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# Seasonal Variation of Groundwater Quality status of Thiruvarur Taluk, Tamil Nadu, India

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***Abstract*: This study aimed to assess groundwater quality in the Thiruvarur Taluk of southern India, which has intensive agricultural activities. The variation in groundwater quality was identified by analyzing chemical components such as pH, EC, TDS, major cations, and anions. This region was sampled during pre-monsoon (PRM) and post-monsoon (POM) seasons, with 40 groundwater samples collected from the bore and dug wells in 2018. Hill-Piper plot, 57.5 % (POM) and 50 % (PRM) of the study area are Sodium Chloride. Effluent from untreated industries pollutes it. There is no contamination of any kind in the remaining groundwater samples. Mixed type (No Cation-Anion exceeds 50%) affected 37.5% (POM) and 42.5 % (PRM) of the samples, and the Magnesium bicarbonate type affected 5% (POM) and 7.5 % (PRM). Most samples are plotted in the rock dominance plot from Gibb's boomerang. Rock water interaction dominated most of the portion since no surface water bodies were observed in this area. In groundwater quality maps produced by inverse distance weighting of ArcGIS, according to the World Health Organization.**

***Keywords*: Groundwater, GIS, Piper, Thiruvarur Taluk.**

## 1. Introduction

The groundwater supply is continually replenished through various processes; however, to use it sustainably, a balance must be maintained between yearly recharges and development (Kumar, 2020). In the groundwater, geochemical processes occur, and interactions with minerals in the aquifer significantly impact the water quality (Rao et al., 2021; Jampani et al., 2020; Paul et al., 2019; Amalraj and Pius, 2018). Freshwater consumption continues to rise due to an ever-increasing human population. Natural and human-made hydrological systems are strained by diversifying freshwater to meet agricultural, industrial, household, and municipal needs (Sajil Kumar et al., 2020; Sangeetha et al., 2020; Pradeep and Anandakumar, 2016). It is possible to have a limited supply of fresh water throughout the year or a variable supply by region or season. In addressing the water management issue, studying water quantity alone is inadequate since water quality is the only variable that matters in the diverse uses of water.

Groundwater of a high enough quality for drinking and agriculture has been overused in many parts of the world (Balamurugan et al., 2020). As a result, groundwater is becoming an increasingly valuable commodity in various arid and semi-arid regions. It is because groundwater is becoming increasingly scarce. Groundwater quality significantly impacts land improvement, rock formation, and anthropogenic activities (Chidambaram et al., 2018; Wang et al., 2017). The pollution of groundwater that may be caused by expanding urbanization can adversely affect both prosperity and condition. The groundwater is being contaminated as a result of the excessive use of fertilisers and pesticides, as well as the expansion of human activities and the rapid growth of businesses. As a result, groundwater is the best and most ideal resource for hard water, as it nearly completely adjusts the convergence of salt for human consumption (Loh et al., 2021). Unfortunately, water resources are becoming more contaminated and unsafe for use (Kumari and Rai, 2020).

Knowing safe drinking water, water for industrial use, and water for irrigation, it is necessary to understand groundwater's chemical quality. It is because some chemical elements render groundwater unsuitable for industrial and agricultural use (Balamurugan et al., 2020; Saravanan et al., 2016). In assessing the water quality, various research has been carried out in distinct parts of India (Devaraj et al., 2022; Vincent et al., 2020; Shanthi et al., 2016). Systematic analysis has been carried out by Ashwani & Abhay (2014) to study groundwater chemistry in Pratapgarh district, Uttar Pradesh. Kalaivanan et al. (2017) have investigated the hydrogeochemistry of groundwater in the Southern region of Tamil Nadu, India. The present work aims to identify the spatial and temporal variability of groundwater quality and the main hydrogeochemical processes controlling the evolution of groundwater chemistry in the study area.

## 2. Material Methods

### A. Location and Geology

Located to the northwest of the Thiruvarur District in Tamil Nadu lies the taluk name of Thiruvarur. Specifically, between 79°40'45" and 77°33'24" to the east of the Prime Meridian. The latitude ranges from 10°48'54" to 10°43'20" north. The region's drainage patterns are both parallel and sub-parallel. The study area represents a key part of the Cauvery basin. The rivers Vettar and Bamini both contribute to the Cauvery. Overall, the taluk covers an area of 315.08 $km^2$ (Fig. 1). The region is covered by the Survey of India toposheets 58 N/09, 58 N/10, 58

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Table 1
Result of physio-chemical parameters

| Elements | WHO Standard-2011 | | | Maximum | | Minimum | | Average | |
|---|---|---|---|---|---|---|---|---|---|
| | Most desirable | Maximum allowable | Not Permissible | POM | PRM | POM | PRM | POM | PRM |
| pH | 6.5 to 8.5 | - | <6.5 and >8.5 | 8.90 | 8.90 | 7.40 | 7.40 | 8.54 | 8.31 |
| EC µS/cm | <1500 | - | >1500 | 5680 | 8890 | 140 | 590 | 1760 | 1897 |
| TDS mg/L | <500 | 500 to 1500 | >1500 | 10125 | 11101 | 89 | 338 | 1190.03 | 1235 |
| TH mg/L | <100 | 100 to 500 | >500 | 1682 | 2000 | 40 | 90 | 300.18 | 317.38 |
| $Ca^{2+}$ mg/L | <75 | 75 to 200 | >200 | 215 | 244 | 4 | 4 | 34.88 | 35.10 |
| $Mg^{2+}$ mg/L | <50 | 50 to 150 | >150 | 423.58 | 403.38 | 4.86 | 15.80 | 53.25 | 55.80 |
| $Na^{+}$ mg/L | <200 | - | >200 | 2306 | 3401 | 3 | 30 | 325.55 | 330.70 |
| $K^{+}$ mg/L | <10 | - | >10 | 211 | 137 | 0.10 | 0.10 | 21.08 | 21.17 |
| $NO_3^-$ mg/L | <45 | - | >45 | 11 | 38 | 0.10 | 0.10 | 3.57 | 4.53 |
| $Cl^-$ mg/L | <200 | 200 to 600 | >600 | 3382 | 5672 | 14 | 43 | 418.43 | 444.58 |
| $SO_4^{2-}$ mg/L | <400 | - | >400 | 1168 | 1392 | 5 | 11 | 160.40 | 148.48 |

