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GEOSPATIAL APPROACH FOR ASSESSMENT OF GROUNDWATER QUALITY

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Abstract:

Increasing population, erratic distribution of rainfall, and their rising demand for water in domestic and irrigation is 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 areal extent of 45.1 km². For the water quality assessment, samples were drawn from 53 locations from the sources like open well, bore well and hand pumps, etc., Parameters of pH, EC, TDS, Anions - CO₃²⁻, HCO₃³⁻, Cl⁻, SO₄²⁻, Cations - Ca²⁺, Mg²⁺, B³⁺, 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 it was found that 25% 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 90% of the area, the water is suitable for irrigation purposes and a few locations (10%) wherein the salt content of water are relatively higher than the entire study area.

Keywords: Water Quality Index, Geo-spatial analysis, Groundwater quality, Piper Diagram, Gibb plot, Wilcox Plot.

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 great 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 easy to be contaminated (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

1 groundwater in a particular area or region (Sakram et al. 2018). The declining quality and quantity of water supply
2 in the area, because of overexploitation and mismanagement of the groundwater resources, need to be intervened at
3 priority (Muthukumar et al. 2011). However, groundwater also has some disadvantages for exploitation, such as
4 being more difficult to be accessed than surface water (Selvaganapathi et al. 2017). Since groundwater is buried
5 underground and requiring a full understanding of the distribution rules before use, it makes it difficult to estimate
6 the capacity of the aquifer and its exploration of good quality aquifers (Jang et al. 2016). Hence it is a need for
7 groundwater quality assessment to ensure its suitability in different sectors carefully.

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

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

25 Human life is also under threat when the contaminated water is to be used for consumption. The presence
26 of contaminants in water along with elements beyond their permissible limits can adversely affect human health
27 (Brhane, 2018). Due to intense agricultural practices, leading to the intensive usage of chemical fertilizers and
28 increased groundwater pumping has not just affected the water quality resulting in quality degradation (Reddy
29 2013). Therefore, water quality monitoring should be emphasized in an area at the highest preference as it indirectly
30 affects human health in the form of different problems (WHO, 2006).

31 Water quality evaluation is of prime importance for the protection and sustainable management of
32 groundwater resources, to meet the demands, and to climate change. An effective method for determining water
33 quality is by using different indices (Adimalla et al. 2020). Water Quality Index (WQI) is a widely used tool in the
34 evaluation of water quality (Selvaganapathi et al. 2017; Iqbal et al. 2020; Brhane 2018). It summarizes different
35 water quality parameters in a single number, which is simple to understand, easy to interpret, and acts as a key in
36 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 the 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 the water quality the following approaches four different methods present across the globe are National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministries of the Environment Water Quality Index (CCMEWQI), 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 which elaborates the fitness of groundwater for agriculture use (Jafari et al. 2018; Khanoranga and Khalid, 2019; Revathy et al. 2017)

GIS can be defined as a technique for capture, store, retrieve, interpret, analyses and predict (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 concentration values of different chemical constituents (Jha et al. 2020). Geographical information system (GIS) is used for a variety of applications from micro-level planning to macro-level planning, evaluation, implementation, and regular monitoring (Patel 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, defense, 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 provide detailed, quick and reliable information, which can be used further for interpolation of WQI data spatially by interpolation and also formulate decision support system to adopt strategy related to water quality (Singh et al. 2020).

2.0 MATERIALS AND METHODS

The groundwater samples were analyzed 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 Lalgudi and Pulambadi block of Trichy district with an aerial extent of 45.1 sq. km. The average annual rainfall of this region is 881.412 mm. Rainfall is concentrated in June to September (Southwest monsoon) and October to December (Northeast monsoon), which has a major contribution to annual rainfall (Vaidheki and Arulanandu 2017). The Pullambadi canal (distributaries of the Cauvery River) also acts as a source of irrigation. Besides, during post-monsoon 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 $78^{\circ} 85'$ and the northern latitude of $11^{\circ} 00'$ and $10^{\circ} 89'$. The water sampling was done in September 2019, December 2019, and March 2020 in 100 days intervals. Water was collected from the sources of groundwater like open dug wells, hand pumps, and bore wells. The details of the sample locations are given 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 Puvalur. 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 such as 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, lies 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, 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 to 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 was noted along with a landmark near the source for identification. The coordinates were obtained from the handheld GPS device (accuracy of 5m). 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 minutes 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 litre.

