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Delineation and mapping of groundwater quality in Salem district: A comprehensive assessment of contaminant sources

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Abstract

A comprehensive study was conducted at block level in Salem District, Tamil Nadu, India, to evaluate the major ionic chemistry and to assess the suitability of ground water for irrigation purpose. A total of 200 groundwater samples were systematically collected through grid survey and analyzed for major ionic constituents and irrigation water quality parameters. The resulting water quality parameters were interpreted based on established hydrochemical guidelines. The classification of groundwater samples under various quality categories based on pH, electrical conductivity (EC), residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) indicates that many blocks (70 %) in the study area exhibit good-quality groundwater suitable for irrigation. However, exceptions (30 %) were observed in the blocks of Omalur, Mecheri, Kolathur and Pethanaickenpalayam having been observed with saline and alkali water quality. This might be due to the underlying metamorphic and crystalline rocks carrying the element calcium and sodium rich minerals are responsible for the development of saline/alkali groundwater. It was observed that mushrooming of industrial complexes in these blocks might also be the reasons for the development of saline or alkali groundwater. The need for this work is to evaluate groundwater quality for irrigation in Salem District and identify areas affected by saline and alkali contamination due to natural and industrial influences.

Keywords

groundwater quality; saline and alkali contamination; hydrocchemical analysis; water quality classification; ionic chemistry; industrial impact; groundwater contamination mapping; Salem district

Introduction

Water is a fundamental element for agricultural productivity and plays a crucial role in ensuring global food security. Groundwater is particularly vital, supplying approximately 40 % of irrigation water globally and this figure is expected to surpass 50 % in India due to increasing demand and reliance on groundwater resources (1). Globally, millions of farmers depend on groundwater for irrigation, contributing to around 40 % of the world's agricultural output (2). However, the quality of both surface water and groundwater is increasingly deteriorating, which poses a significant challenge to sustainable agricultural practices (3). Understanding hydrochemistry is essential for accurately assessing groundwater quality, especially for irrigation and potable uses. Hydrochemical studies offer valuable insights into the subsurface geological conditions influencing water quality, helping to identify potential contamination sources and trends (4). Comprehensive assessments of groundwater geochemistry have been conducted globally, highlighting various factors affecting water quality, including natural processes and anthropogenic impacts (5, 6).

In India, extensive research has been undertaken to evaluate groundwater quality across many states, providing critical information for water resource management (7, 8). In Tamil Nadu, groundwater quality assessments have been performed in most districts; however, the Salem district remains relatively underexplored (9). Located inland within Tamil Nadu, Salem district is not significantly affected by seawater intrusion, a common issue in coastal regions. Nonetheless, the district faces potential groundwater quality challenges due to industrial activities. The presence of numerous industrial facilities can introduce pollutants, including saline and alkaline effluents, which may degrade groundwater quality (10).

Therefore, a focused assessment of groundwater quality in Salem is imperative to understand its suitability for irrigation and to implement effective management strategies. Addressing groundwater quality in Salem requires a nuanced approach that considers both natural geological factors and industrial influences. Detailed hydrochemical analysis and continuous monitoring are essential to ensure that groundwater resources remain viable for agricultural use and to safeguard long-term water quality.

Materials and Methods

About the Study area

Salem District, established in 1772, is located between 11°14' and 12°53' North Latitude and 77°44' and 78°50' East Longitude. It is bordered by Dharmapuri, Trichy, Namakkal, Kallakurichi, Perambalur, Erode and Karnataka. The district comprises 20 blocks: Salem, Gangavalli, Thalaivasal, Attur, Pethanaickenpalayam, Valappady, Ayothiyapattinam, Yercaud, Panamarathupatty, Veerapandi, Edappadi, Sankari, Kadayampatti, Kolathur, Konganapuram, Magudanchavadi, Mecheri, Nangavalli, Omalur and Tharamangalam.The district experiences a warm climate, with temperatures reaching up to 39.8°C in May and dropping to 16.7°C in December. It receives an average annual rainfall of 979.9 mm. Agriculture is crucial, with 30 % of the population engaged in farming. The district's soils include red, black, alluvial and loamy types. These support crops such as turmeric, tapioca, cotton and paddy. Groundwater is essential for irrigation but faces issues from over-extraction, pollution and climate change. This study utilizes GIS technology to assess groundwater quality. It aims to create a quality map and propose conservation measures.