N/13, and 58 N/14. Water for irrigation in the district comes mostly from surface water canals (89%), followed by drilled wells and tube wells (11%). The region forms a delta with a slight decline towards the Bay of Bengal. Fluvial deposits include sand, silt, clay, and gravel and are found in the flood plain, flood basin, point bar, channel bar, and palaeo channels. Bricks may be made from the sandy silt and clay found in riverbeds and floodplains.

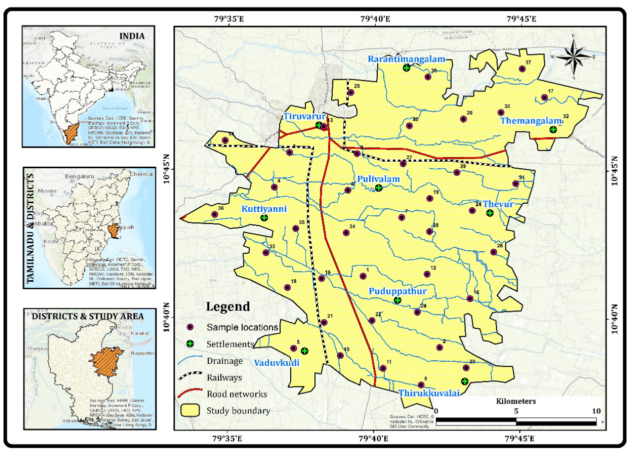


Fig. 1. Water sample location map of the study area

## B. *Sampling Analysis*

In the research region, 40 groundwater samples were taken (Fig.1). Analyzing and conserving all samples according to methods ensures accuracy and reliability (APHA 1995). Before usage, one-liter polyethylene bottles were rinsed with distilled water. The analysis used 0.45 lm filter paper. Samples were chilled below 4°C. pH and EC meters were used on site. Analyzed physical and chemical properties Groundwater samples were tested for pH, EC, TDS, cations, and anions (Kalaivanan et al., 2018; Hem, 1991). Conductivity meters' measure EC and TDS. Using EDTA as a standard, determine the solution's calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$). Bicarbonate ($HCO_3^-$) and chloride ($Cl^-$) concentrations were evaluated using acid titration with Silver Nitrate ($AgNO_3$) and HCL. Flaming photometers monitored $Na^+$, $K^+$, and $SO_4^-$, $NO_3^-$ spectrophotometry was also performed. All equipment and instruments were calibrated to perform appropriately. Sample GPS coordinates were imported into ArcGIS to create a base map. Eq. (1) was used to calculate sample accuracy using % CBE.

$$\%CBE=\frac{\Sigma\text{ cation} - \Sigma\text{ anion}}{\Sigma\text{ cation} + \Sigma\text{ anion}}\times 100 \qquad \text{(Eq.1)}$$

It is permissible to have a percentage of CBE that is either lower than or equal to 5%. Since the highest significant relative error in this study was 1.67%, which is below the acceptable range for error, the conclusions of this investigation may be trusted to be correct (Sunitha et al., 2022).

# 3. Result and Discussion

## A. *Physical Parameters*

In the study area, pH values varied from 8.90 to 7.40 (POM) and 8.90 to 7.40 (PRM), with an average of 8.54 (Table 1), according to the World Health Organization (WHO 2011). The pH values on the spatial maps reveal that 28 of the samples fall under the not permissible (> 8.5). The remaining 12 nos. of samples fall in the most desirable (6.5 to 8.5) category in post-monsoon (POM) seasons (Fig.2a). In the pre-monsoon (PRM), most groundwater samples fall within the most desirable limit (Fig.2b) category. Groundwater quality is generally acceptable for drinking purposes. Therefore, the pH of the water in the study area is within permissible limits.

The EC value for POM is 5680, whereas the EC value for PRM is 8890 (Table 1). The result revealed that 18 well samples show higher EC values than the permissible limit in POM (Fig.2c). 14 well samples fall in high EC values greater than the permissible limit in PRM (Fig.2d). Factors contributing to drastic deviations in EC are identified. Ramesh & Elango (2012) identify several geochemical processes, including silicate weathering, rock-water collaboration, ionic exchange, and oxidation processes. The high EC demonstrates the presence of salts in the groundwater in the examination region. The concentration of high EC value in these samples is due mainly to the high value of Na+ and Cl-. High EC in groundwater influences gastrointestinal irritation in human lives after long-term use (Ramesh and Elango, 2012).