1 III. The water should be collected as such, without bothering about the turbidity, as it does not affect the test
2 results.

3 IV. From the well, the sample was drawn either during irrigation, just before the water falling into the irrigation
4 channel or by drawing it with the help of a bucket or any clean container using a rope. The water surface
5 should not be disturbed for the removal of floating impurities. Place the cap on the bottle tightly.

6 V. On a piece of paper of suitable size, the name, address, sample number, identification mark, etc. were written
7 with the marker and pasted firmly on the bottle.

8 VI. These samples were further used for the analysis of water quality.

9 The groundwater sample parameters viz. pH, EC, TDS, TH, CO_3^{2-} , HCO_3^{3-} , Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , B^{3+} , Na^+ , and
10 K^+ were estimated using the standard analytical procedure as per Raghunath 1987. The detailed estimation of each
11 parameter was given below.

- 12 • Electrical Conductivity is the reciprocal of electrical resistivity expressed in mho/cm.
- 13 • pH is a measure of alkalinity or acidity of water. It can be also defined as the hydrogen ion concentration
14 in water.
- 15 • Total dissolved solids (TDS) were estimated by using the following formula: EC to be multiplied by 0.64
16 (Brown *et al.* 1970). It can be also represented with the following formula:
17 $\text{TDS (mg/l)} = \text{EC (dsm}^{-1}) \times 640$ ----- (2.1)
- 18 • Cations dominant in the water like Ca^{2+} , Mg^{2+} , B^{3+} , Na^+ , and K^+ were estimated and used to understand
19 the dominance of the cations in the groundwater.
- 20 • Anions like CO_3^{2-} , HCO_3^{3-} , Cl^- , SO_4^{2-} were analyzed to understand the dominance of anions in the
21 groundwater sample.
- 22 • The different parameters analyzed, and the methodologies used for the computation of these parameters
23 were presented in Table 1.

24 2.5.1 Water Quality Index (WQI) for drinking purpose.

25 For evaluating the water quality for drinking purposes, Water Quality Index (WQI) was calculated. Further,
26 the quality rating or sub-index (Q_n) was calculated using the following equations.

27
$$Q_n = 100 * \left[\frac{(V_n - v_i)}{(V_s - v_i)} \right] \text{-----} (2.2)$$

28 Where

29 Q_n = Quality rating for the n^{th} water quality parameter.

30 V_n = Actual value of the n^{th} parameter.

31 v_i = Ideal value of this parameter.

32 V_s = Standard permissible value of the n^{th} parameter.

33 [Note: Consider $v_i = 0$ for all except pH where $v_i = 7$ for pH].

34 The water quality index also called the weighted arithmetic index method was used for the calculation of
35 WQI. The unit weight value is the reciprocal of the recommended standard value (V_n), to the corresponding
36 parameter.

$$W_n = \frac{K}{V_s} \text{ -----(2.3)}$$

$$\text{where: } K = \frac{1}{\sum_{n=1}^n \left(\frac{1}{V_s}\right)}$$

W_n = Unit weight for the n^{th} parameters.

K = constant for proportionality.

V_s = standard value for the n^{th} parameters.

The method of classifying the water quality is based on the overall water quality index (WQI), which are calculated by aggregating the quality rating Q_n linearly as expressed as follows:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \text{ -----(2.4)}$$

Based on the obtained values of WQI, the classification of the groundwater sample will be done as excellent, good, and 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 was 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 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 normalizes 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

$$\text{Na (\%)} = \frac{(\text{Na}^+ + \text{K}^+) / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)}{100} \text{-----(2.5)}$$

2.6.2 Sodium Absorption Ratio (SAR)

A ratio 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:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \text{-----(2.6)}$$

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

$$\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-})}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100 \text{-----(2.7)}$$

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:

$$\text{KR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \text{-----(2.8)}$$

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.

$$\text{MH} = \frac{\text{Mg}^{2+}}{(\text{Ca}^{2+} + \text{Mg}^{2+})} \times 100 \text{-----(2.9)}$$

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

$$\text{PS} = \text{Cl}^- + \frac{1}{2} \text{SO}_4^{2-} \text{-----(2.10)}$$

2.10 United State Salinity Laboratory (USSL) diagram

United State Salinity Laboratory (USSL 1954) diagram is a graphical geochemical representation of groundwater quality suggests 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 and SAR for the first, second, and third sampling in the study area and the classification of water quality was done by plotting it into USSL diagram.

