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Spatial Analysis and Mapping of Ground Water Quality in Tiruvallur District

A. Mohan[1], Dr. R. Bala murugan[2], Dr. S. Selvamuthukumar[3]

[1]*Assistant Professor, Department of Civil Engineering, SRM Easwari Engineering College, India.*
[2]*Associate Professor, Department of Civil Engineering, FEAT, Annamalai University, India*
[3]*Assistant Professor, Government College of Engineering, India*
E-mail: mohananbarasu@gmail.com

This study focuses on evaluating groundwater quality in Tiruvallur district, Tamil Nadu, India, a region heavily reliant on groundwater for drinking due to limited surface water availability. The investigation involves gathering data through various means such as maps, topographic sheets, and sampling from 10 dug well stations. Key physicochemical parameters including pH, Total Hardness (TH), Total Dissolved Solids (TDS), and Electrical Conductivity are assessed to calculate the Water Quality Index (WQI). The suitability of groundwater for both irrigation and drinking purposes is examined, and spatial variation analysis is conducted using Geographic Information System (GIS) techniques like QGIS for mapping outcomes. These parameters are compared against standards set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO). Notably, box plot analysis highlights a strong correlation between Total Dissolved Solids and Electrical Conductivity.

Keywords: Water Quality Index, Ground Water, QGIS.

1. Introduction

Groundwater plays a critical role globally, serving as a vital source of drinking water for humans and supporting ecosystems by maintaining base flow to rivers. Typically, groundwater is of excellent quality, naturally filtered as it percolates through the ground, often clear, colorless, and free from microbial contamination, requiring minimal treatment. However, a growing threat arises from the increasing presence of soluble or dissolved chemicals stemming from urbanization, industrial activities, and modern agricultural practices. The chemistry of groundwater is influenced by various factors including atmospheric inputs, soil and water-rock interactions, and pollutants from sources such as mining, land clearance, agricultural practices, and acid rain. Once groundwater becomes polluted, restoring its quality is challenging, as simply halting pollutant sources doesn't reverse contamination. GIS has emerged as a powerful tool in storing, analyzing, and visualizing spatial data, aiding decision-making processes in numerous fields, including engineering and environmental management.

2. Literature Review

Various studies have utilized Geographic Information System (GIS) technology and remotely sensed data to manage water resources and assess groundwater quality. Sharma Pradeep Kumar et al. (2016) conducted an in-depth investigation of twelve hydro-chemical parameters, identifying three factors through factor analysis. Their primary objective was to analyze spatial variations and estimate groundwater quality across different locations. Velayutham Raj and Neelakantan (2020) utilized the USEPA approach to assess non-carcinogenic health risks associated with fluoride and nitrate exposure from groundwater consumption. Spatial distribution plots were employed to establish non-carcinogenic risks and other water quality parameters using the Water Quality Index (WQI) map.

Durga Srilakshmi Hari et al. (2019) focused on identifying the parameters polluting groundwater. Through spatial analysis using GIS, they highlighted the elevated levels of total hardness, conductivity, and pH, emphasizing the need for groundwater pollution monitoring. Patil S (2000) investigated groundwater quality in Sangli city, finding high levels of hardness and chloride, rendering the water unfit for irrigation due to elevated Sodium Adsorption Ratio (SAR). The deterioration in quality was attributed to untreated sewage and industrial wastewater disposal in the Krishna River. Reddy B.M. (2003) studied groundwater quality in Bangalore city, revealing high nitrate concentrations indicative of significant pollution, likely from municipal wastewater or leachates from garbage dumps.Palanisamy et al. (2007) assessed groundwater quality in and around Gobichettipalayam town, Erode district, Tamil Nadu. While some samples exhibited lower dissolved oxygen levels, they concluded that this did not impact the water's suitability for drinking. Shah et al. (2008) examined physico-chemical parameters of groundwater in forty villages of Gandhinagar taluk, Gujarat state, India. They found poor quality for drinking but suitable for irrigation, primarily due to domestic wastewater seepage. They recommended purification treatment for drinking water use.

3. Study Area

The study area chosen is Thiruvallur District, one of the administrative districts in the Indian state of Tamil Nadu, with its bustling city serving as the district headquarters. Thiruvallur District exhibits a blend of urban and rural characteristics, spanning across approximately 3422 sq. km. It lies between the latitudes of 12º15' N and 13º15' N, and the longitudes of 79º15' E and 80º20' E, as depicted in Figure 1 of the study. The district's soil composition comprises predominantly red non-calcareous and coastal alluvial soil, characterized as sandy and mixed with soda or alkali. The region experiences an average annual rainfall of 1152.8 mm, with maximum temperatures peaking at 37.9ºC and minimum temperatures averaging around 23.6ºC.

In terms of groundwater resources, Thiruvallur District boasts approximately 70 dug wells. For this study, specific blocks within the district were selected, namely Madhavaram, Ponneri, Poonamallee, and Ambattur. Within these blocks, 11 dug wells were chosen based on their proximity to industrial, commercial, and residential areas. These wells are situated in villages such as Thiruthani, Thirvalangadu, Thiruvallur, Thirumullaivoiyil, Thiruverkadu, Madhavaram, Thiruvottriyur, Ennore, Periyapalayam, Gummudipoondi, and Redhills. Table 1 in the study provides the sampling locations within the study area, along with their corresponding latitudes and longitudes, facilitating precise data collection and analysis..