The TDS value of the samples varies from 10125 to 140 mg/L. The average is 1190.03 mg/L (POM-2017), 11101 to 338 mg/L, and 1235 (PRM-2018) Table 1. The WHO standards spatial pattern of TDS value in Thiruvarur taluk is shown in Fig.4, .5, and 4.6. The POM of the study area shows different orders of TDS values. The TDS values below 500 - 1500 mg/L class fall in 30 locations, and 7 water samples fall under the not permissible > 1500 mg/L category). Only 3 locations fall with the most desirable class (< 500 mg/L) out of 40 groundwater samples (Fig.2e). In PRM seasons, the result revealed that 10 well samples show in < 500 mg/L, 19 samples fall under the 500 - 1500 mg/L maximum allowable limit category, and 12 samples have a high TDS value more than the permissible limit, respectively (Fig. 2f).

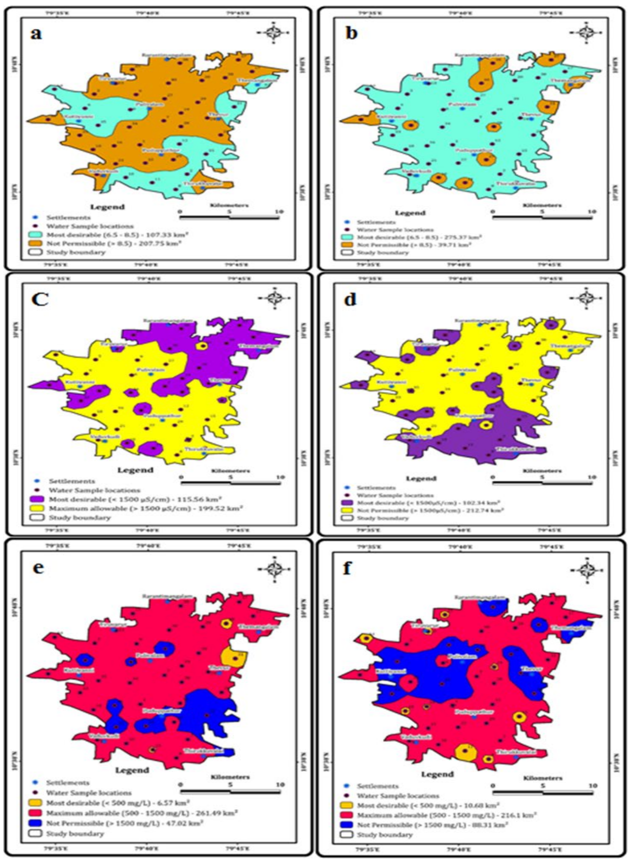

Fig. 2. Spatial Distribution map of pH.EC and TDS

### B. *Cations Chemistry*

The calcium values are from 4 to 215 mg/L, and the average is 34.88 mg/L (POM-2017) and 4 to 244 mg/L, and the average is 35.10 mg/L (PRM-2018) in the region (Table 1). The desirable limit of Ca2+ for drinking water quality is less than 75 mg/L classified by the WHO, 2011. Thirty-seven water samples fall under the most desirable limit, whereas 2 nos. (4 and 15) of samples were noted in the allowable limit during post-monsoon (POM) (Fig.3a). During pre-monsoon periods, 37 nos. of water samples belong to the most desirable limit, whereas 2 nos. (26, and 34) of groundwater samples shows allowable limit category, respectively (Fig.3b). The high concentration of Ca2+ in groundwater is attributed to carbonate or silicate weathering. It is due to seasonal variations in rainfall and the influence of groundwater.

$Mg^{2+}$ in groundwater ranges from 4.86 mg/L to 423.58 mg/L with averages of 53.25 mg/L during POM (Table 1). In PRM season value ranges from 15.80 mg/L to 403.38 mg/L with averages of 55.80 mg/L. A higher concentration observed during POM (423.58 mg/L) indicates a contribution from silicate minerals, Mg-calcite, dolomite, and sulfate minerals (Appelo and Postma 2005). During the post-monsoon period, 26 of the water samples fall with the most desirable (<50 mg/L) respectively (Fig.3c). The high concentration of Mg2+ is due to the leaching process of dolomites, limestones, and gypsum; similar results are achieved. At the same time, the reverse cationic exchange occurs with sodium reducing the concentration of Ca2+ and Mg2+ ions (Thomson Jacob et al. 1999). About 52 % of samples in the pre-monsoon and 56 % in the post-monsoon seasons were observed in the most desirable limit by WHO (2011) standard ((Fig. 3d).