2.11 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.

2.12 Gibbs's plot

Gibbs diagrams were used to understand the relative importance of three major natural mechanisms, which 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.

$$\text{Cations} = \frac{\text{Na}^+ + \text{K}^+}{\text{Na}^+ + \text{K}^+ + \text{Ca}^{2+}} \text{-----} (2.11)$$

$$\text{Anions} = \frac{\text{Cl}^-}{\text{Cl}^- + \text{HCO}_3^-} \text{-----} (2.12)$$

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.

2.13 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.

2.14 Residual Sodium Carbonate (RSC)

This was calculated employing the equation (Eaton, 1950) as:

$$RCS = [CO_3^{2-} + HCO_3^-] - (Ca^{2+} + Mg^{2+}) \text{-----} (2.13)$$

2.15 Interpolation of water quality maps

Based on the water quality indices and parameters, the thematic maps of the study area 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.

3.0 RESULTS AND DISCUSSION

To check the groundwater quality for irrigation and drinking, the collected groundwater sampling were analyzed and the constituent parameters were studied.

3.1 Water sampling and analyzing

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 below 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 $\mu\text{S}/\text{cm}$ with an average of 833.40 $\mu\text{S}/\text{cm}$ 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 amongst 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 amongst the cations and anions, which denote very high variability in the observed data.

The calcium and magnesium varied from 4.80 - 206.40 mg/L and 7.68-91.20 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 to 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 due to boron is found in traces unless contaminated by agricultural sources (Sakram et al. 2018; Brhane 2018).

Anions like chlorine and sulphate ranged from 42.60 – 738.40 mg/L and 242.55 – 393.85 mg/L and the corresponding range of means were 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 were high in chlorine. CV was low in sulphate and bicarbonate. Bicarbonate ranged from 170.89 to 927.20mg/L, with a mean of 576.39mg/L and the details were summarized in Table 4.

3.2.2 Season – II (December 2019)

The second sampling was collected during 2019 and the results were 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 EC ranged from 180 to 3800 $\mu\text{S}/\text{cm}$ with an average of 861.18 $\mu\text{S}/\text{cm}$, 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 amongst 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 amongst the cations and anions, which denote very high variability in the observed data. Similar behaviour could be seen in sampling season-I also. When analyzing the Calcium and magnesium the minimum and maximum were ranges from 8 – 158 mg/L and 7.20 - 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 in the range of 0.20 - 1.75mg/L with a mean of 0.54 mg/L. The dispersion from the mean was low and the variability was high within the dataset due to a substantial amount of rice was seen in the study area for the concentration of boron (Sakram et al. 2018; Brhane 2018).

Anions like chlorine and sulphate ranged from 28.40 - 937.20 mg/L and 43.23 - 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 - 366mg/L with a mean of 208.12mg/L and it was found that the carbonate was absent in the sampling area (Adimalla et al. 2020).

3.2.3 Season – III (December 2019)

The third and final sampling was done during March 2020 and depicts 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 μ S/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 amongst 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 that 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 amongst 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 – 280 mg/L and 19.2 – 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 - 1.50 mg/L and the dispersion from the mean was low and the variability was high within the dataset due to 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 – 1082.75 mg/L and 69.64–1082.83 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 were 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 of the parameters across the seasons, the plot depicts the changes in the concentration of the parameters across the three observations, like