3.1 Objective of the present study

- The primary objectives of the present study are outlined as follows:
- To assess the physical and chemical properties of groundwater, aiming to comprehensively evaluate the quality of the sampled groundwater.
- To utilize QGIS for generating maps depicting the spatial distribution of groundwater quality. These maps will visually illustrate the correlation between measurement locations and the degree of contamination across the study area.

4. Methodology

4.1. Physico-Chemical Analysis

The fresh groundwater samples were collected from each of the 11 locations during the pre-monsoon period. Sterilized bottles were employed for water sample collection, which were initially cleaned with the water being sampled and rinsed for 5 minutes before being filled with water. Subsequently, the collected samples were transported to the laboratory for analysis. In the laboratory, the collected samples underwent analysis for various physicochemical parameters including pH, Total Hardness, Total Dissolved Solids (TDS), Chlorides, and Electrical Conductivity, following standard test procedures. The results obtained from this analysis formed the attribute database for the present study. The physicochemical analysis results are detailed in Table 2, showcasing the measurements of each parameter. To evaluate the groundwater quality, each parameter was compared against the desirable standard limits stipulated for drinking water, as prescribed by the Bureau of Indian Standards (BIS) Standards (2012) and the World Health Organization (WHO) guidelines from 1983, aimed at safeguarding public health. The measured results were then compared with the permissible limits for drinking water, as defined by BIS 10500 (2012) and WHO standards, and are presented in Table 3 for comprehensive assessment and comparison..

4.2 Preparation of spatial database using QGIS

Geographic Information System (GIS) is a powerful technology that facilitates various geospatial applications. It encompasses functions such as data collection, storage, management, retrieval, conversion, analysis, modeling, and display. By connecting data to a map, GIS integrates location information with other descriptive data, providing a foundational tool for mapping and analysis across different industries. In the context of groundwater quality assessment, GIS utilizes interpolation techniques to estimate the quality of groundwater at unknown locations based on the known parameters of nearby points. This process creates a continuous surface representation, illustrating the spatial distribution of water quality parameters across large areas.

QGIS, an open-source cross-platform desktop GIS software, serves as a valuable tool in this study. It enables users to analyze, edit, compose, and export spatial information, facilitating the integration of physicochemical analysis results of groundwater samples from 11 locations into the GIS platform. Thematic maps depicting the spatial distribution of groundwater quality parameters across the entire Tiruvallur district are generated using the Inverse Distance Weighted (IDW) interpolation method in QGIS. Figures 2 to 6 present the generated spatial distribution maps. Furthermore, the study incorporates ground water quality data spanning a decade, from 2010 to 2020, obtained from the State Ground and Surface Water Resources Data Centre, Taramani. This secondary data, alongside primary data collected from the study area, underwent a comparative analysis on various parameters including Electrical Conductivity, Total Dissolved Solids, Total Hardness, pH, and Chlorides. The comparative analysis diagrams, generated using QGIS, are illustrated in Figures 7 to 10, providing insights into temporal trends and variations in groundwater quality over the years.

4.3 Determination of Water Quality Index

The Water Quality Index (WQI) serves as a valuable tool for assessing and depicting the overall status of water quality in a single term, aiding in the selection of appropriate treatment techniques to address pertinent issues. In the present study, the WQI was calculated using the Weighted Arithmetic Index Method. Initially, a quality rating scale (Qi) was developed for each parameter. The sub-index value of each parameter was then estimated by multiplying the rating scale with the respective weighing factor. The overall WQI was obtained by aggregating these sub-indices.

Table 4 presents the rating assigned to the quality of water based on the Water Quality Index (WQI) as per the Bureau of Indian Standards (BIS). Additionally, the computed Water Quality Index and the status of selected groundwater samples in Tiruvallur District are provided in the same table. The overall status of the water quality scenario is depicted in Figure 11. It is observed that certain block stations, such as Thiruverkadu and Thiruvalangadu, have achieved higher Water Quality Index values, indicating exceptional water quality within the prescribed limits for drinking water. Conversely, the water quality status in Redhills and Thirumullaivoyal is noted to be very poor. The water quality in the remaining sample sites is categorized as good.

4.4 Generation of Map

The spatial databases generated using QGIS, along with non-spatial data, were integrated to facilitate the generation of spatial distribution maps encompassing all water quality parameters, including the Water Quality Index (WQI) map. This integration process involved combining the spatial datasets, which contain geographic information such as location coordinates, with the non-spatial data containing information on water quality parameters measured at those specific locations.

By merging these datasets, comprehensive spatial distribution maps were created, providing visual representations of the spatial variation of each water quality parameter across the study area. Additionally, the WQI map was generated using the calculated WQI values for each location, allowing for an overall assessment of water quality across the entire study area. This integrated approach ensures a holistic understanding of the spatial distribution of water quality parameters, aiding in decision-making processes related to water resource management and quality improvement efforts..