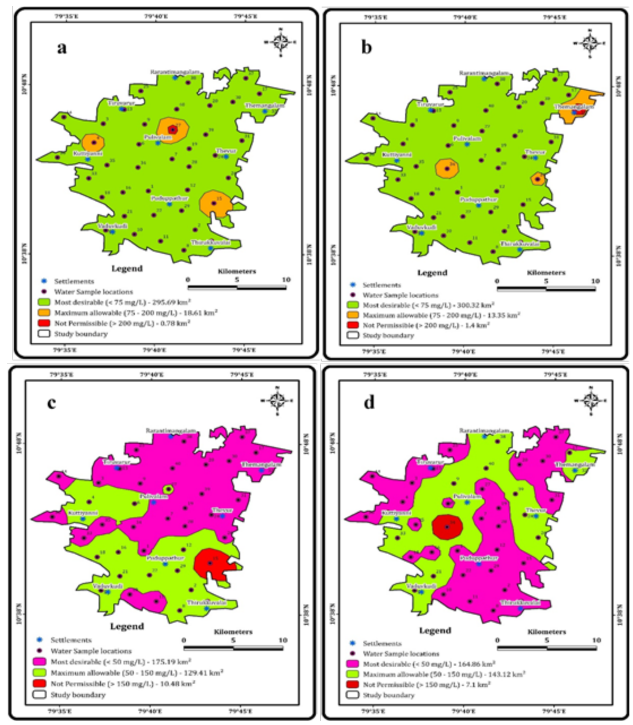

Fig. 3. Spatial distribution map of Ca & Mg

The sodium rates in groundwater vary from a minimum value of 2 mg/L to 2306 mg/L and a mean of 325.55 mg/L in POM. In the PRM period, values were 30 to 3401 mg/L, and the mean was 330.70 mg/L (Table 1). From the POM season, 259.85 km2 with an extreme level of WHO irrespective of the season. The height amount of Na+ changed in the process, where Ca2+ and Mg2+ ions concentration is replaced with Na+. The Na+ in drinking water is 15 of the sample in POM (Fig.4a). During the PRM season, 21 of the samples were within the maximum allowable limit (< 200 mg/l), respectively. In the study area, most of the samples fall under the not permissible (> 200 mg/l) limit in POM (25 samples) and PRM (18 samples) seasons (Fig.4b). The presence of sodium in these areas is because of the hardness of the water through. It is essential in determining the quality of irrigation. From the suggestions, the drinking of high concentrations of Na+ in groundwater samples may source hypertension, arteriosclerosis, oedema, and kidney problems (Alaya et al. 2014).

The potassium rates in groundwater vary from a minimum value of 0.10 mg/L to a maximum of 211 mg/L, with an average of 21.08 mg/L in POM and PRM period varies from 0.10 to 137 mg/L, by an average of 21.17 mg/L (Table 1). Potassium concentrations in the study area, 25 samples in Post-monsoon and 23 samples in Pre-monsoon groundwater samples fall within the maximum allowable (< 10 mg/l) Category. Fifteen samples and 17 of the samples fall in the Not permissible >10 mg/l Post- and Pre-monsoon season, respectively (Fig.4c & d). The study results represent both seasons in most groundwater samples were within the permissible limit. The $K^+$ concentration increases due to the surface runoff and percolation from agricultural activities and industrial wastes.

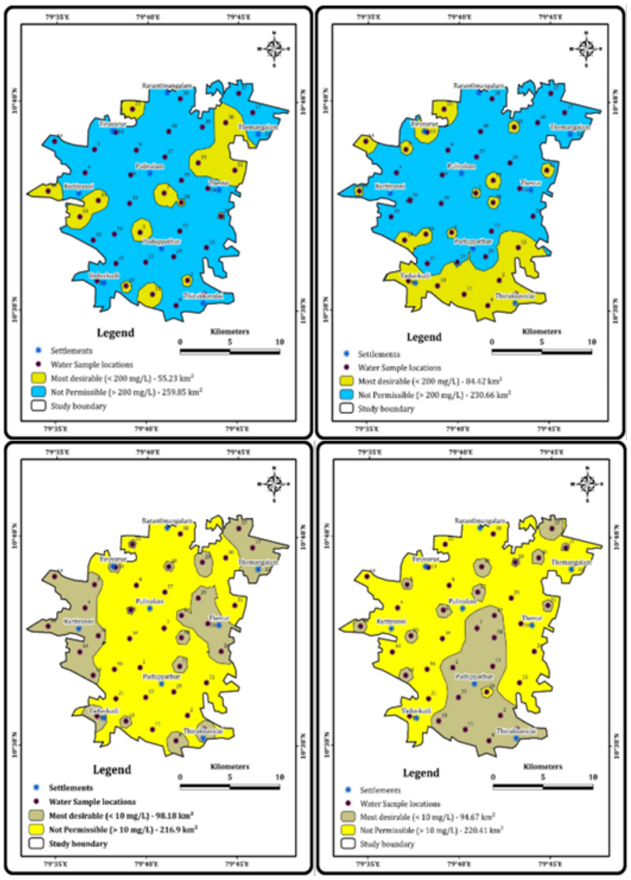


Fig. 4. Spatial distribution map of Na & K

## C. Anions Chemistry

The Nitrate concentration of the Thiruvarur taluk ranges between 0.10 and 11 mg/L POM and 0.10 to 38 mg/L PRM season, respectively (Table 1). Hence, the nitrate concentration of the groundwater is within the permissible limit in POM and PRM periods according to WHO standards. The organic material decomposes through bacterial action. The complex proteins change from amino acids to ammonia nitrites and nitrates. Some nitrates produced may be leached by percolating water and eventually reach the groundwater (Gurugnanam, 2009). In POM and PRM, 100 % of the area falls within the permissible limit and is spatially distributed in the entire area (Fig.5 a & b). The highest concentration is significantly confined to where farming exercises dominated the study area.

The water sample analysis revealed that chloride varies between 14 to 3382 mg/L, and the average is 418.463 mg/L (Table 1). In Thiruvarur taluk, POM season, the chloride concentration of 21 locations of the groundwater is within the most desirable limit (<200 mg/l). 13 locations of water sample fall in the maximum allowable (200 - 600 mg/l). Only six water samples fall under the (> 600 mg/l) Not permissible Category (Fig.5c). During PRM season 24 location of the groundwater is within the most desirable limit (<200 mg/l). Seven locations of water sample fall in the maximum allowable (200 - 600 mg/l). Only 9 water samples fall under the (> 600 mg/l) Not permissible Category (Fig.5d). The highest Cl- concentration in water is occupied as an index of pollution and is considered the source contamination of groundwater (Loizidou and Kapetanios 1993). The high chloride concentration in the study region is mainly due to the influence of municipal sewages, municipal wastes, and surface runoff from agricultural land observations.

