with the marker and pasted firmly on the bottle.
VI. These samples were further used for the analysis of water quality.

The groundwater sample parameters, viz. pH, EC, TDS, TH, CO$_3^{2-}$, HCO$_3^-$, Cl$^-$, SO$_4^{2-}$, Ca$^{2+}$, Mg$^{2+}$, B$^{3+}$, Na$^+$, and K$^+$, were estimated using the standard analytical procedure as per Raghunath (1987). The detailed estimation of each parameter was given below.

- Electrical Conductivity is the reciprocal of electrical resistivity expressed in mho/cm.
- pH is a measure of alkalinity or acidity of water. It can be also defined as the hydrogen ion concentration in water.
- Total dissolved solids (TDS) were estimated by using the following formula: EC to be multiplied by 0.64 (Brown et al. 1970). It can be also represented with the following formula:
Cations dominant in the water like \( \text{Ca}^{2+}, \text{Mg}^{2+}, \text{B}^{3+}, \text{Na}^+ \) and \( \text{K}^+ \) were estimated and used to understand the dominance of the cations in the groundwater.

Anions like \( \text{CO}_3^{2-}, \text{HCO}_3^-, \text{Cl}^- \), \( \text{SO}_4^{2-} \) were analysed to understand the dominance of anions in the groundwater sample.

The different parameters analysed, and the methodologies used (given by Rawat 2018) to compute these parameters are presented in Table 1.

### 2.5.1 Water quality index (WQI) for drinking purpose

For evaluating the water quality for drinking purposes, Water Quality Index (WQI) was calculated. Further, the quality rating or sub-index (\( Q_n \)) was calculated using the following equations (Horton 1965; Brown et al. 1970).

\[
Q_n = 100 \times \left[ \frac{(V_n - v_i)}{(V_s - v_i)} \right] \tag{2.2}
\]

where \( Q_n \) = Quality rating for the \( n^{th} \) water quality parameter. \( V_n \) = Actual value of the \( n^{th} \) parameter. \( v_i \) = Ideal value of this parameter. \( V_s \) = Standard permissible value of the \( n^{th} \) parameter.

[Note: consider \( v_i = 0 \) for all the samples except the pH value where \( v_i = 7 \); because pH 7.0 denotes a neutral value for the water sample which indicates no change in the rating of water quality].

The Water Quality Index also called the weighted arithmetic index method was used for the calculation of WQI. The unit weight value is the reciprocal of the recommended standard value (\( V_n \)), to the corresponding parameter.

\[
W_n = \frac{K}{V_s} \tag{2.3}
\]
where \( K = \frac{1}{\sum_{n=1}^{N} \left( \frac{1}{W_n} \right)} \), \( W_n = \) unit weight for the \( n \)th parameters. \( K = \) constant for proportionality. \( V_S = \) standard value for the \( n \)th parameters.

The constant of proportionality \( (K) \) is involved in the equation to normalize the effect caused due to combination of different elements in the water quality. The method of classifying the water quality is based on the overall Water Quality Index (WQI), which is calculated by aggregating the quality rating \( Q_n \) linearly as expressed as follows:

\[
WQI = \frac{\sum Q_n W_n}{\sum W_n}
\] (2.4)

Based on the obtained values of WQI, the classification of the groundwater sample will be done as excellent, good, permissible, very poor and unsuitable.

### 2.5.2 Water quality standards

The standards prescribed by the World Health Organization (WHO 2011) and Bureau of Indian Standards (BIS 2012) for the suitability of water for the drinking purposes and the permissible limits of each parameter were used for assigning the quality rating and the unit weight of the parameters, for the computation of WQI. The standard permissible limits for each parameter are given in Table 2.

### 2.5.3 Statistical analysis

The hydro-chemical evaluation of the groundwater done by chemical analysis like mean, range, maximum, minimum, standard deviation (STD) and coefficient of variation (CV) was computed for every individual water quality parameter. The water parameters were

| Parameter | Permissible limit of a parameter for drinking (WHO 2011) | Permissible limit of a parameter for drinking (BIS 2012) | Undesired effect |
|-----------|--------------------------------------------------------|-------------------------------------------------|-----------------|
| pH        | 8.5                                                    | 8.5                                            | Taste           |
| EC        | 1000                                                   | 1000*                                          | Gastrointestinal irritation |
| TDS       | 1500                                                   | 2000                                           | Gastrointestinal irritation |
| TH        | 120                                                    | 120*                                           | –               |
| Ca\(^{2+}\) | 200                                                    | 200                                            | –               |
| Mg\(^{2+}\) | 150                                                    | 100                                            | –               |
| Na\(^+\)  | 200                                                    | 200*                                           | High blood pressure |
| K\(^+\)   | 12                                                     | 12*                                            | Bitter taste    |
| Cl\(^-\)  | 600                                                    | 1000                                           | Salty taste     |
| SO\(_4^{2-}\) | 400                                                    | 400                                            | Laxative effect |
| CO\(_3^{2-}\) | 120                                                    | 120*                                           | –               |
| HCO\(_3^{-}\) | 1000                                                  | 1000*                                          | –               |
| B3 +      | 2.5                                                    | 1                                              | Affect internal organs |

*indicates the parameters are adopted from WHO (2011), since the values for corresponding parameters are not there in BIS code
interpreted, statistically using the tools like correlation and principal component analysis for the study area.

The correlation was a measure, to understand the relationship between two variables. The correlation coefficient was computed using the Pearson method. The value of Pearson’s correlation coefficient ‘r’ lies in the range of ±1. There is no correlation between the parameters if the value of ‘r’ is zero. A strong correlation was shown with higher correlation values and vice versa.

As the groundwater quality parameters play a different role in affecting the water quality, principal component analysis was done to reduce the dependency of numerous variables for determining the water quality. The methods to evaluate the major parameters affecting the water quality normalize it and can be further used for the more important features extraction with minimum principal components.

2.6 Water quality for irrigation water using irrigation indices

For evaluating the water quality for drinking purposes, different indices were used. Some of them are used in this study to find the quality of groundwater present within the study area. The concentrations of the individual parameters obtained for the computation need to be expressed in milli-equivalents per litre (meq/L). Further, the irrigation water quality was also evaluated using the United State Salinity Laboratory (USSL) diagram, Gibbs’s plot, Piper plot and Wilcox plot were also used to determine the various irrigation classes of groundwater.