(Rawat, 2018) found in Kanjeeपुरam. The parameters like pH, Ca, Cl and HCO_3 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 SO_4 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; Sureshkumar 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 weak correlation was found with Ca. K has positive correlations with HCO_3 , EC and TDS whereas a mild positive correlation with Na, B, Mg, SO_4 , Ca and Cl. K is moderately correlated with EC, TDS, HCO_3 , B, Ca and Mg, Na, SO_4 , Cl. Na is positively correlated with HCO_3 , SO_4 , Cl, EC, TDS, B, Mg and Ca. HCO_3 is strongly correlated with SO_4 , EC and pH, and positively correlated Ca and Cl, B and Mg towards the positive. B is positively correlated with SO_4 , Cl, EC and pH, Ca and Mg towards positive. Mg is positively correlated with SO_4 , Ca, Cl, EC and TDS. Mg is positively correlated with SO_4 , Ca, Cl, EC and TDS. SO_4 is strongly correlated with 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, the positive correlation of pH with K and HCO_3 , whereas negatively correlated with B, Mg, Cl, Na, SO_4 , EC and TDS. K is negatively correlated with B whereas positively correlated with HCO_3 , Mg, Cl, Na, SO_4 , EC and TDS. HCO_3 was found to be negatively correlating with B whereas it was positively correlating with Mg, Cl, Na, SO_4 , EC and TDS. B is positively correlated with Mg and SO_4 whereas it was negatively correlated with Cl, Na, EC and TDS. Ca was strongly correlated with SO_4 , 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 SO_4 . Na and SO_4 were strongly correlated amongst 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).

In sampling-III magnesium has a strong correlation with Cl, followed by Cl, EC, TDS Na, SO_4 , HCO_3 , pH and B whereas negative correlation with K. Ca was found to have a strong correlation with Cl, EC and TDS followed by SO_4 , Na, HCO_3 , K and pH and negatively correlated with B. Cl has a strong correlation with Na, TDS, EC, SO_4 and weakly correlated with pH, HCO_3 and K and negatively correlated with B. HCO_3 is correlated positively with SO_4 , Na, EC, TDS, K and B whereas there was a negative correlation with pH. Na exhibited a strong correlation with SO_4 , EC and TDS and positively correlated with pH, K and B. SO_4 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; Sakramet 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 Fig. 4 to 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 Thachankuruchi 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.

Fig. 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 was 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 has 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 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.

Alike all the parameters were analyzed 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 were given in Table 7 (Selvaganapathi et al. 2017). The graphical representation of the water quality index for all three seasons was depicted in Fig. 15.

In sampling S-I & S-III, there are 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). In sampling S-II 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).

A Spatial analysis tool using the IDW method, 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 were 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 in all three samplings is tabulated under Table 8. All the 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.

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 etc., (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 exist no sample under the unsuitable category. In the doubtful category lies 0.72 km², 0.09 km² 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 the table, across the sampling duration for approximately 95 % of the samples from S-I and S-II lies 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 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 ($\ll 1$ 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.

3.7 Kelly's Ratio

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 rise in the period of S-III (60.38%, 27.45% and 60.38%).

From Fig. 20, we can see 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.

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.

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 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.

3.10 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 has been depicted in Table 9.

3.11 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 were 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 has been presented in Table 10.

3.12 Piper Diagram

Piper diagram (Piper, 1944) is a comprehensive diagram to investigate the hydrochemistry of a sample and its hydrochemical 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 hydrochemical type suggest that alkali metal has the advantage over alkali earth metal ($\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} + \text{Mg}^{2+}$) and weak acid anion has the advantage over strong acid anion ($\text{HCO}_3^- > \text{Cl}^- + \text{SO}_4^{2-}$). 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, we can see 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.

For sampling – II, the hydrochemical type suggest that alkali metal has the advantage over alkali earth metal ($\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} + \text{Mg}^{2+}$) and the strong acid anion are advancing the weak acid anions ($\text{HCO}_3^- > \text{Cl}^- + \text{SO}_4^{2-}$). 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 hydrochemical type suggest that alkali metal has the advantage over alkali earth metal ($\text{Na}^+ + \text{K}^+ > \text{Ca}^{2+} + \text{Mg}^{2+}$) 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, we can see the clear dominant effect of NaCl in 58% of the samples and 4% fall under MgHCO_3 .