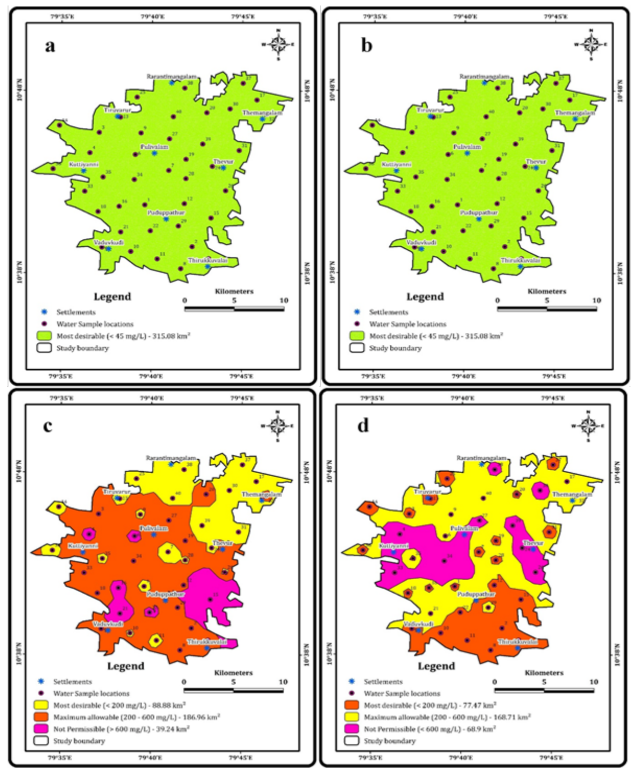


Fig. 5. Spatial variations map of $NO_3$ & Cl

Sulfate is flimsy for drinking when it crosses the most extreme reasonable worth of 400 mg/L (WHO 2011) and prompts the purgative impact on the human plan by the overabundance of mg in groundwater. In Thiruvarur taluk, POM season, Sulfate (SO42-) concentration in 39 locations of the groundwater is within the most desirable limit (<400 mg/l). Only one (15) water sample falls under the (> 400 mg/l) Not permissible Category (Fig. 6a). During PRM season 38 location of the groundwater is within the most desirable limit (<400 mg/l). Only 2 water samples fall under the (> 400 mg/l) Not permissible Category (Fig. 6b). The higher sulfate concentration is due to the weathering sulfide-bearing minerals like pyrite subjected to oxidative weathering, a higher concentration of sulfate, which dissolves in water.

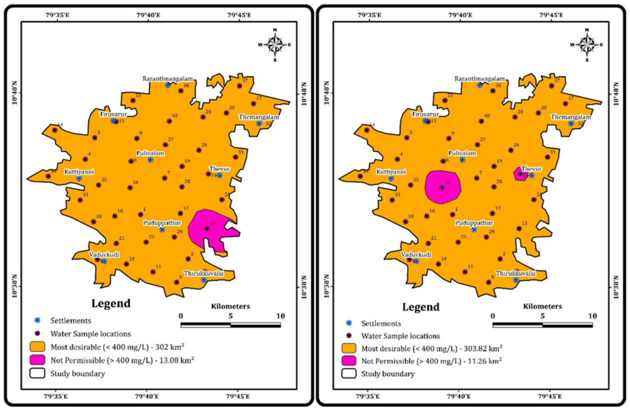


Fig. 6a & b. Spatial variations map of $SO_4^{2-}$

## *D. Hydrogeochemical Facies*

The groundwater of the taluk having different compositions is classified using Piper's tri-linear diagram (Piper 1944). The general quality of the water is addressed in the diamond-formed field by extending the situation of the plots in the triangular field. Minor alkalies are clubbed with significant ions. The important water types revealed by Piper's tri-linear diagram are as follows. An Overview of the chemical relationships of groundwater with the help of a tri-linear diagram reveals that 82.5 % (POM) and 75 % (PRM) of the samples are Alkalies that exceed alkaline earth, and Strong acids exceed Weak acids. Using a trilinear system, POM and PRM seasons of the synthetic connections in groundwater have been portrayed in more clear terms. The plot (Fig.7a & b) shows the scattering of the examples in different areas without any clustering. So, the area comprises groundwater differing in quality in different areas. In the study area, 57.5 % (POM) and 50 % (PRM) are of Sodium Chloride type. It is polluted by external influence (untreated industrial effluent). The remaining groundwater samples are unpolluted by any internal or external influence. 37.5 % (POM) and 42.5 % (PRM) of the samples as not affected by Mixed type (No Cation-Anion exceeds 50%), 5 % (POM), and 7.5 % (PRM) by Magnesium bicarbonate type.

## *E. Mechanisms Controlling the Chemistry of Groundwater*

Gibbs (1970) proposed a method for identifying the relationship between water composition and the mechanism controlling groundwater chemistry due to three main hydrological processes: input from the atmosphere, rock weathering, and evaporation. Gibbs plot is constructed by plotting the weight ratio of Na+/(Na++Ca2+) on the X axis against TDS on the Y axis and for anions Cl-/ (Cl-+HCO3-) on the X axis and TDS on the right. When rock weathering dominates, water dissolves Ca2+ and HCO3- as predominant ions with moderate TDS values and the sample plot in the middle of the Gibbs plot. Water samples along the plot's lower right represent sodium chloride from atmospheric precipitation. The atmospheric precipitation processes and sample data plot lie in the boomerang's lower right corner. During the POM and PRM seasons, the GIBBS cations diagram (Fig.8a, b, c & d), respectively. Most of the samples are plotted in the rock dominance. The majority of the portion was found to be rock water-interaction dominance because this area observed cannot be any surface water bodies (Srinivasamoorthy et al. 2008). Therefore, water resides in the void space of rock or soil (Rock water interaction). As elucidated by some researchers, Charbonneau and Dornhaus (2015); Alfonso et al. (2010), groundwater chemical ionic concentration of the Thiruvarur region is the chemistry that results from the interaction of evaporation crystallization with rock types.