Ground water sampling locations

The bore /tube well samples around 200 were collected across 20 blocks of Salem district, during February -March 2024, via a grid survey with intervals of approximately 10 sq. km between two sampling points in different blocks of Salem district, Tamil Nadu. The locations of the sample sites were recorded via a portable GPS receiver (Garmin GPS). The samples were collected in clean polyethylene bottles. To evaluate the quality of the irrigation water, laboratory analyses were conducted following standard analytical techniques. The samples were tested for pH, electrical conductivity, cations (Ca^{2+} and Mg^{2+} using the versenate method), anions (CO_3^{2-}, HCO_3^- and Cl- using the titrimetric method), K^+ and Na^+ (using flame photometry) and SO_4^{2-} (using turbidimetry), according to the protocol outlined by Richards (11).

Versenate method: The Versenate method measures the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a sample using EDTA in a complexometric titration. The sample is adjusted to a pH of about 10, ensuring the metal ions are in their free ionic state. Eriochrome Black T is introduced as an indicator, forming a red complex with the Ca^{2+} and Mg^{2+} ions. EDTA is titrated into the solution, binding the metal ions and causing the red color to fade at the endpoint. The amount of EDTA used is then used to determine the concentration of the metal ions (12).

Titrimetric method: The titrimetric method is employed to measure the concentrations of carbonate (CO_3^{2-}), bicarbonate (HCO_3-) and chloride (Cl-) ions in a sample. Carbonate ions are titrated with a standard acid and the endpoint is reached when all carbonate is converted to carbonic acid. Bicarbonate is titrated similarly, with the endpoint occurring when it forms carbonic acid, which then decomposes to CO_2. Chloride ions are measured by titrating with silver nitrate ($AgNO_3$), with the endpoint signaled by forming a white silver chloride precipitate. The amount of titrant used allows for the calculation of ion concentrations (12).

Flame photometry: Flame photometry measures the concentrations of potassium (K^+) and sodium (Na^+) ions by analyzing their characteristic emission spectra. When the sample is introduced into a flame, the ions emit light at specific wavelengths - violet for potassium and yellow for sodium. The intensity of the emitted light is measured and compared to standard solutions with known concentrations. This intensity correlates with the ion concentrations in the sample. The concentrations of K^+ and Na^+ are determined using a calibration curve based on the emission intensities (13).

Turbidimetry: Turbidimetry is used to measure sulfate (SO_4^{2-}) concentration by assessing the turbidity formed when sulfate reacts with barium chloride ($BaCl_2$). Barium sulfate ($BaSO_4$) precipitates, causing the solution to become cloudy. The intensity of this turbidity is measured with a photometer, which correlates with the sulfate concentration. A calibration curve from standard solutions allows the determination of the sulfate level. This method is quick, simple and effective for sulfate analysis. (14)

Water quality parameters, including Sodium Adsorption Ratio (SAR) (1) and Residual Sodium Carbonate (RSC) (2), were calculated based on concentrations of cations and anions. The formulas used are as follows:

SAR= Na+/√ (Ca2+ + Mg2+)/2 (1)

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

The Central Soil Salinity Research Institute (CSSRI) in Karnal evaluated groundwater samples for irrigation suitability using EC, SAR and RSC values (Table 1). Based on the CSSRI water quality classification, thematic maps of groundwater quality in Salem district were created with ArcGIS software. The ArcGIS Geostatistical Analyst technique was used to generate

Table 1. Grouping of poor-quality groundwater for irrigation in India

Water quality	EC_{iw} (dS/m)	SAR_{iw} (m mol/L)	RSC (meq/L)
A. Good	<2	<10	<2.5
B. Saline			
Marginal saline	2-4	<10	<2.5
Saline	>4	<10	<2.5
High SAR saline	>4	>10	<2.5
C. Alkali water			
Marginally alkali	<4	<10	2.5-4.0
Alkali	<4	<10	>4
Highly alkali	Variable	>10	>4

various thematic maps and ArcGIS Spatial Analyst was used to produce the final groundwater quality map. The inverse distance weighting (IDW) interpolation technique was employed to determine the spatial distribution of groundwater quality parameters (15).

Results and Discussion

The groundwater samples from various blocks of the Salem district were analyzed to determine their suitability for irrigation. Out of 200 samples collected from 20 blocks, 66.5 % were found to be of good quality, 20.5 % were saline and 13 % were alkali (Fig 1). Among 20 blocks of Salem district, four block viz Omalur, Mecheri, Kolathur and Pethanaickenpalayam were affected by high levels of salinity and alkalinity water.