2.6.1 Sodium percentage (Na %)

Sodium percentage (Na %) is an indication of the soluble sodium content of the groundwater and used to evaluate Na hazard. In all-natural waters, % Na is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability. It was calculated by using the equation (Todd, 2004) as

\[
\text{Na} \, (\%) = \frac{(\text{Na}^+ + \text{K}^+) / (\text{Ca}^{2+}\text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)}{100}
\]  \hspace{1cm} (2.5)

2.6.2 Sodium absorption ratio (SAR)

A ratio is used to express the relative activity of sodium ions in an exchange reaction with water in which ionic concentrations are expressed in milliequivalents per litre (meq/l). The rise in SAR of irrigation water increases SAR of the soil, which ultimately increases exchangeable sodium of the soil. This was calculated employing the following equation (Raghunath 1987) as:

\[
\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}
\]  \hspace{1cm} (2.6)
2.6.3 Permeability Index (PI)

The classification of water for irrigation based on PI was suggested by Doneen (1964), which takes into consideration the effect of Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), and HCO\(^{-3}\) contents of the soil. It was calculated by using the equation as

\[
\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-})}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100
\]  

(2.7)

2.7 Kelly’s ratio (KR)

Kelly’s ratio (KR) is based on the influence of cations like Na, Ca and Mg levels in the groundwater. This was calculated employing the equation (Kelly 1963) as:

\[
\text{KR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})}
\]  

(2.8)

2.8 Magnesium hazard ratio (MH)

Due to the presence of magnesium in a higher concentration than calcium, there is a higher degree of magnesium saturation which destructs the soil structure. It also decreases soil productivity. The magnesium hazard (MH) ratio values are calculated by using the equation proposed by Doneen (1964) for irrigation water where.

\[
\text{MH} = \frac{\text{Mg}^{2+}}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \times 100
\]  

(2.9)

2.9 Potential salinity (PS)

Potential salinity is the measure of available salt content in the form of chlorides and sulphates in the irrigation water. Based on the available salt content, the water was categorized for its suitability for different kinds of the soil

\[
\text{PS} = \text{Cl}^- + \frac{1}{2}\text{SO}_4^{2-}
\]  

(2.10)

2.9.1 United State Salinity Laboratory (USSL) diagram

United State Salinity Laboratory (USSL 1954) diagram is a graphical geochemical representation of groundwater quality suggesting that the majority of the water samples belongs as the quality of water is an important consideration for the evaluation of salinity or alkali conditions in an irrigated area. The diagram was drawn by plotting the electrical conductivity values concerning SAR for the first, second and third sampling in the

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study area, and the classification of water quality was done by plotting it into the USSL diagram.

2.9.2 Piper plot

Piper plot (Piper 1944) is a graphical representation of the hydrochemistry of the groundwater, which was evaluated by plotting the cation and anions in meq/l, in Piper’s trilinear diagram. It was important for understanding the major ions and cations present in the water samples. The piper plot was plotted for the first, second and third sampling in the study area, and the classification of water based on its hydrochemistry was done by plotting it in Piper’s trilinear diagram.

2.9.3 Gibbs’s plot

Gibbs diagrams (Gibbs 1970) were used to understand the relative importance of three major natural mechanisms, controlling water chemistry, viz; (i) atmospheric precipitation, (ii) mineral weathering and (iii) evaporation and fractional crystallization. Using the following formula, the ratios for cations and anions were computed and plotted against the total dissolved solids.

\[
\text{Cations} = \frac{\text{Na}^+ + \text{K}^+}{\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+}} \\
\text{Anions} = \frac{\text{Cl}^-}{\text{Cl}^- + \text{HCO}_3^-}
\]  

(2.11)  
(2.12)

The groundwater samples were plotted using the formulas for the cations and anions. The classification was done for understanding the chemistry of water in the study area.

2.9.4 Wilcox plot

Wilcox 1955 classifies the water based on the relative percentage of sodium over the total cations, viz., sodium, potassium, calcium and magnesium. The results depicted suitable for irrigation. The diagram was plotted for the first, second and third sampling, and water quality was determined.

2.9.5 Residual sodium carbonate (RSC)

Residual sodium carbonate is the means of estimating the hazard of restrictive permeability due to sodium considering the concentration of carbonates, bicarbonates and magnesium in irrigation water. This was calculated employing the equation (Eaton 1950) as:

\[
\text{RCS} = \left[ (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \right]
\]  

(2.13)
2.9.6 Interpolation of water quality maps

Based on the water quality indices and parameters, the thematic maps of the study area for the Water Quality Index and the spatial distribution of the concentration of different anions and cations were generated. In the GIS platform, IDW (inverse distance weightage) interpolation tool was used to generate the map. This interpolation technique is based on the proximity of the measured entity; the measure of the unknown entity will be based on its distance from the known quantity (Kawo 2018; Mueller 2004). ESRI’s ArcGIS 10.5 software was used for generating the thematic maps.

3 Results and discussion

To check the groundwater quality for irrigation and drinking, the collected groundwater sampling was analysed and the constituent parameters were studied.
3.1 Water sampling and analysing

Groundwater sample collection of the study area was done by three times, viz., Season-I, II & III in August–September 2019, December 2019 and March 2020. The summary of the collected water sampling is given in Table 3.

3.2 Water sample analysis

3.2.1 Season-I (August–September 2019)

The season-I sampling with its summary is presented in Table 4. The pH was found to be 6.9 to 8.7, the low standard deviation (STD) denotes the cluster of data around the mean, and the low coefficient of variation (CV) depicts the low variability of pH within the observed dataset. The EC ranged from 120 to 1920 µS/cm with an average of 833.40 µS/cm, whereas the TDS varies from 76.8 to 1228.8 mg/L with an average of 533.36 mg/L. The high value of the STD for EC and TDS revealed that the spread of data from the mean value and the value of CV shows the intermediate to low variation among it. The sodium ranged from 19.75 to 353.85 mg/L with an average of 138.95 mg/L, and the high values of STD and CV depict that the wider scatter of points from the mean and high variation of the dataset within the observed samples (Sakram et al. 2018). Potassium was found in the range of 0 to 410.60 mg/L and the average was 33.27 mg/L, when compared to sodium, there is lesser dispersion of values from the mean, but the CV is the highest among the cations and anions, which denote very high variability in the observed data.