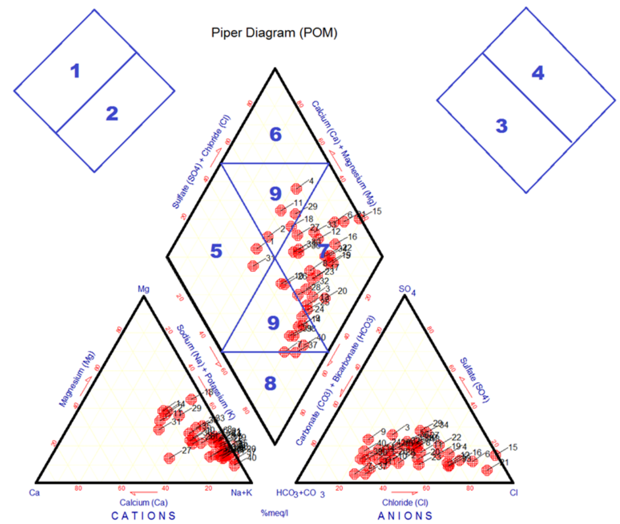


Fig. 7a. Piper's Tri-Linear Diagram – POM

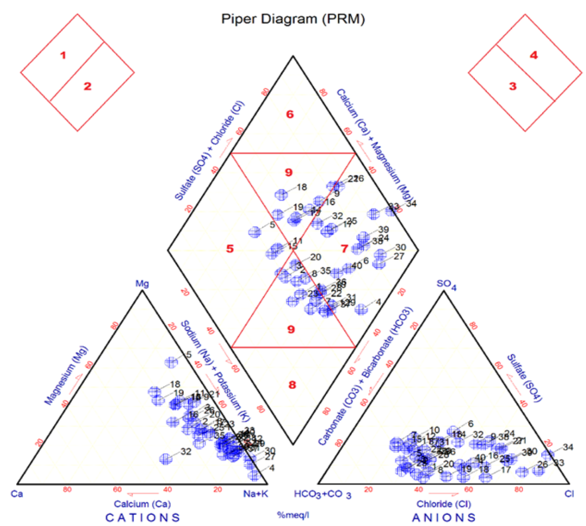


Fig. 7b. Piper's Tri-Linear Diagram – PRM

## *F. Irrigation Purposes*

### *1) USSL Diagram of Irrigation Rating*

As already outlined, salinity, alkali, and residual sodium carbonate have been extensively evaluated to assess irrigation quality. The plots of groundwater chemistry of Thiruvarur Taluk U.S. Salinity Laboratory diagram (USSL 1954) in post-monsoon (POM) season, 17.5.5% samples fall in C2-S1 class is excellent for irrigation, 22.5% samples fall in C3-S1 class, and 35% samples in C3-S2 class are indicating medium and high salinity respectively and low alkalinity. 2.5% of samples fall in a C3-S3 category, indicating that medium sodium hazard and high salinity moderate suitability for irrigation. A minor amount of samples falls C4-S2 (7.5%), C4-S3 (7.5%), and C4-S4 (7.5%) fields not suitable for irrigation (Fig.9a). This type of water can also be used for irrigation.

In the pre-monsoon (PRM) season, 2.5% of samples fall in the C1-S1 class, and 20% fall into the C2S1 class, and both are good for irrigation as they have medium to high salinity hazard and low alkalinity hazard. 42.5% of samples fall in the C3-S2 class and 12.5% fall in the C3-S3 of high salinity and medium alkalinity. 5% (C4-S2) and 12.5 (C4-S3) 12.5% of the sample fall into and Category, respectively (Fig.9b). This Category is predominant in the study area and is suitable for irrigation in pre- and post-monsoon seasons. In the study area, representing such water can adversely affect fine-textured soils where frequent cation exchange occurs, and applying gypsum in agricultural fields can overcome this problem. When the options are limited, these waters can be used in coarse-grained soils where sizable pore spaces do not allow cation exchange (Karanth, 1987).

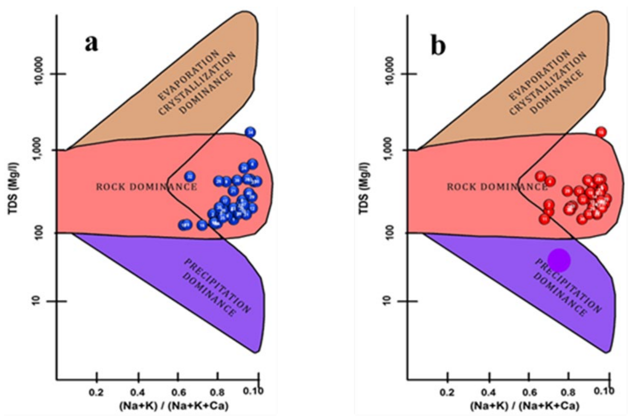


Fig. 8a & b. Cation and Anion GIBBS Diagram - (POM)