5. Results and Discussions

pH serves as an indicator of the acid-base equilibrium in natural water. In the groundwater samples collected, pH ranged from 5.75 to 7.06, with an average of 6.54 across the study area. Thirvalangadu exhibited the highest pH at approximately 7.06, while Redhills showed the lowest pH at 5.75. Notably, all locations except Thirvalangadu had pH values below 7. The residential nature of this area suggests that fluctuations in pH may impact local residents. The higher pH in Thirvalangadu may be attributed to geological variations, with regions containing heavy rocks and minerals with high alkalinity leading to increased pH levels. Importantly, the pH values of all tested samples fall within the permissible limits for both drinking and irrigation, as prescribed by both BIS and WHO standards. The majority of the study area exhibits a pH value of less than or equal to 6.5, indicating moderately acidic groundwater.

Total Dissolved Solids (TDS) is a measure of the combined content of all organic and inorganic substances in water, reflecting aesthetic characteristics and the presence of chemical contaminants. TDS levels in collected samples varied between 324 and 1072 mg/l, with an average of 634.36 mg/l. While all samples remained within permissible limits according to BIS guidelines, those from Thiruttani, Thiruvallur, Thiruverkadu, Thiruvottriyur, and Periyapalayam exceeded WHO recommended limits. This could be attributed to salt leaching from industrial effluents and other anthropogenic sources such as urban and agricultural activities. Scale formation within wells also contributes to increased TDS levels, which can be mitigated through regular maintenance and cleaning. A comparative analysis over ten years indicates that wells in Thirvalangadu, Thiruverkadu, and Redhills have shown consistent TDS rates, potentially due to effective maintenance practices and the influence of rainfall in reducing dissolved solids.

Electrical Conductivity (EC) reflects the saltiness of groundwater and estimates the amount of dissolved solids present. In the study area, EC ranged from 540 to 1787 µs/cm, with an average of 1057 µs/cm. While Thirumullaivoiyil, Thiruverkadu, Thiruvottriyur, and Gummudipoondi showed significant variations in EC rates, they remained within desirable ranges. Conversely, areas such as Thirvalangadu, Madhavaram, Redhills, Ennore, and others exhibited lower EC levels, potentially due to reduced TDS concentrations. Spatial distribution analysis over the past ten years indicates a marginal increase in EC in certain areas, attributed to higher TDS values and exceedance of permissible limits.

Hardness in water arises from dissolved salts of calcium and magnesium. The groundwater samples exhibited hardness levels ranging from 152 to 640 ppm, with an average of 312 ppm. Thiruthani recorded the highest hardness at 640 ppm, while Redhills had the lowest at 152 ppm. With the exception of Thiruthani, all locations fell within acceptable and permissible limits according to BIS standards. The elevated hardness in Thiruthani may be attributed to excessive application of untreated chemical and mining effluents. Despite increasing industrial activity, certain areas such as Thirvalangadu, Thirumullaivoiyil, Madhavaram, Gummudipoondi, and Redhills showed decreasing water hardness, suggesting effective effluent treatment. Conversely, a marginal increase in hardness was observed in Redhills, indicating well-maintained dug wells.

Chloride concentrations ranged from 36 to 370 mg/l, with a mean of 160 mg/l across the study area. Periyapalayam exhibited the highest chloride concentration at 370 mg/l, while Thirvalangadu had the lowest at 36 mg/l. All locations except Periyapalayam remained within WHO permissible limits. Spatial distribution analysis over the past ten years revealed a decrease in chloride concentration in areas such as Thirvalangadu, Thirumullaivoiyil, Madhavaram, Ennore, and Gummudipoondi. Conversely, Thiruthani, Thiruvallur, Thiruverkadu, Thiruvottriyur, and Redhills showed a drastic increase in chloride concentration, albeit remaining below BIS and ISO standards. Overall, Table 5 presents the computed Water Quality Index and the status of selected groundwater samples in Tiruvallur District, providing a comprehensive overview of water quality assessment results.