The calcium and magnesium varied from 4.80 to 206.40 mg/L and 7.68 to 91.20 mg/L with the averages of 58.05 and 31.82, respectively. The dispersion from the mean in magnesium is more than two times that of calcium and both values are having high values of CV, due to its concentration variability across the study area. The boron was found in trace and ranged between 0.1 and 1.55 mg/L, with a mean of 0.54 mg/L and its scattering from the mean was low and the variability was high within the dataset because boron is found in traces unless contaminated by agricultural sources (Sakram et al. 2018; Brhane 2018).

| Parameters | Min | Max | Mean | STD | CV |
|------------|-----|-----|------|-----|----|
| pH         | 6.90| 7.90| 7.40 | 0.22| 0.03|
| EC         | 180.00| 3800.00| 861.18| 564.38| 0.66|
| TDS        | 115.20| 2432.00| 551.15| 361.21| 0.66|
| Na         | 35.30| 941.40| 212.74| 155.97| 0.73|
| K          | 4.45| 363.85| 43.88| 76.04| 1.73|
| Ca         | 8.00| 158.00| 57.88| 33.58| 0.58|
| Mg         | 7.20| 321.60| 39.58| 44.08| 1.11|
| Cl         | 28.40| 937.20| 118.89| 132.22| 1.11|
| SO₄        | 43.23| 1116.70| 281.02| 194.52| 0.69|
| CO₃        | 0.00| 0.00| 0.00| 0.00| 0.00|
| HCO₃       | 61.00| 366.00| 208.12| 70.10| 0.34|
| B          | 0.20| 1.75| 1.04| 0.47| 0.46|
Anions like chlorine and sulphate ranged from 42.60 to 738.40 mg/L and 242.55 to 393.85 mg/L, and the corresponding range of means was 234.43 and 271.46, respectively. Very high SD of the cluster from the mean was observed in chlorine and bicarbonate than sulphate, and CV was high in chlorine. CV was low in sulphate and bicarbonate. Bicarbonate ranged from 170.89 to 927.20 mg/L, with a mean of 576.39 mg/L, and the details are summarized in Table 4.

3.2.2 Season-II (December 2019)

The second sampling was collected during 2019, and the results are presented in Table 5. The results revealed that the pH ranged from 6.9 to 7.9 with a mean of 7.40 and the low STD for pH indicates that the cluster of data around the mean and the low CV depicts the low variability of pH within the observed dataset. The amount of rainfall received between SI and SII was 515.4 mm. The EC ranged from 180 to 3800 µS/cm with an average of 861.18 µS/cm, whereas the TDS varies from 115.2 to 2432 mg/L with an average of 551.15 mg/L. The high value of the STD for EC and TDS denotes the spreading of data from the mean value, and the value of CV shows intermediate of data to low variation among it (Sakram et al. 2018). Sodium ranged from 35.3 to 941.40 mg/L with an average of 212.74 mg/L, and the high values of STD and CV show a wider scatter of points from the mean and high variation of the dataset within the observed samples.

Potassium was found in the range of 4.45 to 363.85 mg/L and the average was 43.88 mg/L when compared to sodium, there is lesser dispersion of values from the mean, but the CV is highest among the cations and anions, which denote very high variability in the observed data. Similar behaviour could be seen in sampling season-I also. When analysing the calcium and magnesium the minimum and maximum were ranged from 8 to 158 mg/L and 7.20 to 321.60 mg/L with an average of 58.05 and 31.82 mg/L, respectively. The distribution of potassium is highly scattered across the observed samples, whereas the boron is in the range of 0.20–1.75 mg/L with a mean of 0.54 mg/L. The dispersion from the mean was low and the variability was high within the dataset because a substantial amount of rice was seen in the study area for the concentration of boron (Sakram et al. 2018; Brhane 2018).

### Table 6 Summary of parameters analysed in sampling III of the study area

| Parameters | Min  | Max  | Mean  | STD  | CV  |
|------------|------|------|-------|------|-----|
| pH         | 6.90 | 8.30 | 7.77  | 0.32 | 0.04|
| EC         | 140.00 | 2750.00 | 949.40 | 446.16 | 0.47|
| TDS        | 89.60 | 1760.00 | 607.61 | 285.54 | 0.47|
| Na         | 22.70 | 579.35 | 204.17 | 116.00 | 0.57|
| K          | 2.45  | 262.40 | 37.09  | 60.33 | 1.63|
| Ca         | 16.00 | 280.00 | 93.65  | 60.41 | 0.65|
| Mg         | 19.20 | 196.80 | 55.08  | 31.40 | 0.57|
| Cl         | 44.38 | 1082.75 | 239.96 | 195.33 | 0.81|
| SO₄        | 69.64 | 1003.83 | 284.74 | 152.66 | 0.54|
| CO₃        | 0.00  | 0.00  | 0.00   | 0.00  | 0.00|
| HCO₃       | 122.00 | 610.00 | 382.11 | 107.07 | 0.28|
| B          | 0.05  | 1.50  | 0.50   | 0.31  | 0.61|
Anions like chlorine and sulphate ranged from 28.40 to 937.20 mg/L and 43.23 to 1116.70 mg/L, and the corresponding ranges of a mean of chloride and sulphate were found to be 234.43 and 271.46, respectively. Very high STD was observed in chlorine and bicarbonate than sulphate, whereas the CV was low in sulphate and bicarbonate. Bicarbonate ranged from 61 to 366 mg/L with a mean of 208.12 mg/L, and it was found that the carbonate was absent in the sampling area (Adimalla et al. 2020).

3.2.3 Season-III (March 2019)

The third and final sampling was done during March 2020 and is depicted in Table 6. The pH ranged from 6.9 to 8.3, with a mean of 7.7, and similar characters were found. The EC ranged from 140 to 2750 μS/cm, and it was observed that the EC was reduced when compared to the previous sampling, whereas the TDS varies from 89.6 to 1760 mg/L with an average of 607.61 mg/L. The high value of the STD for EC and TDS denotes the spread of data from the mean value, and the value of CV shows intermediate to low variation among it. Sodium ranged from 22.7 to 579.35 mg/L with an average of 204.17 mg/L, and the high values of STD and CV show the wider scattering of points from the mean and high variation of the dataset within the observed samples.