3.13 Gibbs Ratio

The Gibbs ratio for the study area was plotted against the total dissolved solids for all three sampling periods are shown in Fig. 26, 27 & 28. For understanding the influence of dominance of precipitation, rock or evaporation in the groundwater (Mugo and Odera 2019) need to be analyzed 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 fresh water 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.

3.14 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 area was under permissible and 40.5 km² area was under doubtful conditions. The summary of irrigation indices with comparing of all the parameters was presented in Table 12.

4.0 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 is 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 spatial interpolation of these points across the study area was done and displayed all the water quality parameters in the study area.

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%) wherein the salt content of water are relatively higher than the entire study area.

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DECLARATIONS

Hereby, I assure that, this manuscript is fulfilled for the following:

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

1 REFERENCES

- 2 Abbasnia A, Radfard M, Mahvi AH, Nabizadeh R, Yousefi M, Soleimani H, Alimohammadi M (2018)
3 Groundwater quality assessment for irrigation purposes based on irrigation water quality index and its
4 zoning with GIS in the villages of Chabahar, Sistan and Baluchistan, Iran. Data in Brief. 19: 623–631.
5 <https://doi.org/10.1016/j.dib.2018.05.061>
6
- 7 Abijith D, Saravanan S, Singh L, Jennifer JJ, Saranya T, Parthasarathy KSS (2020) GIS-based multi-criteria analysis
8 for identification of potential groundwater recharge zones - a case study from Ponnaniyar watershed,
9 Devanatham, Tamil Nadu, India. J Hydro-Research. <https://doi.org/10.1016/j.hydres.2020.02.002>
10
- 11 Adimalla N, Dhakate R, Kasarla A, Taloor AK (2020) Appraisal of groundwater quality for drinking and irrigation
12 purposes in Central Telangana, India. J Groundwater for Sustainable Development 10: 100334.
13 <https://doi.org/10.1016/j.gsd.2020.100334>.
14
- 15 Adimalla N, Qian H (2019) Groundwater quality evaluation using water quality index (WQI) for drinking purposes
16 and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. J Eco-
17 toxicology and Environmental Safety 176(126): 153–161. <https://doi.org/10.1016/j.ecoenv.2019.03.066>.
18
- 19 Asadi E, Isazadeh M, Samadianfard S, Ramli MF, Mosavi A, Nabipour N, Shamshirband S, Hajnal E, Chau KW
20 (2020) Groundwater quality assessment for sustainable drinking and irrigation. J Sustainability
21 (Switzerland) 12(1): 1–10. <https://doi.org/10.3390/su12010177>.
22
- 23 (BIS), Bureau of Indian Standards (2012) Indian Standard Drinking Water — specifications (Second Revision) IS
24 10500 (2012): Drinking water. In Bureau of Indian standards (Vol. 25, Issue May).
25
- 26 Brhane GK (2018) Characterization of hydrochemistry and groundwater quality evaluation for drinking purpose in
27 Adigrat area, Tigray, northern Ethiopia. J Water Science 32(2): 213–229.
28 <https://doi.org/10.1016/j.wsj.2018.09.003>.
29
- 30 Dendukuri S, Asadi S, Raju MVS (2017) Estimation of water quality index by weighted arithmetic water quality
31 index method: A model study. Inter J Civil Engineering and Technology 8: 1215–1222.
32
- 33 Doneen LD (1964) Notes on Water Quality in Agriculture.
34
- 35 Gates JB, Scanlon BR, Mu X, Zhang L (2011) Impacts of soil conservation on groundwater recharge in the semi-
36 arid Loess Plateau, China. Hydrogeology Journal 19(4): 865–875. <https://doi.org/10.1007/s10040-011-0716-3>.
37
38
- 39 Gupta SK, Deshpande RD (2004) Water for India in 2050: First-order assessment of available options. J Current
40 Science 86(9): 1216–1224.
41
- 42 Iqbal AB, Rahman MM, Mondal DR, Khandaker NR, Khan HM, Ahsan GU, Jakariya, Hossain MM (2020)
43 Assessment of Bangladesh groundwater for drinking and irrigation using weighted overlay analysis. J
44 Groundwater for Sustainable Development 10: 100312. <https://doi.org/10.1016/j.gsd.2019.100312>.
45
- 46 Jafari K, Asghari FB, Hoseinzadeh E, Heidari Z, Radfard M, Saleh HN, Faraji H (2018) Groundwater quality
47 assessment for drinking and agriculture purposes in Abhar city, Iran. Data in Brief 19: 1033–1039.
48 <https://doi.org/10.1016/j.dib.2018.05.096>
49
- 50 Jang CS, Chen CF, Liang CP, Chen JS (2016) Combining groundwater quality analysis and a numerical flow
51 simulation for spatially establishing utilization strategies for groundwater and surface water in the Pingtung
52 Plain. J Hydrology 533(December): 541–556. <https://doi.org/10.1016/j.jhydrol.2015.12.023>.
53