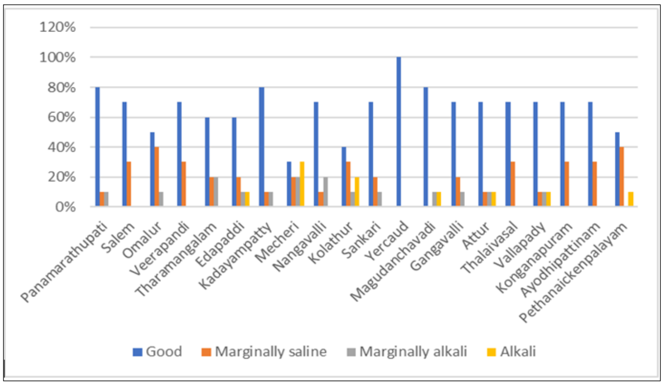

Fig. 1. Percentage distribution of groundwater quality in various blocks of Salem district.

Omalur block:

Omalur Block features a diverse terrain comprising fertile plains and rocky regions, shaped by local geological formations. The block encounters issues with water management, soil quality and the influence of geological factors on agricultural output. Analysis of ten water samples from Omalur Block revealed that 50 % were of good quality, 40 % were saline and 10 % were alkaline (Fig 2). Additionally, 50 % of the samples exhibited elevated levels of alkalinity and salinity (Fig 3). The area's geological composition includes crystalline rocks, which contribute calcium and sodium minerals to the groundwater. Furthermore, the improper disposal of untreated or inadequately treated sewage and wastewater can introduce contaminants, exacerbating issues of salinity and alkalinity.

In contrast, the Omalur block exhibited a predominance of saline water, with 45 % of its samples showing high salinity levels. This suggests that groundwater in Omalur may be less suitable for irrigation, potentially impacting crop growth and yield due to the adverse effects of high salt concentrations.

Mecheri block:

Mecheri block's topography and soil types are shaped by the local geological formations, which include metamorphic and crystalline rocks. These geological features influence water resources and agricultural productivity in the area. The block faces significant challenges with water management and soil quality, including issues with salinity and soil fertility that impact agricultural yields. Analysis of ten water samples from Mecheri Block showed that 30 % were of good quality, 20 % were saline and 50 % were alkaline (Fig 2). Furthermore, 70 % of the samples exhibited elevated levels of alkalinity and salinity (Fig 3). Inefficient irrigation practices, such as over-irrigation and inadequate drainage, contribute to salt accumulation in the soil. As water evaporates, it leaves behind salts, which build up over time and the use of saline or brackish water for irrigation exacerbates soil salinity.

Kolathur block:

Kolathur Block features a varied landscape with both cultivable land and areas shaped by local geological formations. The block faces challenges related to water management and soil quality, which affect agricultural productivity. Improving irrigation systems and managing groundwater resources are essential for enhancing agricultural output and sustainability in Kolathur Block. Analysis of ten water samples from Kolathur Block revealed that 40 % were of good quality, 30 % were saline and 30 % were alkaline (Fig 2). Additionally, 60 % of the samples showed increased levels of alkalinity and salinity (Fig 3). The geological formations in Kolathur Block primarily consist of hard rock types, including granite, gneiss and metamorphic rocks, which influence groundwater occurrence and movement.

Pethanaickenpalayam block:

Pethanaickenpalayam Block features a diverse topography with both flat and undulating terrain, shaped by the underlying metamorphic and crystalline rock formations. The block encounters significant challenges related to soil salinity and water management, which can affect agricultural productivity. Analysis of ten water samples from Pethanaickenpalayam Block showed that 50 % were of good quality, 40 % were saline and 10 % were alkaline (Fig 2). Furthermore, 50 % of the samples exhibited elevated levels of alkalinity and salinity (Fig 3). Salinity issues in this block arise from a combination of natural and

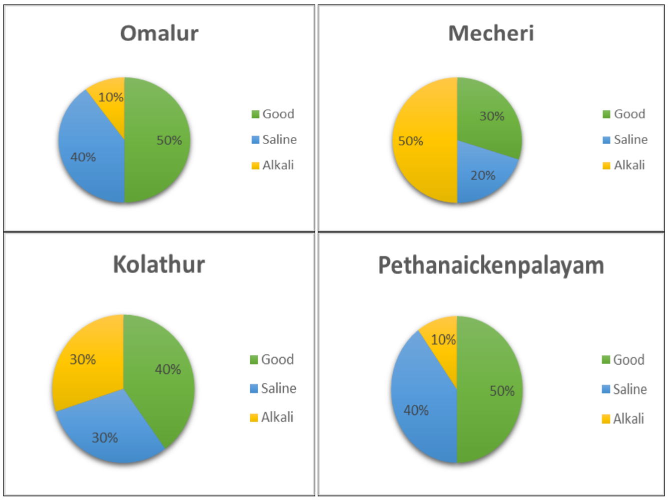

Fig. 2. Percentage distribution of groundwater quality in different blocks of Salem district.