The quantity of potassium was found in the average of 37.09 mg/L when compared to sodium, there is a lesser dispersion of values from the mean, but the CV is the highest among the cations and anions, which denotes very high variability in the observed data. Similar behaviour could be seen in sampling-I for calcium and magnesium; it was varied from 16 to 280 mg/L and 19.2 to 196.80 mg/L with averages of 93.65 and 55.08, respectively. The distribution of potassium was observed in highly scattered across the observed samples. Boron is found in trace, ranged between 0.05 and 1.50 mg/L and the dispersion from the mean was low and the variability was high within the dataset because the
substantial amount of reduction was noticed in the concentration of boron (Adimalla et al. 2020; Jha et al. 2020).

Anions like chlorine & sulphate ranged from 44.38 to 1082.75 mg/L and 69.64 to 1082.83 mg/L, and the corresponding mean values were 239.96 and 284.74 mg/L, respectively. Very high STD was observed in chlorine and bicarbonate than sulphate, whereas the CV was low in sulphate and bicarbonate. The third sample also found that the carbonate was absent in the study area.

Based on the results obtained in the samplings, the changes in the parameters are plotted in Fig. 2. The changes in the parameters can be associated with the rainfall received within the sampling period. There has been a fluctuation in concentrations of the parameters seen from the analysis. The averages values of concentration of anions and cations across three seasons in the study area denote the variability in the concentration of the parameters across the three observations. Similar results were found from Rawat 2018. The parameters like pH, Ca, Cl and HCO₃ concentration reduced with rainfall and further as the pumping increased, and the concentration increased. Other parameters like Na, K and B concentration increased with rainfall and decreased with the rise of pumping and the EC, TDS, Mg and SO₄ concentration rose with time.

3.3 Correlation matrix of water

Pearson’s correlation coefficient was computed to verify the relationship between the studied parameters. The correlation matrix was created in R-Studio software for all the physicochemical parameters of water quality (Singh et al. 2013). The classification of the significantly correlated negatively correlated and weak correlated was done for all the sample collection period. The negative or positive value of correlation analysis indicates the influence of each parameter (Barakat 2016; Suresh kumar et al. 2015). Corresponding to the correlation value of the diagonal element of the correlation element, a colour was chosen from the pallet with the scale displayed beside the matrix, denoting the type of relationship for visual understanding.

The results represented in the matrix format in Fig. 3 for all three sampling seasons. S-I shows that pH has a weak correlation to a significantly negative correlation with all the parameters. A dominant and significantly week correlation was found with Ca. K has positive correlations with HCO₃, EC and TDS, whereas a mild positive correlation with Na, B, Mg, SO₄, Ca and Cl. K is moderately correlated with EC, TDS, HCO₃, B, Ca and Mg, Na, SO₄, Cl. Na is positively correlated with HCO₃, SO₄, Cl, EC, TDS, B, Mg and Ca. HCO₃ is strongly correlated with SO₄, EC and pH, and positively correlated Ca and Cl, B and
Mg towards the positive. B is positively correlated with SO₄, Cl, EC and pH, Ca and Mg towards positive. Mg is positively correlated with SO₄, Ca, Cl, EC and TDS. Mg is positively correlated with SO₄, Ca, Cl, EC and TDS, whereas Ca is strongly correlated with Cl. Cl has a very strong correlation with EC and TDS. EC and TDS are directly correlated as TDS is obtained from the values of EC. Similar results were found by Sureshkumar et al. 2016; Tirkey et al. 2017; Soleimani et al. 2018.

For sample II, there is positive correlation of pH with K and HCO₃, whereas negatively correlated with B, Mg, Cl, Na, SO₄, EC and TDS. K is negatively correlated with B whereas positively correlated with HCO₃, Mg, Cl, Na, SO₄, EC and TDS. HCO₃ was found to be negatively correlating with B, whereas it was positively correlating with Mg, Cl, Na, SO₄, EC and TDS. B is positively correlated with Mg and SO₄, whereas it was negatively correlated with Cl, Na, EC and TDS. Ca was strongly correlated with SO₄, EC and TDC and positively correlated with Mg, Cl and Na, whereas Mg was strongly correlated with Cl, followed by EC, TDS, Na and Cl. Cl was strongly correlated with EC and TDS followed by Na and SO₄. Na and SO₄ were strongly correlated among themselves as well as with EC and TDS. Similar results were found by Sureshkumar et al. 2016; Tirkey et al. 2017; Soleimani et al. 2018.)
Fig. 6  Spatio-temporal variation of magnesium (August 2019–March 2020) in the study area

Fig. 7  Spatio-temporal variation of sodium (August 2019–March 2020) in the study area

Fig. 8  Spatio-temporal variation of potassium (August 2019–March 2020) in the study area
Fig. 9 Spatio-temporal variation of chlorine (August 2019–March 2020) in the study area

Fig. 10 Spatio-temporal variation of sulphate (August 2019–March 2020) in the study area

Fig. 11 Spatio-temporal variation of bi-carbonate (August 2019–March 2020) in the study area
Fig. 12  Spatio-temporal variation of electrical conductivity (August 2019–March 2020) in the study area

Fig. 13  Spatio-temporal variation of total dissolved solids (August 2019–March 2020) in the study area

Fig. 14  Spatio-temporal variation of pH (August 2019–March 2020) in the study area
In sampling-III magnesium has a strong correlation with Cl, followed by Cl, EC, TDS Na, SO₄, HCO₃, pH and B whereas negative correlation with K. Ca was found to have a strong correlation with Cl, EC and TDS followed by SO₄, Na, HCO₃, K and pH and negatively correlated with B. Cl has a strong correlation with Na, TDS, EC, SO₄ and weakly correlated with pH, HCO₃ and K and negatively correlated with B. HCO₃ is correlated positively with SO₄, Na, EC, TDS, K and B, whereas there was a negative correlation with pH. Na exhibited a strong correlation with SO₄, EC and TDS and positively correlated with pH, K and B. SO₄ exhibited a strong correlation with EC and TDS followed by a positive correlation with K and B. There is no correlation between SO₄ and pH, EC has a strong correlation as TDS is derived from EC. Further, it exhibited a positive correlation with K, B and pH. pH has a negative correlation with B and a mild positive correlation with K. K and B are mildly correlated with each other. The significance of variability of the concentration and its dependency on other parameters is the physical, ecological and chemical function, and it can change based on time, as in the obtained results. Similar results were found by Sureshkumar et al. 2016; Sakram et al. 2018; Soleimani et al. 2018; Abijith et al. 2020).