- 1 Jha Madan Kumar, Shekhar, A, Jenifer MA (2020) Assessing groundwater quality for drinking water supply using
2 hybrid fuzzy-GIS-based water quality index. J Water Research 179: 115867 – 115882.
3 <https://doi.org/10.1016/j.watres.2020.115867>.
4
- 5 Kawo NS, Karuppannan S (2018) Groundwater quality assessment using water quality index and GIS technique in
6 Modjo River Basin, central Ethiopia. J African Earth Sciences 147(June): 300–311.
7 <https://doi.org/10.1016/j.jafrearsci.2018.06.034>.
8
- 9 Kelly WP (1963) Use of Saline Irrigation Water. J Soil Science 95(4): 355–359.
10
- 11 Khanoranga Khalid S(2019) An assessment of groundwater quality for irrigation and drinking purposes around brick
12 kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate
13 statistical approaches. J Geochemical Exploration 197: 14–26.
14 <https://doi.org/10.1016/j.gexplo.2018.11.007>.
15
- 16 Khare D, Singh R, Mishra N, Shukla R (2015) Assessment of Surface Runoff in a Barinallah Watershed using
17 Distributed Parameter Model (SWAT Model). J Water Resources and Environment Engineering 1: 31–38.
18
- 19 Khatri N, Tyagi S, Rawtani D, Tharmavaram M, Kamboj RD (2020) Analysis and assessment of ground water
20 quality in Satlasana Taluka, Mehsana district, Gujarat, India through application of water quality indices. J
21 Groundwater for Sustainable Development 10(13): 100321. <https://doi.org/10.1016/j.gsd.2019.100321>.
22
- 23 Khawla K, Mohamed H (2020) J Hydro-geochemical assessment of groundwater quality in greenhouse intensive
24 agricultural areas in coastal zone of Tunisia: Case of Teboulba region. J Groundwater for Sustainable
25 Development 10: 100335. <https://doi.org/10.1016/j.gsd.2020.100335>.
26
- 27 Mueller TG, Pusuluri NB, Mathias KK, Cornelius PL, Barnhisel RI, Shearer SA (2004) Map Quality for Ordinary
28 Kriging and Inverse Distance Weighted Interpolation. J Soil Science Society of America 68(6):
29 2042–2047. <https://doi.org/10.2136/sssaj2004.2042>.
30
- 31 Mugo GM, Odera PA (2019) Site selection for rainwater harvesting structures in Kiambu County-Kenya. Egyptian J
32 Remote Sensing and Space Science 22(2): 155–164. <https://doi.org/10.1016/j.ejrs.2018.05.003>.
33
- 34 Muthukumar S, Lakshumanan C, Santhiya G, Krishnakuma P, Viveganandann S (2011) Assessment of water quality
35 in Trichy City, Tamil Nadu, India. Inter J Environmental Sciences 1(7): 1841–1855.
36
- 37 Patel DP, Gajjar CA, Srivastava PK (2013). Prioritization of Malesari mini-watersheds through morphometric
38 analysis: A remote sensing and GIS perspective. J Environmental Earth Sciences 69(8): 2643–2656.
39 <https://doi.org/10.1007/s12665-012-2086-0>.
40
- 41 Piper AM (1944) A graphic procedure in the geochemical interpretation of water-analyses. Eos, Transactions
42 American Geophysical Union 25(6): 914–928. [https://doi.org/https://doi.org/10.1029/](https://doi.org/https://doi.org/10.1029/TR025i006p00914)
43 [TR025i006p00914](https://doi.org/https://doi.org/10.1029/TR025i006p00914).
44
- 45 Raghunath HM (1987) Groundwater (2nd ed.). Published by Wiley Eastern Ltd.
46
- 47 Rawat KS, Singh SK (2018) Water Quality Indices and GIS-based evaluation of a decadal groundwater quality. J
48 Geology, Ecology and Landscapes 2(4): 240–255. <https://doi.org/10.1080/24749508.2018.1452462>.
49
- 50 Reddy KS (2013) Assessment of groundwater quality for irrigation of Bhaskar Rao Kunta watershed, Nalgonda
51 District, India. Inter J Water Resources and Environmental Engineering 5(7): 418–425.
52 <https://doi.org/10.5897/IJWREE2012.0375>.
53
- 54 Revathy V, Shanmugasundram M, Nagarajan M (2017) Assessment of Groundwater Quality for Irrigation Purpose
55 in Manapparai Block, Tiruchirapalli District, Tamilnadu. Inter J Agricultural Science and Research
56 7(5): 511–520. <https://doi.org/10.24247/ijasroct201759>.

