GEO-EYE

RESEARCH ARTICLE

# Spatio-temporal Assessment and Monitoring of Groundwater Quality for Irrigation in Cheyyar Watershed, Tamil Nadu

**J Killivalavan**[1]*, **P Masilamani**[2]

**1** *Research Scholar, Department of Geography, Bharathidasan University, 620 024, Tiruchirappalli, 620 024, Tamil Nadu, India*
**2** *Assistant Professor, Department of Geography, Bharathidasan University, Tiruchirappalli, 620 024, Tamil Nadu, India*

OPEN ACCESS

**Received:** 13.03.2023

**Accepted:** 18.06.2023

**Published:** 25.06.2023

**Citation:** Killivalavan J, Masilamani P. (2023). Spatio-temporal Assessment and Monitoring of Groundwater Quality for Irrigation in Cheyyar Watershed, Tamil Nadu. Geo-Eye. 12(1): 20-27. https://doi.org/10.53989/bu.ge.v12i1.3

* **Corresponding author**.
muralikilli11@gmail.com

**Funding:** Indian Council of Social Science Research Doctoral Fellowship (File No. RFD/2021-22/GEN/GEOG/284)

**Competing Interests:** None



Published By Bangalore University, Bengaluru, Karnataka

**ISSN**
Print: 2347-4246
Electronic: XXXX-XXXX

## Abstract

*Groundwater is the major source of freshwater presence in the globe and supports human life on the earth and it is a critical resource for food security. In India since 1970s and now accounts for over 60 percent of the total area irrigated by groundwater in the country. Around 85% of the rural drinking water supply is also met from groundwater sources. Assessing the suitability of groundwater quality for irrigation is more important in increasing the yield of agricultural crops in an area. The Cheyyar watershed in Tamil Nadu has been selected as the study area to carry out the study since the study area has vast extension of agricultural land. The quality of groundwater in the study area has decreasing trend with respect to time. The total geographical area of the study area is around 2,060 sq.km. To carry out this study, data related to groundwater quality was collected from State Ground and Surface Water Resources Data Center, Tharamani, Chennai, Tamil Nadu for last 20 years (2000 – 2019) and nine parameters were selected to examine the irrigation suitability such as Magnesium Ratio, Sodium Adsorption Ratio, Residual Sodium Carbonate, Total Hardness, Soluble Sodium Percentage, Permeability Index, Total Dissolved Solids, Electrical Conductivity and USSL classifications. The weighted overly analysis has been used to derive the overall quality of groundwater for irrigation.*

**Keywords:** Groundwater quality; Irrigation Suitability; Cheyyar watershed; USSL classifications

## 1. Introduction

Over the world, groundwater is an essential source of water supply[1–5] and generally occurred as much cleaner than surface water. Over time groundwater has been the primary source that influenced humankind to establish several civilizations. Water has the capacity to enable the existence of life. For various purposes, groundwater quality is also important as equal to the quantity of the resources[6]. The geochemistry of the groundwater and the quality of the resources mainly depend upon the subsurface lithology, groundwater flow, types of geochemical reactions in the aquifers, solubility of salts, rainfall pattern, infiltration rate and anthropological activities like agriculture, land use, urbanization, and industrialization[7–10]. India is where most of the population is predominantly dependent upon the agricultural industry. The agro industries have shaped the economic structure, while 89% of the groundwater is used in the irrigation sector. After the Green revolution, the exploitation of groundwater resources for irrigation increased, and the extensive use of chemical fertilizers to boost farm production also increased; however, it will intensively affect water quality[11]. The tremendously increased population has led to pressure on agricultural activities and land use and land cover, which creates a great demand for freshwater resources[12,13]. All these anthropogenic activities have led to the pollution of groundwater resources[14,15]. By analyzing the physio-chemical characteristics, the determination of groundwater suitability for agriculture, domestic and industrial uses can be done[15–20]. It is important to maintain water quality because it is the major factor in the food chain and directly affects human health through the consumption of non-standard drinking water; not only human but also has the potential to damage plant and animal life.

So, to fulfill the basic needs of humankind, the required quality of groundwater should be of a specific standard. Numerous studies have been carried out to measure the quality of groundwater by analyzing different kinds of parameters viz., pH, total dissolved solids, hardness, significant cations ($Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$) and anions ($HCO^{3-}$, $Cl^-$, $NO^{3-}$, $SO_4{}^{2-}$ and $F^-$)[21]. In the irrigation suitability of groundwater, The Geographical Information System (GIS) has a vital role in visualizing the spatial distribution of quality parameters. In assessing groundwater suitability for irrigation purposes, several researchers studied various methods[22–25]. The irrigation suitability of groundwater was calculated with different irrigation suitability indexes viz., Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Hardness (TH), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (Na%), Residual Sodium Carbonate (RSC), Magnesium Ratio (MR), Permeability Index (PI), and USSL diagram for the visual representation of the quality of groundwater.