3.4 Spatial interpolation

The spatial interpolation of all water quality parameters was done in the ArcGIS platform using the spatial analysis tool (IDW method) (Selvaganapathi et al. 2017), and the interpolated maps for the parameters are depicted from Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14. The permissible limit for the estimation of the water quality was considered as per the guidelines prescribed by WHO 2011 and BIS 2012, and these standard values were used in the computation of the Water Quality Index for the study area.

Figure 4 shows that the spatial distribution of boron across the study areas in three sampling seasons, and it was found that the boron concentration for the entire study area was below the permissible limits for all three sampling periods. Similarly, the spatial distribution of calcium for the study area was also found to be below the permissible (Fig. 5) except one specific location at Pallapuram (area < 0.001km²) was found in higher concentration due to higher depths of the bore well (Khanoranga and Khalid 2019).

On the contrary, to calcium and magnesium, the concentration and distribution across the study area were observed beyond the permissible limits and very few locations viz., Kumulur, Pallapuram and Thachankurichi were found under the permissible limit (area <0.001km²) as shown in Fig. 6, due to the presence of a higher concentration of exchangeable Na ions (Khanoranga and Khalid 2019). It was also observed that throughout the sampling period, the concentration of magnesium was always higher than the permissible limits.

Figure 7 shows the spatial–temporal distribution of sodium across the study area. As the sampling proceeded from S-I to S-III, there was a gradual rise in the concentration of available sodium ions in the water sample (Szabolcs 1964). The area over the permissible limit increased from 1.15 km², 15.58 km² and 17.18 km² with concerning for to S-I, S-II and S-III which could be due to the geological characteristics or ion exchange (Khanoranga and Khalid 2019).

The distribution of potassium across the study area (Fig. 8), during the sampling period the area with concentration more than the permissible limit, was less. The high concentration was observed in Thachankurichi and Pallapuram, which was eventually reduced with the sampling period (Sakram et al. 2018).
In Fig. 9, the distribution of chlorine across the study area is interpolated. Here the results have shown that the concentration of the chlorine across the study area during the sampling period was within the permissible limit. Some parts of Pallapuram have the concentration over the permissible limits (area < 0.001km²) during S-I and S-III. In S-II, there was a slight rise in the concentration of chlorine in Puduruthamanur (area < 0.001km²) which can be due to more drawdown than recharge (Jang 2016).

The concentration of sulphate has been plotted across the study area as shown in Fig. 10. During the S-I sampling, the concentration was within the permissible limit across the study area, but the area over the permissible limit increased during S-II (1.22 km² area over the permissible limit across Puduruthamanur, Thachankurichi and Pallapuram) and further decreased in S-III (0.76 km² area over the permissible limit) which can be due to the mineralization of sulphates during the sampling period (Khanoranga and Khalid 2019).

Carbonates were absent within the study area. The concentration of bicarbonates across the study area is plotted in Fig. 11. From the interpolation of the concentration of bicarbonate, it is well within the permissible limits of drinking water standards of WHO.

The EC concentration distribution across the study area is interpolated in Fig. 12. As the sampling progressed, the concentration of EC, i.e. amount of salts, has increased in terms of area reduced during S-II and rose in S-III. The area with EC over the permissible limits across the study area during S-I, S-II and S-III was 5.2 km², 4.02 km² and 11.63 km², respectively. Looking up at TDS in Fig. 13, the concentration across the study area is within the permissible limit.

The hydrogen ion concentration observed in the study area was interpolated and is depicted in Fig. 14. During the S-I, there is a small area over the permissible limit (area < 0.001km²), whereas during S-II and S-III the pH is within the prescribed limit.

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Table 7  Water quality ratings for WQI

| WQI | Category        | S-I  | S-II | S-III |
|-----|----------------|------|------|-------|
| <25 | Excellent      | 11   | 0    | 9     |
| 25–50| Good           | 30   | 23   | 27    |
| 50–75| Permissible    | 4    | 18   | 8     |
| 75–100| Very Poor     | 2    | 1    | 2     |
| >100| Unsuitable     | 6    | 9    | 7     |

Fig. 15  Water Quality Index (WQI) for water samples of S-I, S-II & S-III
Alike all the parameters were analysed and interpolated in the GIS environment (Shukla and Saxena 2020). The concentration of the parameters was further used for the estimation of the Water Quality Index.

### 3.5 Water Quality Index (WQI) for drinking purpose

The Water Quality Index for the above concentrations of the different parameter using different formulas and the thresholds for the water quality ratings are given in Table 7 (Selvaganapathi et al. 2017). The graphical representation of the Water Quality Index for all three seasons is depicted in Fig. 15.

In sampling S-I & S-II, 15% of the samples were overshooting the permissible limit of the Water Quality Index (i.e. ID no. 4, 5, 15, 16, 32, 33, 40 & 41) for SI and (ID no. 4, 5, 32, 33, 37, 41 & 44) for SII. In sampling S-III 20% of the samples were overshooting the permissible limit of the Water Quality Index (i.e. ID no. 4, 5, 6, 13, 28, 30, 33, 34, 39 & 41). The high concentration of Ca is found in the places of Tachankurunchi, Pudurutamanur, Pandaravadai villages which influenced by Kaveri canal and its geological formations, high mineral deposition of magnesium is found in the regions of Kumulur, Tachankurunchi, Pudurutamanur, Pandaravadai and Poovalur, high sodium content is influenced by the chemicals used in the intensive agriculture areas, high sulphate in water samples was caused by intensive pumping of groundwater in the highly populated area could be the major reasons where the samples are beyond the permissible limits.