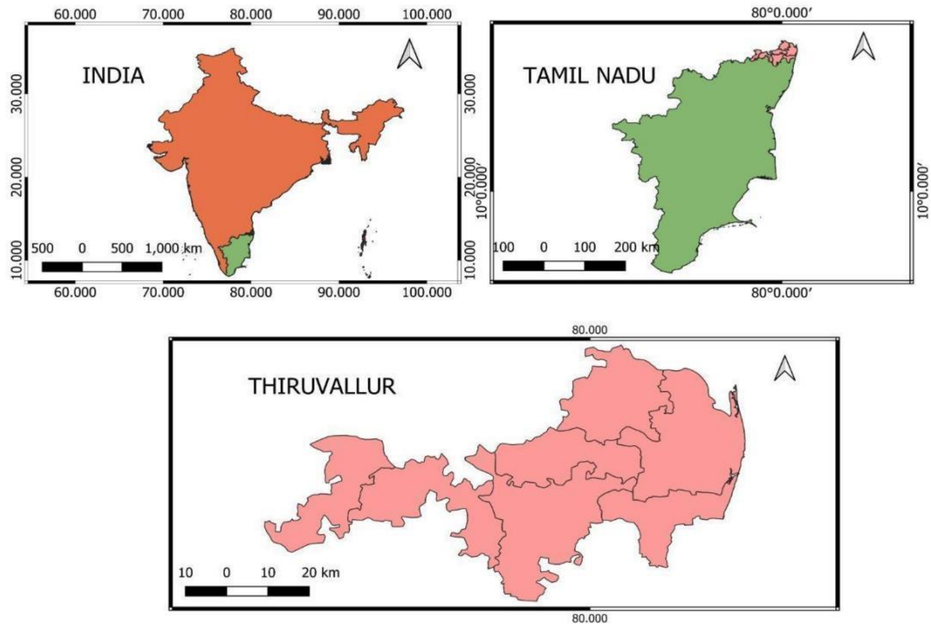

Fig 1: Study Area Map

Table 1 : Sample Locations and GPS coordinates

Sample	Location	Latitude	Longitude (N)
1	Thiruthani	13.18° N	79.63° E
2	Thirvalangadu	13.13° N	79.77° E
3	Thiruvallur	13.12° N	79.91° E
4	Thirumullaivoiyil	13.13° N	79.77° E
5	Thiruverkadu	13.07° N	80.13° E
6	Madhavaram	13.15° N	80.23° E
7	Thiruvottriyur	13.16° N	80.3° E
8	Ennore	13.21° N	80.32° E
9	Periyapalayam	13.31° N	80.05° E
10	Gummudipoondi	13.24° N	80.06° E
11	Redhills	13.19° N	80.19° E

Table 2: Results of physicochemical tests of selected groundwater samples in Tiruvallur District

Location	Electrical Conductivity @25°C (µs/cm)	pH vale @25°C	Total Dissolved solids Mg/L	Total Hardness as $CaCO_3$ Mg/L	Chlorides as Cl^- Mg/L
Thiruthani	1580	6.97	948	640	185
Thirvalangadu	540	7.06	324	242	36
Thiruvallur	1733	6.84	1040	450	235
Thirumullaivoiyil	903	5.88	542	220	182
Thiruverkadu	1082	6.92	649	388	188
Madhavaram	658	6.38	395	164	82
Thiruvottriyur	1150	6.57	690	316	192
Ennore	662	6.52	397	216	62
Periyapalayam	1787	6.69	1072	450	370
Gummudipoondi	892	6.41	535	192	136
Redhills	643	5.75	386	152	136

Table 3: Comparative statistical analysis of the physiochemical parameters analyzed using the Bureau of Indian Standards (BIS) and World Health Organization (WHO) standards

Sl.No	Parameters	BIS Standards (BIS 10500 (2012)) Acceptable – Permissible limits	WHO Standards	Study Area	
				Minimum	Maximum
1	pH	6.5-8.5	7.5-8.5	5.75	7.06
2	Electrical Conductivity(µs/cm),	-	1500	540	1787
3	Total Dissolved Solids(ppm)	500-2000	500	324	1072
4	Total Hardness (ppm)	200-600	200	152	640
5	Chlorides (ppm)	250-1000	250	36	370