Cheyyar watershed in Palar Basin has been selected as the study area. In the study area, agriculture is the principal occupation of the people. The excessive use of chemical fertilizers for high-yield crops can pollute the groundwater, damage the quality of groundwater and lead to unsuitable for irrigation purposes. The study aims to evaluate the Groundwater quality and suitability for irrigation purposes in the Cheyyar watershed. The objective of the study is to assess the groundwater quality by collecting the groundwater data from the State ground and surface water data centre, Tharamani, Chennai; to picturise the quality of groundwater by plotting the USSL diagram and the examination of irrigation suitability of groundwater by calculating Total Hardness (TH), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (Na%), Residual Sodium Carbonate (RSC), Magnesium Ratio (MR) and Permeability Index (PI).

## Study Area

Cheyyar Watershed is situated in Palar Basin, which originates from the Jawad hills. The Cheyyar Watershed covers an area of 12°13'3" to 12°38'27" Northern Latitude and 78°40'04" to 79°24'24" Eastern Longitude (Figure 1). Cheyyar Watershed covers a geographical area of 2060 sq.km. The reserve forest in Cheyyar Watershed covers approximately 670 Sq.km. The most dominant type of Geology found in the study area is Charnockite. The predominant soil type in the study area is said to be Black and Red loam. The dominant soil texture found in the study area is calcareous clayey soil.

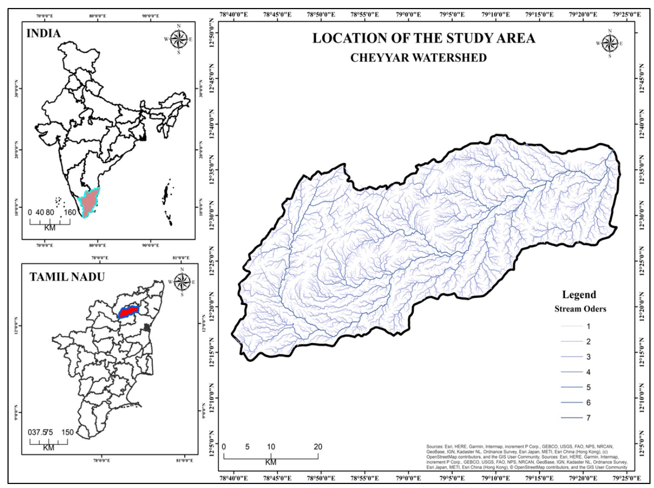


**Fig. 1. Location of the study area**

## 2. Materials and Methods

The study area has been delineated by using ALOS PALSAR DEM and Topographic sheet. To examine the groundwater quality of the study area the groundwater quality data for the year 2000 – 2019 have been collected from state ground and surface water data center, Chennai.

## Irrigation Suitability

The quality of groundwater that influences agriculture productivity is called irrigation groundwater quality. From the major cation (Na, K, Ca, Mg) and Anion ($CO_3$,$HCO_3$,$SO_4$, Cl, $NO_2$, F), the parameters that can influence agriculture productivity have been calculated such as Magnesium Ratio (MR), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Total Hardness (TH), Soluble Sodium Percentage (SSP), Permeability Index (PI), Total Dissolved Solids (TDS), Electrical Conductivity (EC) and USSL classifications to evaluate the irrigation water quality (IWQ)[26–30].

The level of increased concentration of Mg over the concentration of Ca is known as the Magnesium ratio. Usually, the Mg and Ca in the groundwater has some equilibrium in the proportion of 4:1 to 2:1. In case of an increase in the concentration of Mg due to any geogenic or anthropogenic activities that can significantly affect the suitability of irrigation[28,31]. The MR has been calculated by using the Equation (Equation (1)).

$$MR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (1)$$

Continued use of Na, Ca, Mg and $HCO_3$ concentration-rich groundwater for irrigation can significantly reduce the permeability of the soil[26,32]. Soil with low permeability can resist water infiltrating and that can affect the growth of the plant. To quantify the permeability, the PI has been calculated by using the equation (Equation (2)).

$$PI = \frac{(Na + \sqrt{HCO})}{(Ca + Mg + Na)} \times 100 \quad (2)$$

The effect of higher concentrations of $CO_3$ and $HCO_3$ in agriculture can be quantified by using RSC (Equation (3)). The higher amount of RSC can effectively affect the agricultural yield[33,34]. The RSC can be calculated by using the Equation (Equation (3)).