### Table 8 Spatial distribution of area covered (in km²) of Water Quality Index across the sampling period

| Sl. no. | Category   | S-I | S-II | S-III |
|---------|------------|-----|------|-------|
| 1       | Excellent  | 0.20| 0    | 0.08  |
| 2       | Good       | 19.35| 3.57 | 15.00 |
| 3       | Permissible| 11.22| 17.26| 9.31  |
| 4       | Very Poor  | 11.36| 7.44 | 16.03 |
| 5       | Unsuitable | 3.68 | 17.54| 5.39  |
A spatial analysis tool using the IDW method and spatial interpolation of all the points were done in ArcGIS and obtained Water Quality Index map (Fig. 16) across the study area (Brhane 2018). The obtained interpolated maps are depicted in Fig. 16 for all three seasons, and the classification of water quality was done based on the categories mentioned in Table 4 (Selvaganapathi et al. 2017). The computation of the area under the individual category of excellent to very poor conditions in all three samplings is tabulated in Table 8. The results revealed that the places, namely Kumulur, Poovalur, Pudurutamanur, come under excellent category, and the places, viz., Tachankurunchi, Pandaravadai and part of Pudurutamanur, come under very poor unsuitable conditions. The entire S-I, S-II and S-III areas falling under the permissible limits are 30.87 km², 20.82 km² and 24.39 km², whereas areas beyond the permissible limits are 15.04 km², 24.98 km² and 21.42 km², respectively. The higher concentration of the parameters, namely Ca, Mg, Na and EC, observed for a sample result in high WQI, and thus, there are above the permissible limits.

3.6 Water quality for irrigation purpose

The water quality standard for defining the water quality for irrigation purposes was evaluated based on different irrigation indices (Revathy et al. 2017). Assessment of irrigation water for finding its suitability for irrigation was done based on different irrigation indices like SAR, Kelly’s ratio, sodium percentage (Salifu et al. 2017). The obtained concentration in mg/L was converted into me/L. The irrigation indices are as follows:

3.6.1 Sodium percentage

The hazardous effect of sodium on the plants is indicated by an irrigation index called sodium percentage (Selvaganapathi et al. 2017). According to this, water is classified into five classes. From the observation, it was found that 70% in S-I, 60% in S-II and 74% in S-III groundwater samples are above the permissible limits of the standards, indicating its ability for use for irrigation purposes.

From Fig. 17, we can see the classification of irrigation water in five categories. Across the study area, in the three samplings i.e. S-I, S-II and S-III, there exists no sample under the unsuitable category. In the doubtful category lies 0.72 km², 0.09 km²

![Fig. 17 Spatio-temporal variation of sodium percentage (August 2019–March 2020)]
and 0.01 km² area, whereas in permissible category lies 39.70 km², 24.94 km² and 1.30 km² area. The area under the good and excellent category 5.21 km², 20.68 km², 44.49 km² and 0.08 km², respectively, for S-I, S-II and S-III. The study also shows the rising concentration of sodium effect which can be geology or by the influence of other ions in the groundwater (Khanoranga and Khalid 2019).

3.6.2 Sodium adsorption ratio

Sodium adsorption ratio (SAR) is one of the most essential parameters and widely used index for understanding the suitability of water for irrigation purposes.

SAR is one of the import criteria for determining sodium and its effect on the crops. From Table 7, across the sampling duration for approximately 95% of the samples from S-I, S-II and S-III (100%) lie in the excellent category denoting the least influence of sodium for plant growth or agriculture. The results were like that of Revathy et al. 2017, wherein the water is within the permissible limit for irrigation. From Fig. 18, it could

Fig. 18  Spatio-temporal variation of SAR (August 2019–March 2020)

Fig. 19  Spatio-temporal variation of permeability index (August 2019–March 2020)
be seen the spatial distribution of SAR across S-I, S-II and S-III and the area under the doubtful category is very small (<1 km²).

3.6.3 Permeability index

As the permeability of the soil is affected by the influence of the constituents in the water used for the irrigation i.e. salts (Brhane 2018). Hence the permeability index is one of the most important indices to be estimated for finding the quality of the irrigation water. In S-I and S-II, 67.92% and 41.18% were classified under Class-I (denoting unsuitability of water for irrigation), which further decreased in S-III by 26.42%. A clear decreasing trend was observed when sampling proceeded from S-I to S-III, which implies a reduction in the values of the permeability index over time. From Fig. 19, it could be seen the suitability of irrigation water is increasing from S-I to S-III. From the spatial analysis, the area with good water availability is increasing from 10.06 km² from S-I, 34.76 km² in S-II and 43.59 km². Similarly, the area under the unsuitable class in S-I is 35.59 km², S-II is 11.43 km² in S-III is 2.06 km².

Fig. 20 Spatio-temporal variation of Kelly’s ratio (August 2019–March 2020)

Fig. 21 Spatio-temporal variation of magnesium hazard ratio (August 2019–March 2020)
Kelly’s Ratio is one of the measures to indicate the presence of excess sodium content in the irrigation water concerning calcium and magnesium (Iqbal et al. 2020). As the sampling proceeds, the permissible sodium percentage reduces in the water sample, i.e. from S-I to S-II, and rises in the period of S-III (60.38%, 27.45% and 60.38%).

From Fig. 20, it can show the suitability of irrigation water is falling from S-I to S-II and rising in S-III. The suitable area under the suitable range obtained by spatial analysis is 16.63 km², 1.41 km² and 21.82 km². Similarly, the area under unsuitability class is 29.16 km², 44.38 km² and 23.97 km², respectively, for S-I, S-II and S-III.

### 3.8 Magnesium hazard ratio

Suitability of groundwater was assessed using magnesium hazard, based on the presence of magnesium in irrigation water and its influence on the toxicity to the crops (Shukla & Saxena 2020). Water samples under suitability class across the three-sampling period S-I, S-II and S-III were 54.72%, 54.90% and 37.47%, whereas 45.28%, 45.10% and 62.26% samples were classified under the unsuitable category, which shows the rise of magnesium in water.
across the sampling period. The reason of rise of magnesium in the study area may be due to leaching through the rocks in the study region.

From Fig. 21 it could be seen the suitability of irrigation water is decreasing from S-I to S-III. The area under the unsuitable category has increased from 15.58 km², 19.45 km² and 25.13 km² from S-I, S-II and S-III. Corresponding values of the suitability class are 30.21 km², 26.34 km² and 20.67 km², respectively.

### 3.9 Potential salinity

The potential salinity of the irrigation water considers the effect of salts on the soil surface. In the study area for S-I, S-II and S-III, the suitability of all kinds of soil is 0%, 10% and 2%. For the medium and coarse soil, 84.91%, 86.27% and 86.79% of the total samples fall under this type, whereas 18%, 4% and 12% samples are only suitable for coarser soil. A similar fluctuation of potential salinity was observed in Oyo state, Nigeria, by Ogunbode and Akinola (2019) where the concentration varied as the time progressed.