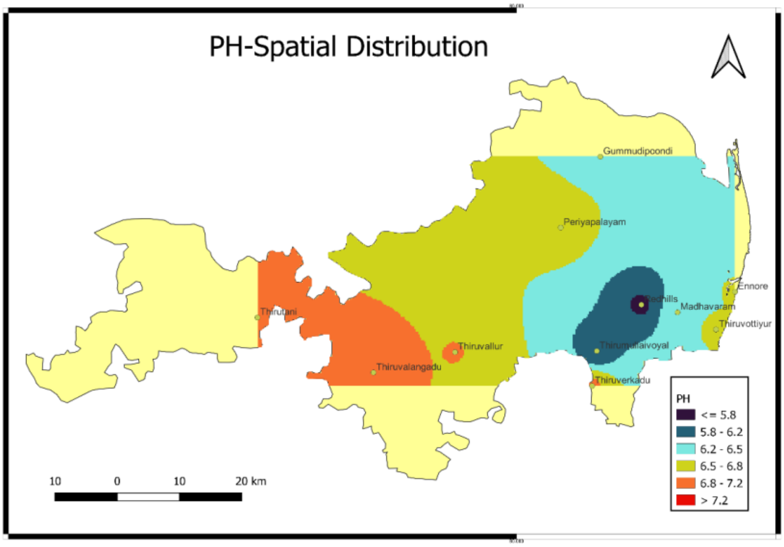

Fig 2 : Spatial Distribution of PH

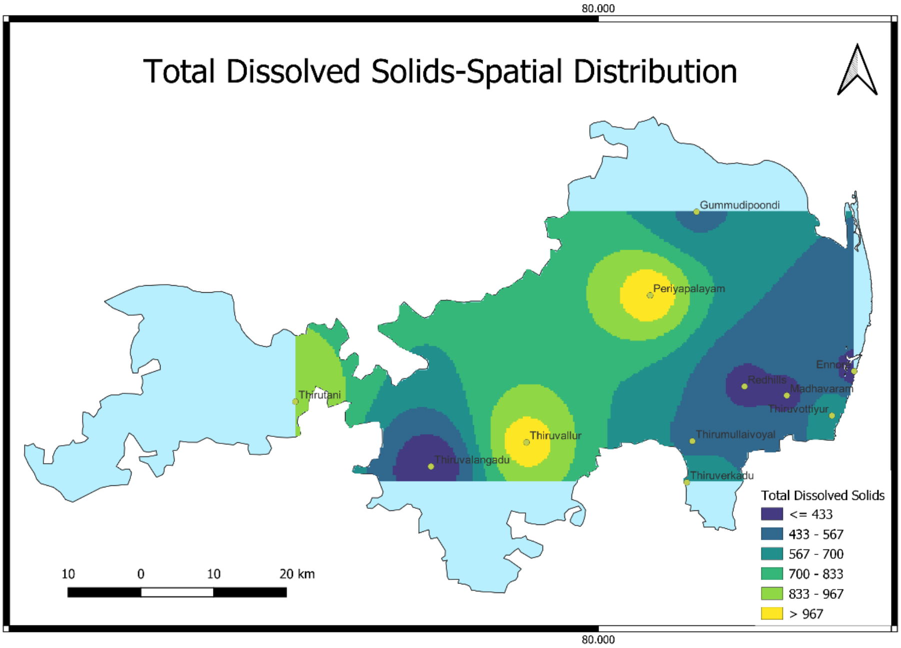

Fig 3 : Spatial Distribution of Electrical Conductivity

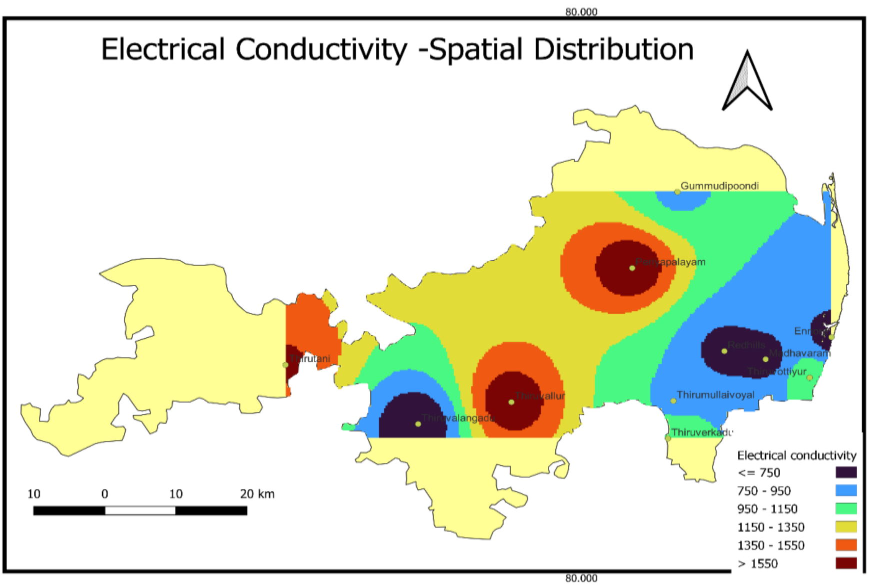

Fig 4 : Spatial Distribution of TDS

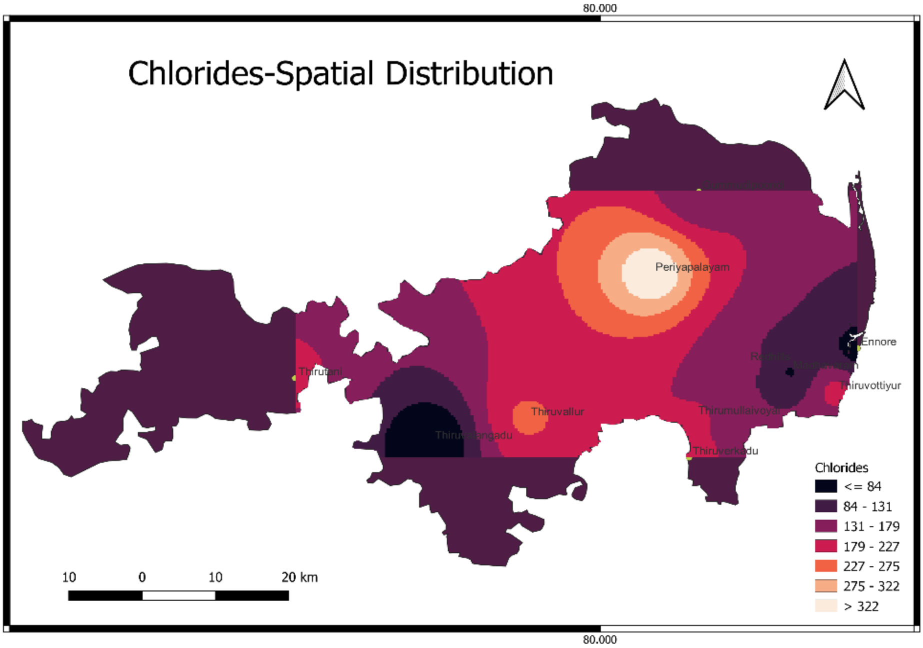

Fig 5 : Spatial Distribution of Total Hardness

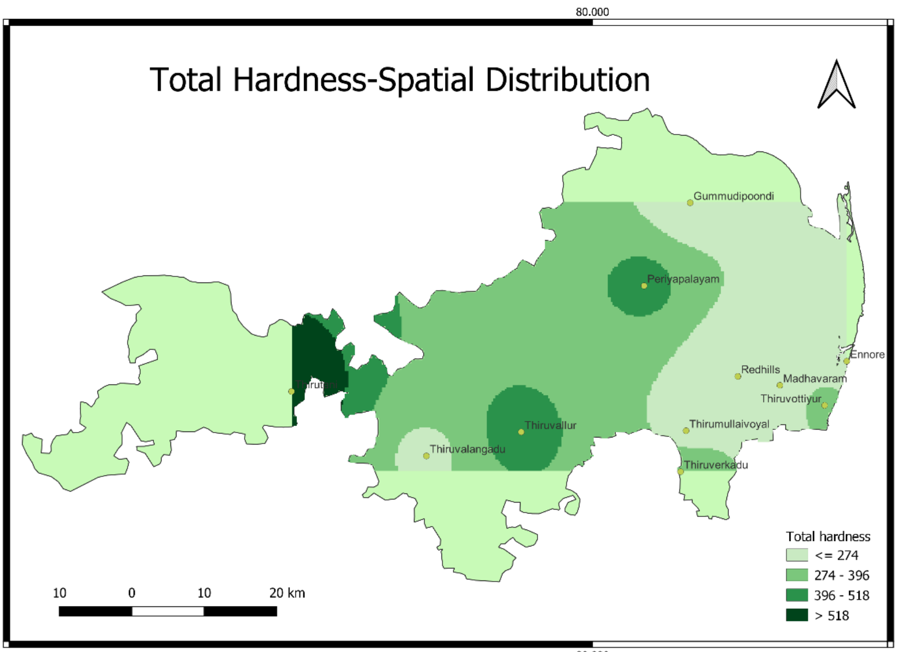

Figure 6 Spatial Distribution of Chlorides

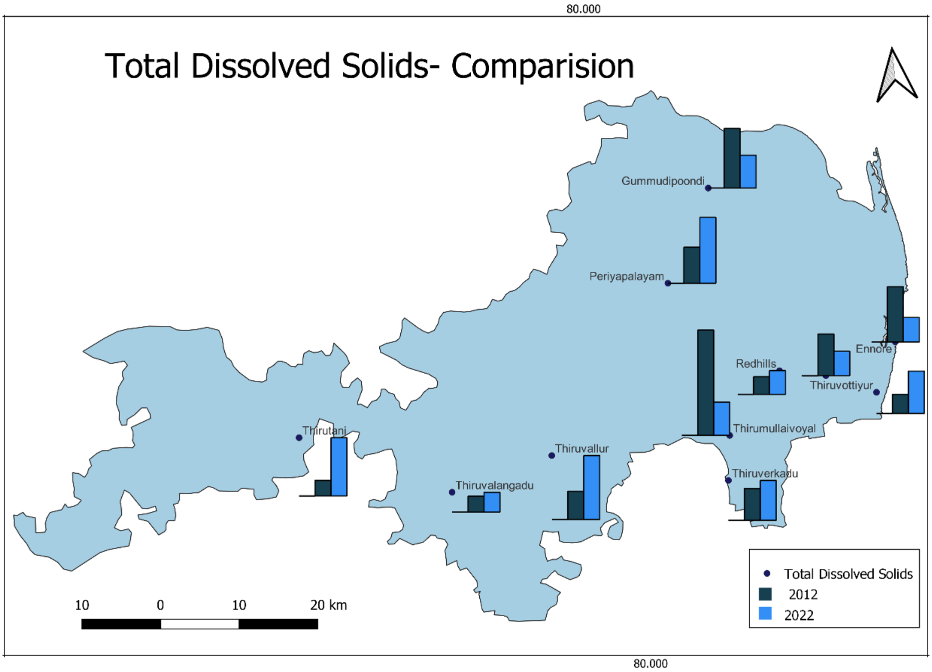

Fig 7: Comparison of Total Dissolved Solids in 2012 and 2022

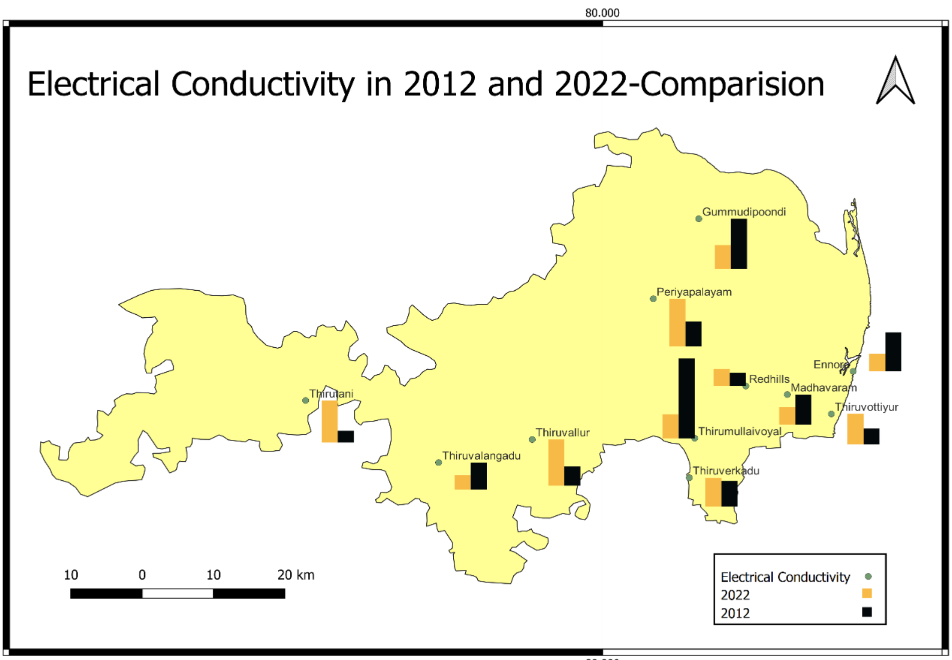

Fig 8: Comparison of Electrical Conductivity in 2012 and 2022

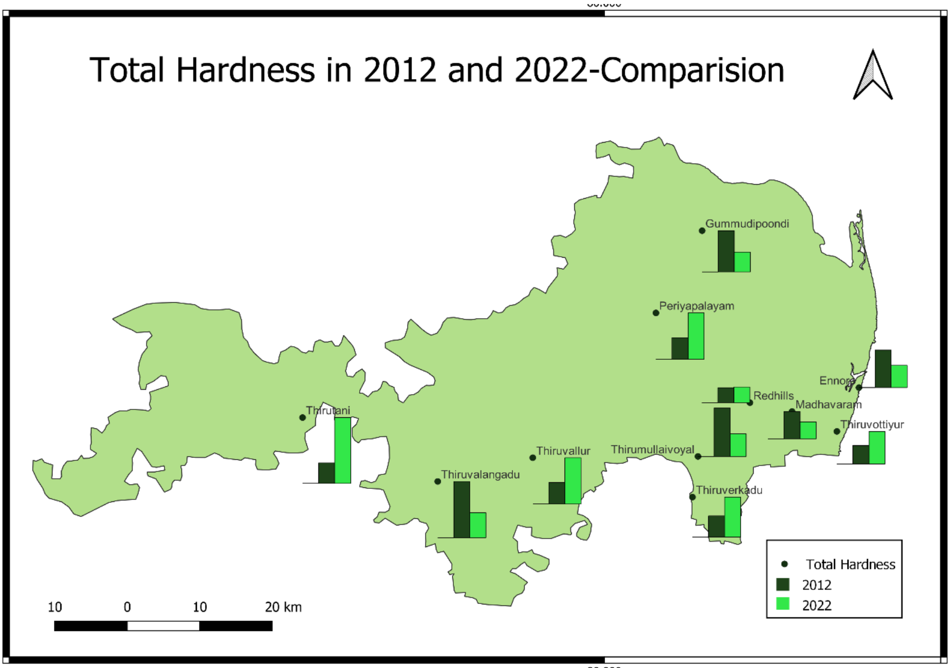

Fig 9: Comparison of Total Hardness in 2012 and 2022

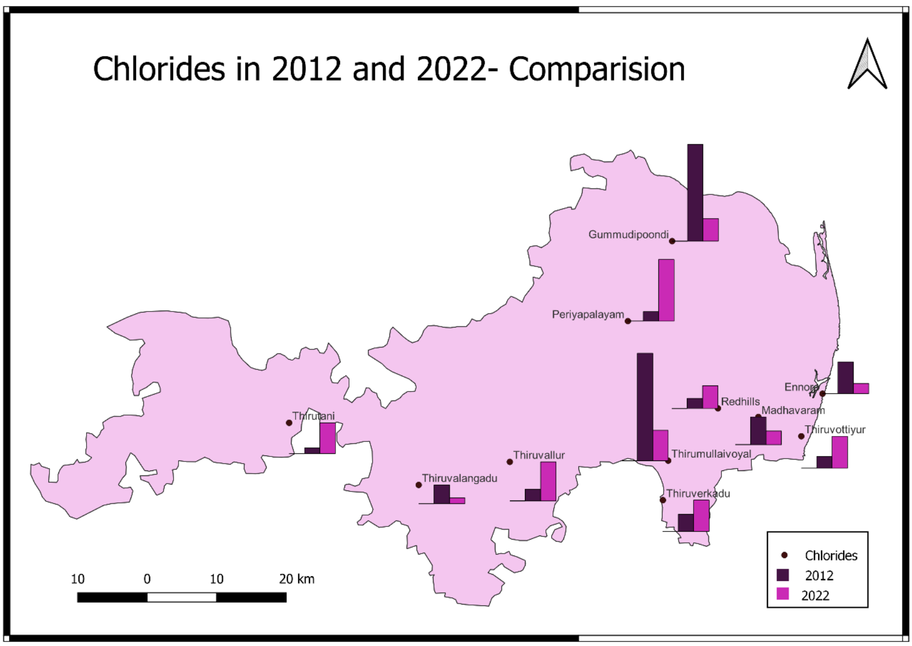