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (3)$$

The Sodium Adsorption Ratio is the measure of relative concentration of Na with respect to Ca and Mg. SAR is the important measure to examine the groundwater quality for irrigation since it represents the sodium hazard of the study area[30,33]. The following equation can be used to examine the SAR (Equation (4)).

$$SAR = \frac{Na^{+}}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \quad (4)$$

The higher concentration of sodium can reduce the permeability and arrest the growth of the plants. All dissolved cations were used to determine the value of SSP using the equation. Higher SSP values represent low irrigation suitability and vice- versa (Equation (5))

$$SSP = \frac{Na^{+} + K^{+}}{Na^{+} + Ca^{2+} + Mg^{2+} + K^{+}} \times 100 \quad (5)$$

Total Hardness (TH) is used to quality the hardness of water with using the concentration of multivalent cations (i.e., calcium and magnesium) in a given water sample[26,35]. TH is examined with using the following equation (Equation (6)).

$$TH = Ca \times 2.497 + Mg \times 4.118 \quad (6)$$

The USSL diagram (USSL, 1954) has been prepared by using the Aqua Chem 4.0. USSL diagram used to examine the sodium and salinity hazard of the study area and it is inevitable for the assessment of irrigation suitability. The spatial distribution maps have been prepared in Arc GIS platform using IDW interpolation method. The concentration and level of each factors have their own influence on agriculture. Based on the influence of each parameter, the weightage ($R_i$) has been assigned (Table 1) from 2 to 10 for low suitability to high suitability respectively. Finally, the IWQ has been examined by integrating the weights of every parameter[36].

**Table 1. Relative weightage of each parameter**

| Parameters | Classes | Weightage ($R_i$) |
|---|---|---|
| USSL Class | Very Good (C1-S1) Good (C2-S1/C1-S2) Moderate (C3-S1/ C4-SI/C2-S2/CI-S3) Poor (C3-S2/C2-S3/C4-S2) Very Poor (C4-S3/C3-S3) | 10 8 6 4 2 |
| Permeability Index (epm) | Suitable ( > 75) Moderately Suitable ( 25 – 75) | 10 8 |
| Magnesium Ratio (epm) | Suitable (0 - 25) Permissible (25 - 50) Doubtful (50- 75) Unsuitable (>75) | 10 6 4 2 |
| Sodium Adsorbtion Ratio (epm) | Excellent (0-5) good (5-10) | 10 8 |
| Residual Sodium Carbonate (epm) | Good (<1.25) Harmful (1.25-2.50) Serious (>2.50) | 10 4 2 |
| Soluble Sodium Percentage (%) | Good (<40) Permissible (40-60) Unsuitable | 10 8 2 |
| Conductivity ($\mu$S/cm) | <750 750-1500 1500-2250 2250-4000 >4000 | 10 8 6 4 2 |
| Total Dissolved Solids (mg/l) | 500 500-2000 2000-3000 | 10 8 6 |
| Total Hardness (mg/l) | 300 300-600 600-900 900-1200 >1200 | 10 8 6 4 2 |

## 3. Results and Discussion

### USSL Classification

For assessing groundwater quality for irrigation purposes, the USSL classification is a significant factor. It will help to

**Table 2. Value ranges of and their respective suitability class**

| Range | Irrigation Suitability Class |
|---|---|
| >75 | Highly Suitable |
| 65-75 | Moderately Suitable |
| 55-65 | Marginally Suitable |
| <55 | Unsuitable |

understand the distribution of SAR and EC over the study region. The sodium hazard is classified as low to very high from S1 to S4 (Figure 2) and the salinity hazard is also classified from low to very high from C1 to C4. The result infers that the salinity hazard is more vulnerable than the sodium hazard. During the study period (2000 – 2019), the overall salinity hazard shifted from medium to high, high to very high. Some samples showed medium to high sodium hazard in the case of sodium hazard. These shifts happened may be due to anthropogenic effluents.

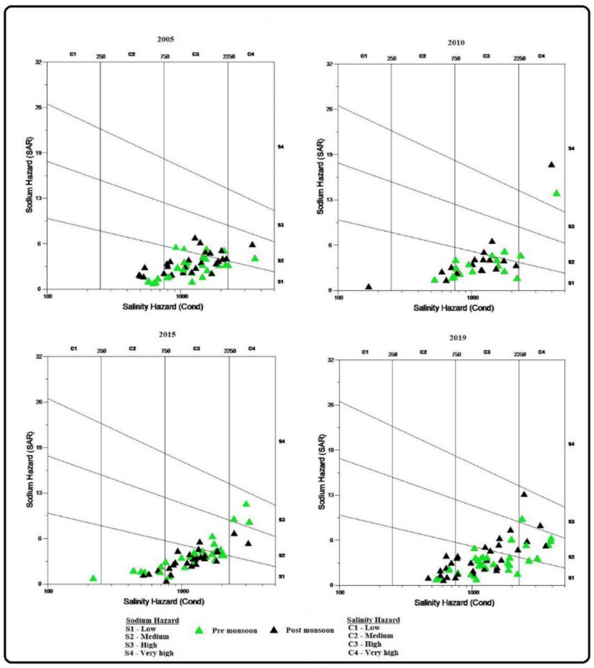


**Fig. 2. USSL Diagram**

## Sodium Adsorption Ratio

The concentration of Calcium and Magnesium is lower than Sodium concentration, and Sodium pollution is very high [36]. The USSL limits have a standard measurement that divides the SAR level into two categories like Excellent (<5epm) and very good (5-10epm). The results (Figure 3) show that the excellent SAR class is dominant over the study area in the studied years, whereas the very good class are scattered in minute portions along the different years.