From Fig. 22, by the spatial analysis, it could find the area under suitability for all kinds of soil are 0.23 km² and 0.045 km² for S-II and S-III, respectively. For medium and coarse

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**Table 9** Summary of USSL diagram for suitability of water for irrigation

| Sl. no. | Samples | Very Good | Good | Medium | Bad | Very bad | Total |
|---------|---------|-----------|------|--------|-----|----------|-------|
| 1       | No. of samples | 1 | 28 | 20 | 3 | 1 | 53 |
|         | %       | 1.89 | 52.83 | 37.74 | 5.66 | 1.89 | 100 |
| 2       | No. of samples | 1 | 26 | 15 | 6 | 3 | 51 |
|         | %       | 1.96 | 50.98 | 29.41 | 11.76 | 5.88 | 100 |
| 3       | No. of samples | 1 | 15 | 26 | 9 | 2 | 53 |
|         | %       | 1.89 | 28.30 | 49.06 | 16.98 | 3.77 | 100 |

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**Fig. 24** The Wilcox plot of S-I, S-II & S-III indicating the hydrochemical type of irrigation water
soil type, 45.54 km², 45.29 km² and 45.03 km² and for areas under coarser soils, are 0.25 km², 0.27 km² and 0.71 km² for S-I, S-II and S-III, respectively.

3.9.1 USSL diagram

According to US Salinity Laboratory (USSL 1954), the classification of water was done based on the plot of sodium absorption ratio (SAR) against the EC (Jha et al. 2020). For the sampling periods, three plots were generated for S-I, S-II and S-III as shown in Fig. 23. Based on the plot, more than 80% of samples are more than the moderate levels of permissibility with high salinity and low sodium (C2-S1 and C3-S1). The summary is depicted in Table 9.

3.9.2 Wilcox plot

Another measure to assess the hazardous effect of in water quality of irrigation water is the Wilcox diagram. It represents the plot of sodium percentage concerning the electrical conductivity of the sample (Wilcox 1955). Based on the criteria, the water classes are divided into excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable demarcated in Fig. 24. From the sampling done in S-I, S-II and S-III are more than 95% sample fall under excellent to the permissible limits of irrigation. The summary is presented in Table 10.

**Table 10 Summary of Wilcox diagram for suitability of water for irrigation purpose**

| Water class  | S-I      | S-II     | S-III    |
|--------------|----------|----------|----------|
| Samples %    | Samples %| Samples %| Samples %|
| Excellent    | 28       | 19       | 18       | 33.96 |
| Good         | 23       | 11       | 17       | 32.08 |
| Permissible  | 20       | 18       | 16       | 30.19 |
| Doubtful     | 2        | 2        | 2        | 3.77  |
| Unsuitable   | 0        | 1        | 0        | 0.00  |

![Fig. 25](image) The Piper diagram of sampling –I, II &III indicating the hydrochemical type of water
3.9.3 Piper diagram

Piper diagram (Piper 1944) is a comprehensive diagram to investigate the hydrochemistry of a sample and its hydro-chemical characteristics (Khawla and Mohamed 2020). For understanding the same, the Piper diagram was plotted for all three-water sampling periods as shown in Fig. 25.

For sampling I, the hydro-chemical type suggests that alkali metal has the advantage over alkali earth metal (Na$^+$ + K$^+$ > Ca$^{2+}$ + Mg$^{2+}$) and weak acid anion has the advantage over strong acid anion (HCO$_3^-$ > Cl$^-$ + SO$_4^{2-}$). Cations contained in groundwater samples are mainly distributed in sodium type and no dominant type where there is an intermediate concentration of other cations. The observed chemical changes may be regulated by both natural geogenic sources (bedrock–groundwater interactions and rock weathering, etc.) and anthropogenic sources (domestic wastes, irrigation return flows, chemical fertilizers, etc.). The proportion of Potassium is relatively low among total cations, while the proportion of Ca in some water samples is relatively high but within the permissible limits. For anions, all water samples fall into bicarbonate type, indicating that the dominant role may be carbonate dissolution and silicate weathering. As shown in Fig., HCO$_3^-$ anion accounts for more than 30%, suggesting these ions have an advantage. Rest of them, lying in the centre in the no dominance where there are intermediate effects of SO$_4$ and Cl. From the diamond, it shows that 29% of samples come under NaCl type and 10% fall under MgHCO$_3$. Others have intermediate concentration and do not exhibit any dominant effect.

Fig. 26 Gibbs plot for S-I: a) anions and b) cations

Fig. 27 Gibbs plot for S-II: a) anions and b) cations
For sampling – II, the hydro-chemical type suggests that alkali metal has the advantage over alkali earth metal (Na\(^+\) + K\(^+\) > Ca\(^{2+}\) + Mg\(^{2+}\)) and the strong acid anion is advancing the weak acid anions (HCO\(_3^-\) > Cl\(^-\) + SO\(_4^{2-}\)). Cations contained in groundwater samples dominated by sodium type cations, followed by calcium and magnesium having an intermediate effect. For anions, most of the water samples fall into sulphate type followed by the combined effect of other anions. As shown in Fig. 25, SO\(_4^{2-}\) anion accounts for more than 33%, suggesting these ions have an advantage. Rest of them, lying in the centre in the no dominance where there are intermediate effects of CO\(_3^{2-}\), HCO\(_3^-\) and Cl\(^-\). From the diamond, we can see the clear dominant effect of NaCl in 80% of the samples.

For sampling – III, the hydro-chemical type suggests that alkali metal has the advantage over alkali earth metal (Na\(^+\) + K\(^+\) > Ca\(^{2+}\) + Mg\(^{2+}\)) and the anions. Cations contained in groundwater samples dominated by sodium type cations, followed by calcium and magnesium having an intermediate effect. For anions, most of the water samples are mostly exhibiting the presence of multiple anions and hence none of the anions exhibits a prominent dominant effect. From the diamond, it shows the clear dominant effect of NaCl in 58% of the samples and 4% fall under MgHCO\(_3\).