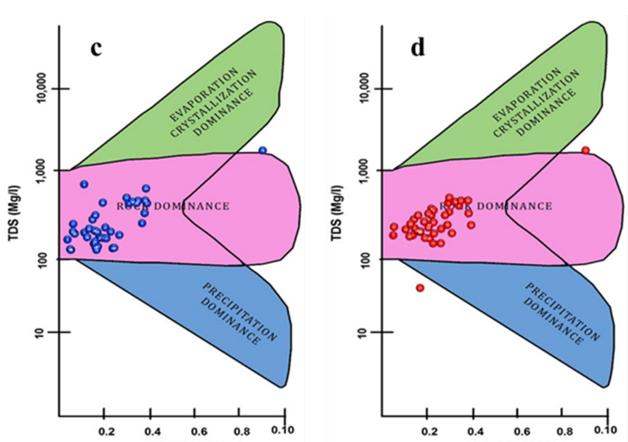


Fig. 8c & d. Cation and Anion GIBBS Diagram - (PRM)

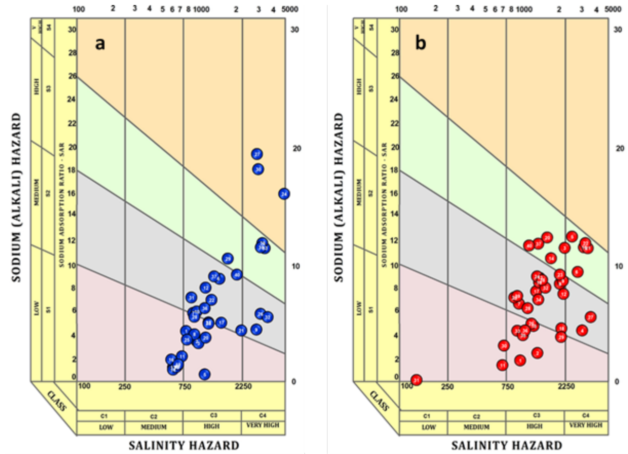


Fig. 9a & b. USSL diagram for Irrigation Classes - POM & PRM

## 4. Conclusion

In Thiruvarur taluk, Tamil Nadu, India, groundwater can be utilized for agricultural/domestic purposes based on hydrogeochemical analysis. Cation and anion concentrations are $Na<Mg<Ca<K$ and $Cl<SO4<NO_3$ in pre- and post-monsoon season, respectively. According to the Hill-Piper plot, 57.5 % (POM) and 50 % (PRM) of the study area is Sodium Chloride. Effluent from untreated industries pollutes it. There is no contamination of any kind in the remaining groundwater samples. Mixed type (No Cation- Anion exceeds 50%) affected 37.5% (POM) and 42.5 % (PRM) of the samples, and the Magnesium bicarbonate type affected 5% (POM) and 7.5 % (PRM). Most samples are plotted in the rock dominance plot from Gibb's boomerang. Rock water interaction dominated most of the portion since no surface water bodies were observed in this area. The groundwater can irrigate almost all types of soil in the study area. Exchangeable sodium is a rare hazard. Researchers will contribute to groundwater management and conservation in the study area through this research. Managing groundwater effectively and monitoring its quality is essential for portability.

## References

[1] Alaya, MB., Saidi, S., Zemni, T., & Zargouni, F. (2014). Suitability assessment of deep groundwater for drinking and irrigation use in the Djefara aquifers (Northern Gabes, south-eastern Tunisia). Environmental Earth Sciences, 71, 3387–3421.

[2] Alfonso HS, Reid A, De Klerk NH. (2010) Retinol supplementation and mesothelioma incidence in workers earlier exposed to blue asbestos (Crocidolite) at Wittenoom, Western Australia, Eur J Cancer Prev, vol.19, pp.355-359.

[3] Amalraj, A. and Pius, A. 2018. Assessment of groundwater quality for drinking and agricultural purposes of a few selected areas in Tamil Nadu South India: a GIS-based study. Sustainable Water Resources Management.

[4] APHA (1995) Standard methods for the examination of water and waste water, 19th ed., American Public Association, Washington D.C., 1467p

[5] Appelo, C.A.J., Postma, D., 2005. Geochemistry, Groundwater and Pollution, second ed. A.A. Balkema, Rotterdam.

[6] Ashwani, KS & Abhay, KT 2014, 'Hydrogeochemical investigation and groundwater quality assessment of Pratapgarh District, Uttar Pradesh', J. Geol. Soc. India, vol.83, pp.329-343.

[7] Balamurugan, P., Kumar, P.S., Shankar, K. and Sajil Kumar, P.J. 2020. Impact of climate and anthropogenic activities on groundwater quality for domestic and irrigation purposes in Attur region, Tamilnadu, India. Desalination and Water Treatment.