## Residual Sodium Carbonate

The RSC values are divided into three classes Good (<1.25 epm), Harmful (1.25 – 2.5 epm) and Serious (>2.5 epm) recommended by USSL (1954). The result of RSC shows that the dominant portion of the watershed falls under good RSC class in all the years and during both seasons. Further, the harmful class was high in the year 2005 (Figure 3) and gradually decreased over the years in 2019. In 2015 pre-monsoon disturbance of RSC was a little high and spread over the region and in post-monsoon was highly harmful.

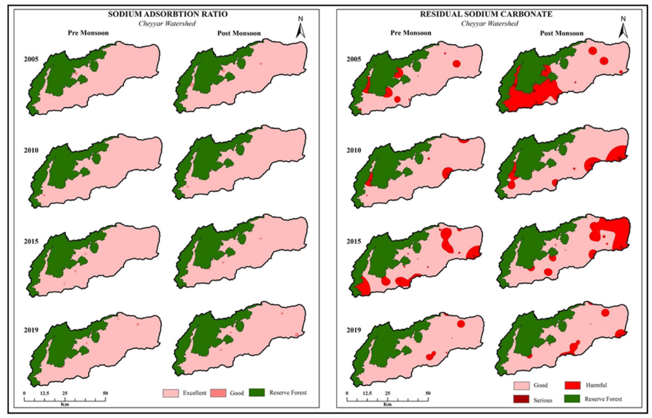


**Fig. 3. Spatial Distribution of SAR and RSC**

## Electrical Conductivity

The EC values of the study area are categorised into four classes excellent, good, poor, and very poor (Figure 4). The result shows that the good EC class covers most of the region in all the years and following this excellent class covers the most. Then the poor class was distributed in minor portions in the years 2005 and 2010. In contrast, in the years 2015 and 2019, the poor EC class have been increased and primarily concentrated in the western portion of the watershed and especially had high distribution in the pre-monsoon season of 2015 and post-monsoon season of 2019.

## Total Dissolved Solids

The TDS values of the study area are divided into excellent, good and poor. The excellent class is the dominant distribution in all the years during both seasons (Figure 4). The good TDS class are present in some minor portions of the study region during 2010 and 2015. But their distribution is high in the pre-monsoon season of 2005 in the eastern portions and both the seasons of 2019 in the western portions. The poor class of TDS are only found in trace amount during the analysed years.

## Magnesium Ratio (MR)

An increase in the magnesium ratio can highly cause the soil and reduce the primary activities severely[31]. A magnesium ratio below 35 ppm is considered to be low and above 350 ppm is considered very high (Figure 5). There were four classes divided Suitable, Unsuitable, Permissible, and Doubtful. In which the doubtful and unsuitable classes were dominant all the years. Notably, in the post-monsoon season of the year 2005 and the pre-monsoon season of the year 2019, almost the entire portion of the study region falls under the unsuitable class of MR class. In pre-monsoon from 2015 to 2019, there was a continuous increase in unsuitable groundwater. But in contrast, during the post-monsoon season, the unsuitable class is gradually decreased and converted to doubtful and suitable water.

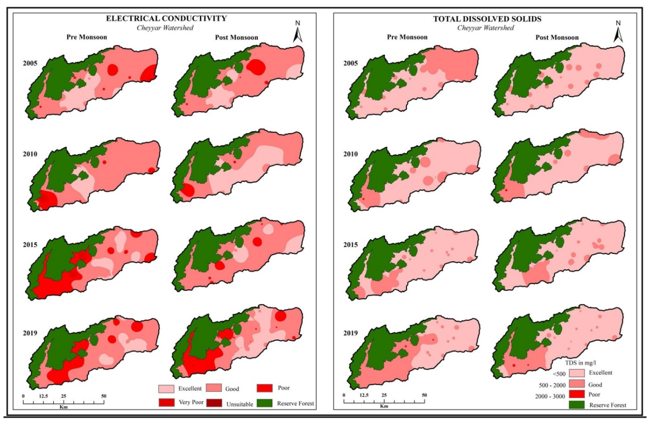


**Fig. 4. Spatial Distribution of EC and TDS**

## Permeability Index (PI)

The PI classes were categorised into 2 Suitable (>75%) and moderately suitable (25-75%) (Figure 5). The Cheyyar watershed the PI falls under the suitable class in all the years (2005, 2010, 2015 & 2019) during both seasons. There are no significant changes in PI values in the analysed years.