- 1
- 2 Sakram G, Kuntamall S, Machender G, Dhakate R, Narsimha A (2018) Multivariate statistical approach for the
- 3 assessment of fluoride and nitrate concentration in groundwater from Zaheerabad area, Telangana State,
- 4 India. *J Sustainable Water Resources Management* 14. <https://doi.org/10.1007/s40899-018-0258-0>.
- 5
- 6 Salifu M, Aidoo F, Hayford MS, Adomako D, Asare E (2017) Evaluating the suitability of groundwater for
- 7 irrigational purposes in some selected districts of the Upper West region of Ghana. *J Applied Water*
- 8 *Science* 7(2): 653–662. <https://doi.org/10.1007/s13201-015-0277-z>.
- 9
- 10 Samadder RK, Kumar S, Gupta RP (2011) Paleo channels and their potential for artificial groundwater recharge in
- 11 the western Ganga plains. *J Hydrology* 400(1–2): 154–164. <https://doi.org/10.1016/j.jhydrol.2011.01.039>.
- 12
- 13 Selvaganapathi R, Vasudevan S, Balamurugan P, Nishikanth CV (2017) Evaluation of groundwater quality and
- 14 water quality index in the Palacode and Pennagaram Taluks, Dharmapuri district, Tamil Nadu, India 3(6):
- 15 *Inter J Applied Research* 3(6): 285 – 290.
- 16 Shukla S, Saxena A (2020) Groundwater quality and associated human health risk assessment in parts of Raebareli
- 17 district, Uttar Pradesh, India. *J Groundwater for Sustainable Development* 10: 100366.
- 18 <https://doi.org/10.1016/j.gsd.2020.100366>.
- 19
- 20 Singh LK, Jha MK, Chowdary VM (2020) Application of catastrophe theory to spatial analysis of groundwater
- 21 potential in a sub-humid tropical region: a hybrid approach. *J Geo carto International* 0(0): 1–20.
- 22 <https://doi.org/10.1080/10106049.2020.1737970>.
- 23
- 24 Singh L, Khare D, Mishr N (2018) Remote Sensing and GIS for Groundwater Potential Zones Ghagger Watershed,
- 25 Himachal Pradesh 6(1): 80–93.
- 26
- 27 Soleimani H, Abbasnia A, Yousefi M, Mohammadi AA, Khorasgani FC (2018) Data on assessment of groundwater
- 28 quality for drinking and irrigation in rural area Sarpol-e Zahab city, Kermanshah province, Iran. *Data in*
- 29 *Brief* 17: 148–156. <https://doi.org/10.1016/j.dib.2017.12.061>.
- 30
- 31 Suresh S (2008) District Groundwater brochure Tiruchirappalli District Tamil Nadu. Central Ground Water Board
- 32 South Eastern Coastal Region Chennai.
- 33
- 34 Sureshkumar M, Sivakumar R, Nagarajan M (2016) Impact of Municipal Solid Waste Dump Yard on Ground Water
- 35 – A Case Study of Kanchipuram Municipality, Tamil nadu, India. *Inter J Chem Tech Research*, 9(09): 571–
- 36 578.
- 37
- 38 Szabolcs I Darb C (1964) The influence of irrigation water of high sodium carbonate on soils. *Proc. 8th Int. Cong.*
- 39 *ISSS, Trans. II*, 803–812.
- 40
- 41 Tirkey P, Bhattacharya T, Chakraborty S, Baraik S (2017) Assessment of groundwater quality and associated health
- 42 risks: A case study of Ranchi city, Jharkhand, India. *J Groundwater for Sustainable Development*
- 43 5: 85–100. <https://doi.org/10.1016/j.gsd.2017.05.002>.
- 44
- 45 Todd David Keith, Mays LW (2004) *J Groundwater Hydrology*. John Wiley & Sons, New York, USA.
- 46
- 47 USSL (1954) Diagnosis and Improvement of Saline and Alkaline Soils. *J Soil Science Society of America*, 18(3):
- 48 348. <https://doi.org/10.2136/sssaj1954.03615995001800030032x>.
- 49
- 50 Vaidheki M Arulanandu U 2017 Estimating Extreme Temperature at Agricultural Engineering College and Research
- 51 Institute, Kumulur Station by Using Generalized Extreme Value Distribution. *Inter J Curr Microbiol App*
- 52 *Sci* 6(11): 3874-3886.
- 53
- 54 WHO (2006) WHO guidelines for drinking-water quality. In World Health Organization 1(1).
- 55
- 56 WHO (2011) Water quality for drinking WHO guidelines. https://doi.org/10.1007/978-1-4020-4410-6_184.