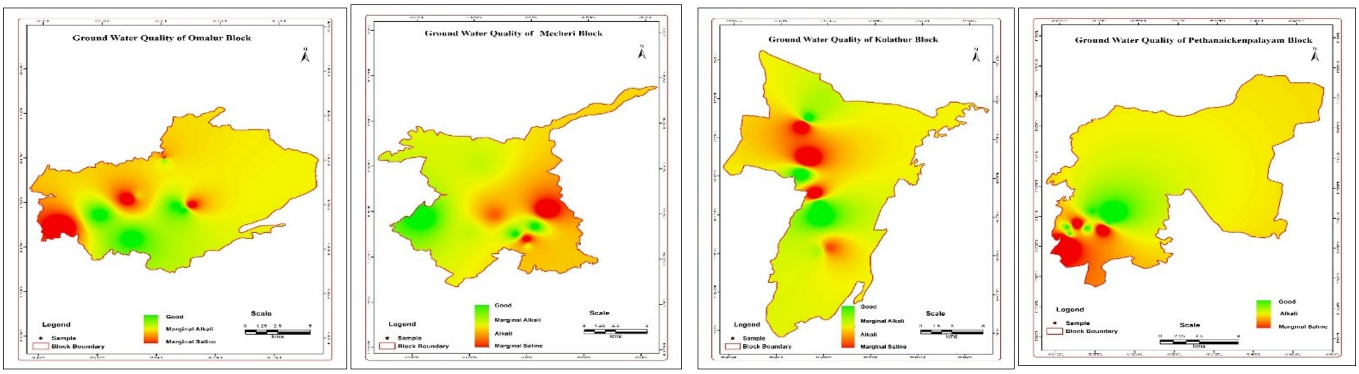

Fig. 3. Spatial distribution mapping of poor-quality groundwater in Salem district.

anthropogenic factors. The presence of saline or brackish groundwater can exacerbate soil salinity through capillary rise, where saline water ascends from the groundwater table to the surface.

Among the 20 blocks in Salem District, Yercaud block was notable for having 100 % of its groundwater samples classified as good quality for irrigation purposes. This indicates that the groundwater in Yercaud is well-suited for agricultural use without significant concerns of salinity or alkalinity. The Mecheri and Kolathur blocks had significant issues with alkali water, with 30 % of Mecheri's samples and 20 % of Kolathur's samples classified as alkali. Alkali water can affect soil pH and nutrient availability, posing challenges for effective crop management and soil health.

Seawater intrusion in the blocks:

Seawater intrusion is not a risk for Salem District due to its inland location within Tamil Nadu. This conclusion is supported by a thorough evaluation of groundwater samples from different blocks in the district, using established criteria for identifying seawater intrusion (Table 2 & 3). The assessment involved analyzing the chemical composition of the groundwater to detect any signs of saline contamination typically associated with seawater intrusion. The results consistently indicated no evidence of such contamination, reinforcing the absence of seawater intrusion in the district's groundwater resources. This finding is critical for managing water quality and ensuring the sustainability of local agricultural practices, as it rules out one of the common sources of salinity affecting groundwater in coastal regions.

Conservation Strategies for Poor-Quality Irrigation water in Salem District

Mixing of good-quality water with saline or alkali groundwater, to acceptable level of water quality for various crops, is also useful in reducing salt stress. Cyclic use of good canal water along with saline/alkali groundwater is also recommended. Table 1 provides the Indian Council of Agricultural Research-Central Soil Salinity Research Institute, Karnal guidelines related to saline water use. Table 4 shows soil and crop management options for poor groundwater quality of Omalur, Mecheri, Kolathur and Pethanaickenpalayam in Salem district. Table 5 shows the crop varieties suitable for saline environment. Thus, it is possible to use saline groundwater with scientific management of soil, crop and irrigation.