## Total Hardness

Total hardness is the quality of the mineral content in the water that is irreversible by boiling. The total hardness is equal to the total sodium and magnesium. TH results (Figure 6) are classified as excellent, good, poor, very poor and unsuitable. The excellent class covers almost 70 % of the area in all the years in both seasons. Then the good quality was distributed in the northeast and southwestern parts from 2005 to 2015 and increased to a larger extent during the pre-monsoon season of 2019. Further, the poor and very poor classes are seen only in central and southern part of Cheyyar watershed throughout the analysed years.

## Soluble Sodium Percentage (SSP)

The SSP is usually classified into three categories Good (<40), Permissible (40-60), and Unsuitable. In the study area, during the analysed year and in both the monsoons, the SSP values of groundwater samples are presiding by unsuitable category in the entire portion of the watershed (Figure 6). This is due to the infiltration of contaminated rainwater into subsurface during monsoonal rainfall.

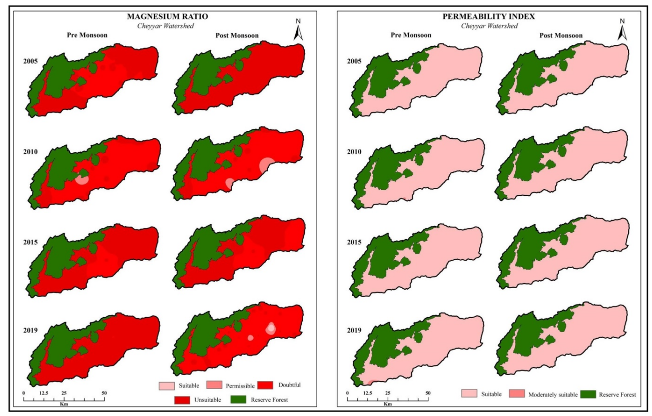


**Fig. 5. Spatial Distribution of MR and PI**

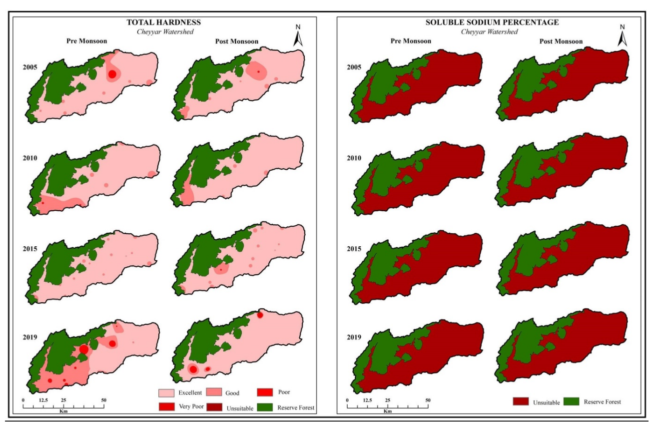


**Fig. 6. Spatial Distribution of TH and SSP**

## Irrigation Suitability

The Irrigation suitability of the Cheyyar watershed is derived for four years (2005, 2010, 2015 and 2019) (Figure 7) using the following factors discussed above. All the factors influencing irrigation suitability are analysed and weighted through weighted overlay analysis for computing the irrigation suitability. The result of Irrigation suitability is categorised into three classes as unsuitable (<55), moderately suitable (65-75), and marginally suitable (55-65) (Table 2). It is inferred that most of the portion of the study region falls under marginally

**Table 3. Percentage of Control wells under Each irrigation Suitability Classes**

| Year | Season | Highly Suitable | Moderately Suitable | Marginally Suitable | Unsuitable |
|---|---|---|---|---|---|
| 2005 | PRM | - | 23.07 | 73.07 | 3.84 |
| | POM | - | 3.84 | 96.15 | - |
| 2010 | PRM | - | 12.5 | 81.25 | 6.25 |
| | POM | - | 25 | 68.75 | 6.25 |
| 2015 | PRM | - | 11.53 | 69.23 | 19.23 |
| | POM | - | 15.38 | 80.76 | 3.84 |
| 2019 | PRM | - | 29.03 | 58.06 | 12.90 |
| | POM | - | 32.25 | 54.83 | 12.90 |

suitable class in all the years. Then the unsuitable class are witnessed only in very minor portions (Table 3). Further the moderately suitable class is changing across the years where it is marked only in minor portions during 2005 to 2015 and is increased to large extent during the year 2019 and is mostly concentrated in the northeastern part of the watershed. The results clearly reveals that the marginally suitable class found during the years 2005 to 2015 are considerably reduced and some portions are converted into unsuitable class during the year 2019 which increased the distribution of unsuitable class from 3.84 in 2005 to 12.90 in 2019. If this condition continues over a longer period, the major portion of the area under marginally suitable class will get converted exponentially into unsuitable class in the future.