### 3.9.4 Gibbs ratio

The Gibbs ratio for the study area was plotted against the total dissolved solids, for all three sampling periods are shown in Figs. 26, 27 and 28. For understanding the influence
Fig. 29 Spatio-temporal variation of residual sodium carbonate (August 2019–March 2020) in the study area

Table 12 Summary of the irrigation indices

| Parameter | Range | Water class | S-I | % | SII | % | S-III | % |
|-----------|-------|-------------|-----|---|-----|---|-------|---|
| SAR       | 0–10  | Excellent   | 51  | 96.23 | 48 | 94.12 | 53 | 100.00 |
|           | 10–18 | Good        | 1   | 1.89  | 2 | 3.92  | 0  | 0.00   |
|           | 18–26 | Doubtful    | 1   | 1.89  | 1 | 1.96  | 0  | 0.00   |
|           | > 26  | Unfit       | 0   | 0.00  | 0 | 0.00  | 0  | 0.00   |
| PI (%)    | > 75  | Class-I (unfit) | 36 | 67.92 | 21 | 41.18 | 14 | 26.42 |
|           | 25–75 | Class-II    | 17  | 32.08 | 30 | 58.82 | 39 | 73.58 |
|           | < 25  | Class-III   | 0   | 0.00  | 0 | 0.00  | 0  | 0.00   |
| MH        | < 50  | Suitable    | 29  | 54.72 | 28 | 54.90 | 20 | 37.74 |
|           | > 50  | Unsuitable  | 24  | 45.28 | 30 | 45.10 | 39 | 62.26 |
| KR        | < 1   | Suitable    | 32  | 60.38 | 14 | 27.45 | 32 | 60.38 |
|           | > 1   | Unsuitable  | 24  | 39.62 | 36 | 72.55 | 21 | 39.62 |
| SP (%)    | < 20  | Excellent   | 0   | 0.00  | 0 | 0.00  | 0  | 0.00   |
|           | 20–40 | Good        | 10  | 18.87 | 3 | 5.88  | 12 | 22.64 |
|           | 40–60 | Permissible | 27  | 50.94 | 27 | 52.94 | 27 | 50.94 |
|           | 60–80 | Doubtful    | 13  | 24.53 | 18 | 35.29 | 14 | 24.62 |
|           | > 80  | Unsuitable  | 3   | 5.66  | 3 | 7.84  | 1  | 0.00   |
| PS (meq/L)| 1–3   | All soils   | 0   | 0.00  | 5 | 9.80  | 1  | 1.89   |
|           | 3–15  | Medium & course soil | 45 | 84.91 | 44 | 86.27 | 46 | 86.79 |
|           | 15–20 | Coarse soil only | 8  | 15.09 | 2 | 3.92  | 6  | 11.32 |
| RSC (meq/L)| < 1.25 | Excellent    | 13  | 24.53 | 48 | 94.12 | 49 | 94.45 |
|           | 1.25–2.5 | Good    | 3   | 5.66  | 1 | 1.96  | 3  | 3.66   |
|           | > 2.5 | Doubtful    | 37  | 69.81 | 2 | 3.92  | 1  | 1.89   |
of dominance of precipitation, rock or evaporation in the groundwater (Mugo and Odera 2019) needs to be analysed for the cations and anions.

For cations, S-I is dominated by precipitation (74%), S-II is dominated by precipitation (94%), and S-III is dominated by rock (70%). The precipitation dominance form indicates the supply of freshwater to the aquifers. For anions, S-I is dominated by rock, S-II is also dominated by rock (96%) and finally, the S-III is dominated by rock (87%). The rock dominance in the study area indicates the influence of rocks on the groundwater in the aquifers. The summary is presented in Table 11. Similar results were obtained when (Singh et al. 2018) plotted the Gibbs plot diagram for the Adyar River Basin.

3.9.5 Residual sodium carbonate

Residual sodium carbonate of the irrigation water considers the effect of salts on the soil surface. In the study area S-II and S-III, the water quality is excellent for almost the entire sampling, for 94% of the area. For the S-I, 24.53% is excellent, 5.66% is good and 69.81% under the doubtful category, which was further improved in S-II and S-III.

From Fig. 29, by the spatial analysis, it could be found that almost the entire area was suitable for S-II and S-III, respectively. For S-I, 0.85km² area was excellent, 4.43 km² areas was under permissible, and 40.5 km² area was under doubtful conditions. The summary of irrigation indices with comparing of all the parameters is presented in Table 12. From this table it summarizes the different classes and their corresponding ranges of values of the different irrigation water quality parameter evaluated during the three sampling. The percentage of the individual class corresponding to the total number of samples is given. The overall classification using different indices considers different inputs due to which all the parameters cannot be evaluated based on considering one as a standard index. The parameters justify the purpose of defining water quality based on individual concentration of the respective parameters.

4 Summary and conclusions

Groundwater is one of the most crucial water resources, meeting the water requirement for domestic, industrial and irrigation purposes. Increasing population, erratic distribution of rainfall and their rising demand for water in domestic and irrigation are fulfilled by groundwater resources. Due to overexploitation, there is the deterioration of groundwater quality and hence to evaluate the groundwater quality. From the study, the results revealed that the presence of carbonates was totally absent in the study area. Change in water quality parameters with the progression of time was observed. It was found that 25% of samples in S-I, 80% samples in S-II and 83% samples in S-III were above the permissible limits for drinking purpose. The varying percentage of the samples justify the improvement of the water quality which must have happen due to the groundwater recharge by Kaveri canal. The high mineral deposition of magnesium is found in the regions of Kumulur, Tachankurunchi, Pudurutamanur, Pandaravadai and Poovalur, high sodium content is influenced by the chemicals used in the intensive agriculture areas, high sulphate in water samples was caused by intensive pumping of groundwater in the highly populated area which could be the major reasons where the samples are beyond the permissible limits.
Suitability of water for irrigation was determined using different irrigation indices and different trends were observed in each index as it progressed from S-I to S-III, depicting different characteristics of water and its usability for irrigation. The results revealed that SAR values are well within the permissible limits, but the magnesium is high in the study area. The dominance of evaporative and rock aspect was found out in the obtained groundwater samples. Overall, for the maximum of 90% of the area, the water is suitable for irrigation purposes and found that a few locations (10%), namely Tachankurunchi, Pandaravadi villages, wherein the salt content of water is relatively higher than the entire study area.

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Declarations

Competing Interests It is our own original research work, which has not been previously published elsewhere and not currently being considered for publication elsewhere. The paper reflects our own research and analysis in a truthful and complete manner. The paper properly credits the meaningful contributions of co-authors and co-researchers. All sources used are properly disclosed (correct citation). All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

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