The general cation abundance in the district's irrigation water follows the sequence: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. This indicates that calcium is the most prevalent cation, followed by magnesium, sodium and potassium. For anions, the order is $HCO_3 > Cl^- > SO_4^{2-}$, suggesting that bicarbonate is the most common anion, with chloride and sulfate following. In samples with good irrigation water quality (EC > 2 dS m^{-1}), the anion and

Table 2. Seawater intrusion values of different blocks of Salem district

Blocks	$Cl^- / (CO_3^{2-} + HCO_3^-)$	Na^+ / Cl^-	Cl^- / HCO_3^-
Omalur	Majority of samples between 0.05 to 1.30	Majority of samples between >1	Majority of samples between >1
Mecheri	Majority of samples between 0.05 to 1.30	Majority of samples between >1	Majority of samples between >1
Kolathur	Majority of samples between 0.05 to 1.30	Majority of samples between >1	Majority of samples between >1
Pethanaickenpalayam	Majority of samples between 0.05 to 1.30	Majority of samples between >1	Majority of samples between >1

Table 3. Indices and Criteria for detection of seawater intrusion in groundwater samples

S. No	Parameters	Critical limit	References
		Ionic Ratios	
1.	$Cl^- / (CO_3^{2-} + HCO_3^-)$	0.05 -Fresh groundwater 0.05 to 1.30 - Slightly contaminated groundwater 1.30 to 2.80 - Moderately contaminated groundwater 2.80 to 6.60 - Injuriously contaminated groundwater 6.6 to 15.5 - Near seawater >20.0- Seawater	(16)
2.	Na^+ / Cl^-	<0.86- salinity due to seawater intrusion 0.86 -1.0 - Fresh groundwater >1-anthropogenic activities	(17)
3.	Cl^- / HCO_3^-	> 1- seawater intrusion	(19)
4.	$Cl^- > Na^+$	Seawater intrusion	(18)

Table 4. Soil and crop management options for poor quality groundwater

Source: (15)

Groundwater quality	Marginally saline	Marginally saline to saline
Crop management	Salt-tolerant crops like vettiver, pearl millet and cashew Salt tolerant varieties 25 % more seed as well as fertilizer recommendations	Salt-tolerant crops 25 % more seed as well as fertilizer recommendations
Soil management	Gypsum application; green manuring along with in situ' ploughing	Gypsum application; green manuring along with in situ' ploughing
Soil and water conservation	Leaching of surface soil and draining Laying of subsurface drainage pipes with coir pith-wrapped perforated holes Laying out of slotted pipes using well-logging techniques	Mixing bore water with good-quality water

Table 5. Crop varieties for cultivation in saline environment

Crop	Cultivar
Wheat	Raj 2325, Raj 2560, Raj 3077, WH 157
Pearl millet	MH269, 331, 427, HHB-60
Mustard	Pusa Bold, CS52, CS54, CS56, CS58, CS60
Cotton	DHY 286, CPD 404, G 17060, GA, JK276-10-5, GDH 9, G. Cot-23
Safflower	HUS 305, A-1, Bhima
Sorghum	SPV-475, 881, 678, 669, CSH 11
Barley	Ratna, RL345, RD103, 137, K169

Source: (15)

cation distribution typically align with the observed order: $Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2-}$ and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, respectively. This pattern reflects the general ionic composition and quality of the irrigation water in Salem District, with chloride being the most dominant anion and sodium the most prevalent cation.

These variations in ion composition are influenced by the electrical conductivity (EC) range of the water samples. High EC values often correlate with higher concentrations of dissolved salts, which can contribute to the observed patterns in ion distribution. The differences in water quality among the blocks highlight the need for tailored water management strategies to address the specific challenges posed by saline or alkaline conditions and to ensure sustainable agricultural practices.

Conclusion

The current study highlights salinity as a critical issue affecting groundwater quality in Salem District. To mitigate this problem, it is crucial to adopt effective management practices for both irrigation water and soil. The research findings indicate that seawater intrusion is not a concern in the district, as evidenced by the seawater intrusion indices and ionic ratios. This conclusion provides a basis for focusing on alternative strategies to manage salinity and improve water quality, such as optimizing irrigation practices and implementing soil conservation measures. Addressing these issues will be essential for enhancing agricultural productivity and ensuring sustainable water use in the region.

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Authors' contributions

All authors have made substantial contributions to the conception, design, analysis and interpretation of data for the work. TR and SJR have contributed to drafting or revising the manuscript critically for important intellectual content. All other authors BM, RS and NM gave final approval of the version to be published and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

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During the preparation of this work the author(s) used ChatGPT to paraphrase the content. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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