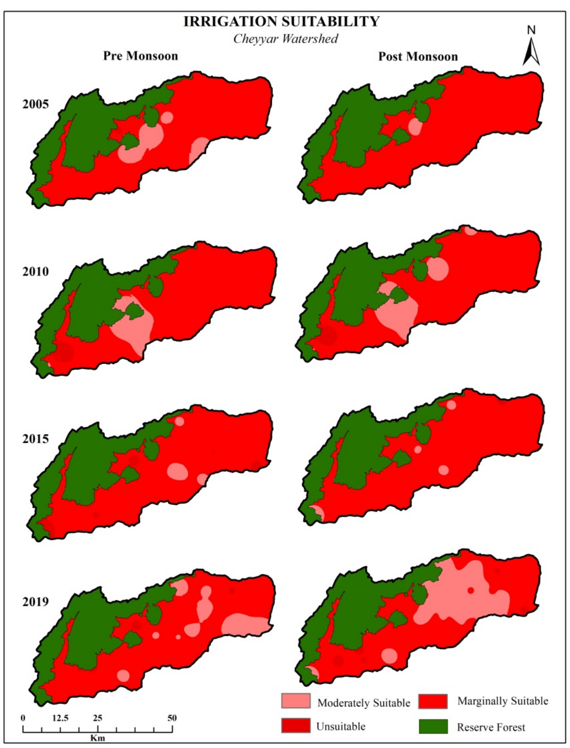


**Fig. 7. Spatial Distribution Irrigation suitability from 2000 to 2019**

## 4. Conclusions

This study focuses on assessing groundwater quality for irrigation suitability over the last two decades. $Na\text{-}Cl\text{-}SO_4$, $Ca\text{-}HCO_3$ and Ca-Cl are the dominant water types that prevail in the study area. The USSL diagram reveals that both the sodium and salinity hazards are getting increase over time. The study area has a vast extension of agricultural land, and the extensive usage of fertilisers and pesticides affects groundwater quality. Improper sewage disposal in the study area directly alters the chemical composition. If this trend continues for a few years about half of the study area will have a very poor quality of water and a few areas have become unsuitable for irrigation. Farmers must want to limit the usage of chemical fertilisers and pesticides to maintain the quality of groundwater. Rainwater harvesting is also a useful method to recover the quality of groundwater. The current study clearly reveals that the groundwater quality of the Cheyyar watershed decreased with respect to time.

## Acknowledgement

JK, is a recipient of Indian Council of Social Science Research Doctoral Fellowship (File No. RFD/2021-22/GEN/GEOG/284). His article is largely an outcome of his doctoral work sponsored by ICSSR. We would like to thank the Department of Geography (UGC-SAP DRS II), Bharathidasan University for providing the essential to carry out the entire work. In addition, thanks to State Ground and Surface Water Data Centre, Tharamani, Chennai for providing the groundwater quality data.