[8] Charbonneau, D & Dornhaus, A (2015) 'Workers 'specialized' on inactivity: Behavioral consistency of inactive workers and their role in task allocation', Behav Ecol Sociobiol, vol.69, pp. 1459-1472.
[9] Chidambaram, S., Pethaperumal, S., Thilagavathi, R., Dhanu Radha, V., Thivya, C., Prasanna, M. V. 2018. Seasonal Variations of Groundwater Geochemistry in Coastal Aquifers, Pondicherry Region, South India. In: Coastal Zone Management: Global Perspectives, Regional Processes, Local Issues.
[10] Devaraj, N., Chidambaram, S., Pradeep, K., Mahalakshmi, M., Muhammed, H., Mohan, Prasanna M.V., Thivya, C. and Thilagavathi, R. 2022. Impact of monsoon shower on the hydrogeochemistry of groundwater along the lithological contact: a case study from South India. Applied Water Science.
[11] Gibbs, R. J., 1970. Mechanisms Controlling World Water Chemistry. Science, 170, 1088-465, 1090.
[12] Gurugnanam B, Suresh M, Vinoth M, Prabhakaran N, Kumaravel S (2009) GIS based microlevel approach for hydrogeochemical studies in upper Manimuktha sub basin, Vellar, South India. Indian J Sci Technol 2:5–10.
[13] Hem, JD (1991), Study and interpretation of the chemical characteristics of natural water, 3rd ed., Jodhpur, India. Scientific Publ., 2254 p.
[14] Jampani, M., Liedl, R., Hülsmann, S., Sonkamble, S. and Amerasinghe, P. 2020. Hydrogeochemical and mixing processes controlling groundwater chemistry in a wastewater irrigated agricultural system of India. Chemosphere.
[15] Kalaivanan, K., Gurugnanam, B., Pourghasemi, H.R., Suresh, M. and Kumaravel, S. 2018. Spatial assessment of groundwater quality using water quality index and hydrochemical indices in the Kodavanar sub-basin, Tamil Nadu, India. Sustainable Water Resources Management, 4, 627–641.
[16] Karanth, K. R. (1987). Quality of ground water. In K. R. Karanth (Ed.), Ground water assessment development and management (pp. 217–275). New Delhi: Tata McGraw Hill.
[17] Kumar, R. 2020. Water management in the Ghaghra basin: Options of sustainable development. International Journal of Emerging Technology and Advanced Engineering.
[18] Kumari, M. and Rai, S.C. 2020. Hydrogeochemical Evaluation of Groundwater Quality for Drinking and Irrigation Purposes Using Water Quality Index in Semi-Arid Region of India. Journal of the Geological Society of India.
[19] Loh, Y.S.A., Addai, M.O., Fynn, O.F. and Manu, E. 2021. Characterisation and quality assessment of surface and groundwater in and around Lake Bosumtwi impact craton (Ghana). Sustainable Water Resources Management.
[20] Loizidou, M., Kapetanios, E.G., 1993. Effect of leachate from landfills on underground water quality. The Science of the Total Environment 128, 69-81.
[21] Paul, R., Brindha, K., Gowrisankar, G., Tan, M.L. and Singh, M.K. 2019. Identification of hydrogeochemical processes controlling groundwater quality in Tripura, Northeast India using evaluation indices, GIS, and multivariate statistical methods. Environmental Earth Sciences.
[22] Piper, A. M. (1994). A geographic procedure in the geochemical interpretation of water analysis. Transactions—American Geophysical Union (Vol. 25, pp. 914–928). Washington D.C.
[23] Pradeep, T. and Anandakumar, S. 2016. Groundwater quality studies in the lower Noyyal river basin, Tamilnadu, India. Ecology, Environment and Conservation.
[24] Ramesh, K., Elango, L., 2012. Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environ. Monit. Assess. 184, 3887–3899.
[25] Rao, N.S., Dinakar, A., Sravanthi, M. and Kumari, B.K. 2021. Geochemical characteristics and quality of groundwater evaluation for drinking, irrigation, and industrial purposes from a part of hard rock aquifer of South India. Environmental Science and Pollution Research.
[26] Sajil Kumar, P.J., Mohanan, A.A. and Ekanthalu, V.S. 2020. Hydrogeochemical analysis of Groundwater in Thanjavur district, Tamil Nadu; Influences of Geological settings and land use pattern. Geology, Ecology, and Landscapes.
[27] Sangeetha, S., Krishnaveni, M. and Mahalingam, S. 2020. GIS based seasonal variation of groundwater quality and its suitability for drinking in Paravanar river basin, Cuddalore district, Tamil Nadu, India. Indian Journal of Geo-Marine Sciences.
[28] Saravanan, K., Srinivasamoorthy, K., Gopinath, S., Prakash, R. and Suma, C.S. 2016. Investigation of hydrogeochemical processes and groundwater quality in Upper Vellar sub-basin Tamilnadu, India. Arabian Journal of Geosciences.
[29] Shanthi, N., Elamvaluthi, M., Kotteswari, M. and Murugesan, S. 2016. Assessment of groundwater quality in and around Thiruvallur district, Tamilnadu. International Journal of Environmental Sciences.
[30] Sunitha, V., Reddy, Y.S., Suvarna, B. and Reddy, B.M. 2022. Human health risk assessment (HHRA) of fluoride and nitrate using pollution index of groundwater (PIG) in and around hard rock terrain of Cuddapah, A.P. South India. Environmental Chemistry and Ecotoxicology, 4, 113–123.
[31] USSL (1954) Diagnosis and improvement of saline and alkali soils. United States Development Agency Handbook 60. Government Printing Office, Washington, DC, p. 147.
[32] Vincent, J., Lekha, C., Bagavathi, Vijaya, B., Bhuvaneshwari and Lakshmi, G. 2020. Physico–Chemical analysis of groundwater quality near the salt-pans of Thoothukudi Districts, Tamilnadu, India. International Journal of Chem. Tech. Research.
[33] Wang, J., Wang, J. and Jin, M. 2017. Hydrochemical Characteristics and Formation Causes of Karst Water in Jinan Spring Catchment. Diqiu Kexue - Zhongguo Dizhi Daxue Xuebao/Earth Science - Journal of China University of Geosciences.
[34] WHO (2011) Guideline for drinking water quality, 4th edn. World Health Organization, Geneva.