Fig 10: Comparison of Chlorides in 2012 and 2022

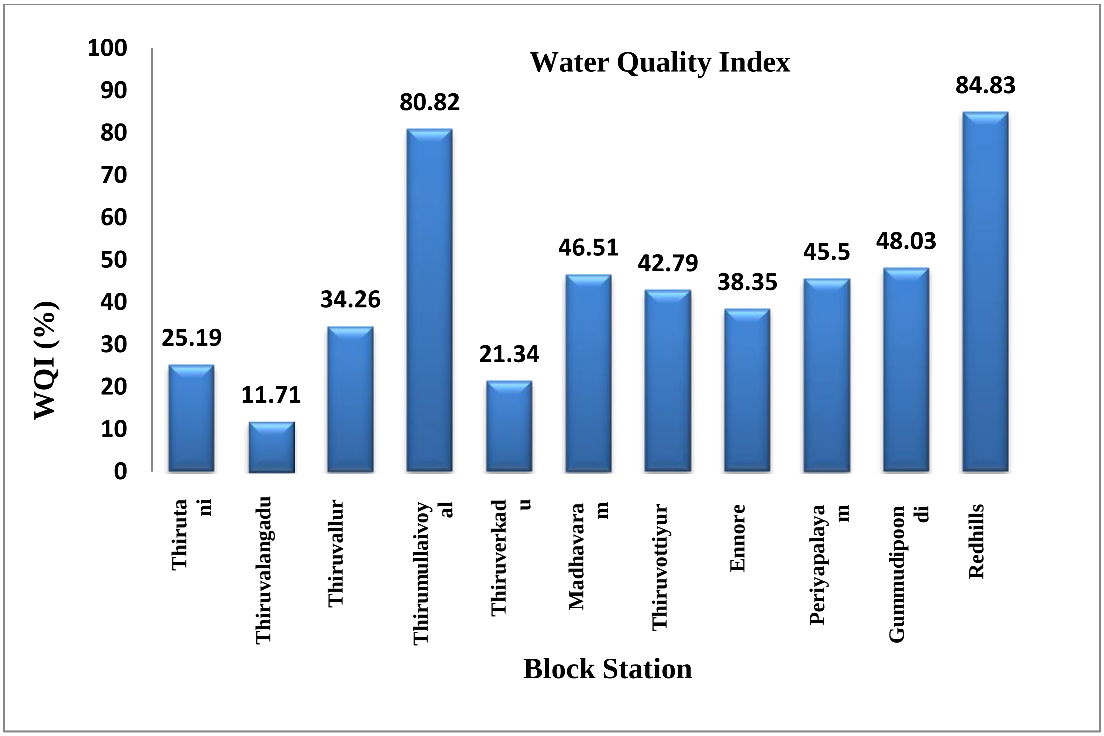

Fig 11: Variation of Water Quality Index in Thiruvallur District

Table 4: Water quality index (WQI) rating and inference of water quality according to BIS

Water quality level	Water Quality status
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for Drinking

Table 5: Results of computed Water quality index and their status of selected groundwater samples in Tiruvallur District

Sl.No	Sample location	Water Quality Index Level	Water Quality Status
1	Thirutani	25.19	Good
2	Thiruvalangadu	11.71	Excellent
3	Thiruvallur	34.26	Good
4	Thirumullaivoyal	80.82	Very poor
5	Thiruverkadu	21.34	Excellent
6	Madhavaram	46.51	Good
7	Thiruvottiyur	42.79	Good
8	Ennore	38.35	Good
9	Periyapalayam	45.50	Good
10	Gummudipoondi	48.03	Good
11	Redhills	84.83	Very poor

6. Conclusions

The study conducted an analysis of 11 specific physicochemical parameters, which were spatially assessed using IDW interpolation. Results revealed that certain areas within the Thiruvallur District exhibit significantly high levels of Conductivity, Total Hardness, and Chloride in groundwater. Consequently, the groundwater quality in these areas is deemed inadequate, failing to meet established standards and guidelines set by BIS for both drinking and domestic use. Addressing groundwater pollution requires effective quantification and management of domestic sewage entering various water bodies. Enhancing natural replenishment capacities and increasing percolation of surface waters into aquifers, identified using GIS tools, can expand the amount of accessible groundwater for abstraction. Preventing sewage leakage from damaged sewers and lining sewer drains is crucial to prevent groundwater contamination. Implementing rainwater harvesting to supplement groundwater resources with collected rainwater is a best practice for maintaining groundwater quality. Continuous monitoring of groundwater table levels, coupled with studies of groundwater quality, can help minimize the likelihood of further deterioration. In conclusion, spatial assessment of groundwater quality is essential for overall evaluation of water management issues in any area, facilitating informed administrative decisions and aiding in the development of comprehensive water management plans.

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