# References


1) Murmu P, Kumar M, Lal D, Sonker I, Singh SK. Delineation of groundwater potential zones using geospatial techniques and analytical hierarchy process in Dumka district, Jharkhand, India. *Groundwater for Sustainable Development*. 2019;9:100239. Available from: https://doi.org/10.1016/j.gsd.2019.100239.
2) Pande CB, Moharir KN, Singh SK, Varade AM. An integrated approach to delineate the groundwater potential zones in Devdari watershed area of Akola district, Maharashtra, Central India. *Environment, Development and Sustainability*. 2020;22(5):4867–4887. Available from: https://doi.org/10.1007/s10668-019-00409-1.
3) Singh S, Singh C, Kumar K, Gupta R, Mukherjee S. Spatial-Temporal Monitoring of Groundwater Using Multivariate Statistical Techniques in Bareilly District of Uttar Pradesh, India. *Journal of Hydrology and Hydromechanics*. 2009;57(1):45–54. Available from: https://sciendo.com/de/article/10.2478/v10098-009-0005-1.
4) Singh SK, Singh CK, Mukherjee S. Impact of land-use and land-cover change on groundwater quality in the Lower Shiwalik hills: a remote sensing and GIS based approach. *Cen Eur J Geosci*. 2010;2:124–131. Available from: https://doi.org/10.2478/v10085-010-0003-x.
5) Singh SK, Srivastava PK, Singh DK, Han D, Gautam SK, Pandey AC. Modeling groundwater quality over a humid subtropical region using numerical indices, earth observation datasets, and X-ray diffraction technique: a case study of Allahabad district, India. *Environmental Geochemistry and Health*. 2015;37(1):157–180. Available from: https://doi.org/10.1007/s10653-014-9638-z.
6) Prasanth SVS, Magesh NS, Jitheshlal KV, Chandrasekar N, Gangadhar K. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. *Applied Water Science*. 2012;2(3):165–175. Available from: https://doi.org/10.1007/s13201-012-0042-5.
7) Ağgca N. Spatial variability of groundwater quality and its suitability for drinking and irrigation in the Amik Plain (South Turkey). *Environmental Earth Sciences*. 2014;72(10):4115–4130. Available from: https://doi.org/10.1007/s12665-014-3305-7.
8) Al-Shaibani AM. Hydrogeology and hydrochemistry of a shallow alluvial aquifer, western Saudi Arabia. *Hydrogeology Journal*. 2008;16(1):155–165. Available from: https://doi.org/10.1007/s10040-007-0220-y.
9) Kouadra R, Demdoum A. Hydrogeochemical characteristics of groundwater and quality assessment for the purposes of drinking and irrigation in Bougaa area, Northeastern Algeria. *Acta Geochimica*. 2020;39(5):642–654. Available from: https://doi.org/10.1007/s11631-019-00393-3.
10) Rao NS, Rao PS, Reddy GV, Nagamani M, Vidyasagar G, Satyanarayana NLVV. Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River Basin, Visakhapatnam District, Andhra Pradesh, India. *Environmental Monitoring and Assessment*. 2012;184(8):5189–5214. Available from: https://doi.org/10.1007/s10661-011-2333-y.
11) Suhag R. Overview of Ground Water in India. PRS. 2016. Available from: https://prsindia.org/files/policy/policy_analytical_reports/1455682937--Overview%2520of%2520Ground%2520Water%2520in%2520India_0.pdf.
12) Amin A, Fazal S, Mujtaba A, Singh SK. Effects of Land Transformation on Water Quality of Dal Lake, Srinagar, India. *Journal of the Indian Society of Remote Sensing*. 2014;42(1):119–128. Available from: https://doi.org/10.1007/s12524-013-0297-9.
13) Singh SK, Singh P, Gautam SK. Appraisal of urban lake water quality through numerical index, multivariate statistics and earth observation data sets. *International Journal of Environmental Science and Technology*. 2016;13(2):445–456. Available from: https://doi.org/10.1007/s13762-015-0850-x.
14) Gautam SK, Maharana C, Sharma D, Singh AK, Tripathi JK, Singh SK. Evaluation of groundwater quality in the Chotanagpur plateau region of the Subarnarekha river basin, Jharkhand State, India. *Sustainability of Water Quality and Ecology*. 2015;6:57–74. Available from: https://doi.org/10.1016/j.swaqe.2015.06.001.
15) Nemčić-Jurec J, Singh SK, Jazbec A, Gautam SK, Kovač I. Hydrochemical investigations of groundwater quality for drinking and irrigational purposes: two case studies of Koprivnica-Križevci County (Croatia) and district Allahabad (India). *Sustainable Water Resources Management*. 2019;5(2):467–490. Available from: https://doi.org/10.1007/s40899-017-0200-x.
16) Gajbhiye S, Singh SK, Sharma SK. Assessing the effects of different land use on water qualify using multi-temporal landsat data. In: Siddiqui AR, Singh PK, editors. Resource Management and Development Strategies: A Geographical Perspective. Allahabad, Uttar Pradesh, India. Pravalika Publication. 2015;p. 337–348.
17) Gautam SK, Singh AK, Tripathi JK, Singh SK, Srivastava PK, Narsimlu B, et al. Appraisal of surface and groundwater of the Subarnarekha River basin, Jharkhand, India: using remote sensing, irrigation indices and statistical techniques. In: Geospatial Technology for Water Resource Applications. CRC Press. 2016;p. 144–169. Available from: https://www.taylorfrancis.com/chapters/edit/10.1201/9781315370989-19/appraisal-surface-groundwater-subarnarekha-river-basin-jharkhand-india-using-remote-sensing-irrigation-indices-statistical-technique.
18) Rawat KS, Jacintha TGA, Singh SK. Hydro-chemical Survey and Quantifying Spatial Variations in Groundwater Quality in Coastal Region of Chennai, Tamilnadu, India – a case study. *Indonesian Journal of Geography*. 2018;50(1):57–69. Available from: https://doi.org/10.22146/ijg.27443.
19) Rawat KS, Jeyakumar L, Singh SK, Tripathi VK. Appraisal of groundwater with special reference to nitrate using statistical index approach. *Groundwater for Sustainable Development*. 2019;8:49–58. Available from: https://doi.org/10.1016/j.gsd.2018.07.006.
20) Singh AK, Patel S, Singh SK. Groundwater quality assessment and its suitability for drinking purposes in Sonbhadra District, U.P. India. In: Tripathi VK, Rakshit A, Chandola VK, Singh RM, Nema AK, Kar SK, editors. Integrated Natural Resources Management the Way Forward. New Delhi, India. New Delhi Publisher. 2018.
21) Rawat KS, Singh SK, Gautam SK. Assessment of groundwater quality for irrigation use: a peninsular case study. *Applied Water Science*. 2018;8(8):1–24. Available from: https://doi.org/10.1007/s13201-018-0866-8.
22) Duan L, Wang W, Sun Y, Zhang C, Sun Y. Hydrogeochemical Characteristics and Health Effects of Iodine in Groundwater in Wei River Basin. *Exposure and Health*. 2020;12(3):369–383. Available from: https://doi.org/10.1007/s12403-020-00348-7.
23) Kükrer S, Mutlu E. Assessment of surface water quality using water quality index and multivariate statistical analyses in Saraydüzü Dam Lake, Turkey. *Environmental Monitoring and Assessment*. 2019;191(2). Available from: https://doi.org/10.1007/s10661-019-7197-6.
24) Kumari M, Rai SC. 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*. 2020;95(2):159–168. Available from: https://doi.org/10.1007/s12594-020-1405-4.
25) Vincy MV, Brilliant R, Pradeepkumar AP. Hydrochemical characterization and quality assessment of groundwater for drinking and irrigation purposes: a case study of Meenachil River Basin, Western Ghats, Kerala, India. *Environmental Monitoring and Assessment*. 2015;187(1). Available from: https://doi.org/10.1007/s10661-014-4217-4.
26) Kamaraj J, Sekar S, Roy PD, Senapathi V, Chung SY, Perumal M, et al. Groundwater pollution index (GPI) and GIS-based appraisal of groundwater quality for drinking and irrigation in coastal aquifers of Tiruchendur, South India. *Environmental Science and Pollution Research*. 2021;28(23):29056–29074. Available from: https://doi.org/10.1007/s11356-021-12702-6.