1
2 Wilcox LV (1955) Classification and use of irrigation waters. U.S. Dept. of Agriculture.
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Figures

Figure 1

Location map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Summary of the water quality parameters

Figure 3

Correlation matrix of water quality parameters in S-I, S-II & S-III

Figure 4

Spatio-temporal variation of Boron (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 5

Spatio-temporal variation of Calcium (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 6

Spatio-temporal variation of Magnesium (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Spatio-temporal variation of Sodium (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country,

territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 8

Spatio-temporal variation of Potassium (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 9

Spatio-temporal variation of Chlorine (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 10

Spatio-temporal variation of Sulphate (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 11

Spatio-temporal variation of bi-carbonate (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 12

Spatio-temporal variation of electrical conductivity (August 2019-March 2020) in the study Note: The designations employed and the presentation of the material on this map do not imply the expression of

any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 13

Spatio-temporal variation of total dissolved solids (August 2019-March 2020) in the study Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 14

Spatio-temporal variation of pH (August 2019-March 2020) in the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 15

Water Quality Index (WQI) for water samples of S-I, S-II & S-III.

Figure 16

Spatio-temporal variation of Water Quality Index (WQI) for water samples (August 2019-March 2020) in the study area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 17

Spatio-temporal variation of Sodium Percentage (August 2019-March 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 18

Spatio-temporal variation of SAR (August 2019-March 2020). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 19

Spatio-temporal variation of Permeability Index (August 2019-March 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or

area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 20

Spatio-temporal variation of Kelly's Ratio (August 2019-March 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 21

Spatio-temporal variation of Magnesium Hazard Ratio (August 2019 March 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of

any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 22

Spatio-temporal variation of Potential Salinity (August 2019-March 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 23

USSS diagram of S-I, S-II & S-III indicating the hydrochemical type of irrigation water

Figure 24

The Wilcox plot of S-I, S-II & S-III indicating the hydrochemical type of irrigation water

Figure 25

The Piper diagram of sampling –I, II & III indicating the hydrochemical type of water.

Figure 26

Gibbs Plot for S-I ; (a) anions and (b) cations

Figure 27

Gibbs Plot for S-II ; (a) anions and (b) cations

Figure 28

Gibbs Plot for S-III ; (a) anions and (b) cations

Figure 29

Spatio-temporal variation of residual sodium carbonate (August 2019-March 2020) in the study area
 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.