27) Killivalavan J, Venkatesh R, Thilagaraj P, Lokeshwari J, Rajagopal J, Palanisamy M. Assessment of Groundwater Quality for Drinking and Irrigation: A Case Study of the Kattar Micro-Watershed, Tamil Nadu. In: Climate Change Impact on Groundwater Resources. Springer, Cham. 2022;p. 93–116. Available from: https://doi.org/10.1007/978-3-031-04707-7_6.
28) Singh KK, Tewari G, Kumar S. Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. *Journal of Chemistry*. 2020;2020:1–15. Available from: https://doi.org/10.1155/2020/6924026.
29) Srinivasamoorthy K, Nanthakumar C, Vasanthavigar M, Vijayaraghavan K, Rajivgandhi R, Chidambaram S, et al. Groundwater quality assessment from a hard rock terrain, Salem district of Tamilnadu, India. *Arabian Journal of Geosciences*. 2011;4(1-2):91–102. Available from: https://doi.org/10.1007/s12517-009-0076-7.
30) Vasanthavigar M, Srinivasamoorthy K, Vijayaragavan K, Ganthi RR, Chidambaram S, Anandhan P, et al. Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment*. 2010;171(1-4):595–609. Available from: https://doi.org/10.1007/s10661-009-1302-1.
31) Paliwal KV. Irrigation with saline water;vol. 2 of I.A.R.I. Monograph. Water Technology Centre, Indian Agricultural Research Institute. 1972. Available from: https://books.google.co.in/books/about/Irrigation_with_Saline_Water.html?id=5qoPAQAAIAAJ&redir_esc=y.
32) Doneen LD. Notes on Water Quality in Agriculture. Issue 4001 of Water science and engineering papers;Davis, USA. Department of Water Science and Engineering, University of California. 1964. Available from: https://books.google.co.in/books/about/Notes_on_Water_Quality_in_Agriculture.html?id=nBStYgEACAAJ&redir_esc=y.
33) Richards LA, editor. Diagnosis and Improvement of Saline and Alkaline Soils;vol. 64. U.S. Department of Agriculture. 1954. Available from: https://www.ars.usda.gov/ARSUserFiles/20360500/hb60_pdf/hb60complete.pdf.
34) Siddiqui A, Naseem S, Jalil T. Groundwater Quality Assessment in and Around Kalu Khuhar, Super Highway, Sindh, Pakistan. *Journal of Applied Sciences*. 2005;5(7):1260–1265. Available from: https://doi.org/10.3923/jas.2005.1260.1265.
35) Raghunath HM. Groundwater. New Delhi, India. Wiley Eastern. 1987.
36) Balasubramani K. Application of Geospatial Technologies in Land and Water Resources Evaluation for Sustainable Development of Andipatti Watershed. Tamil Nadu, India. 2015. Available from: https://www.researchgate.net/publication/315697889_APPLICATION_OF_GEOSPATIAL_TECHNOLOGIES_IN_LAND_AND_WATER_RESOURCES_EVALUATION_FOR_SUSTAINABLE_DEVELOPMENT_OF_ANDIPATTI_WATERSHED_TAMIL_NADU_INDIA.