Assessing Hydrogeochemical Dynamics And Seasonal Variations Of Groundwater Quality In The Kovilpatti Region: Implications For Sustainable Water Management And Irrigation Practices

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Abstract

This study examines groundwater quality in the Kovilpatti region, Tamil Nadu, during the pre-monsoon and post-monsoon seasons of 2023 using spatial analysis and hydrogeochemical plots. Key water quality parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), and concentrations of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-), were analyzed. The pre-monsoon season revealed elevated levels of TDS, Mg, Ca, and Cl, often exceeding WHO standards, suggesting potential health risks and the influence of prolonged rock water interactions and evaporation processes. Post-monsoon samples showed improvement due to rainwater recharge, although TDS and Mg levels remained high. Hydrogeochemical plots, including Piper and Gibbs diagrams, indicate a dominance of alkaline earth metals (Ca^{2+} and Mg^{2+}) and strong acids (Cl^- and SO_4^{2-}) in both seasons. The Wilcox diagram highlights potential risks for agricultural use due to high salinity and sodium content. Water quality indices reveal significant seasonal variations, with pre-monsoon samples showing higher Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) values, posing risks to soil structure and permeability. Post-monsoon conditions reflect a reduction in these risks, indicating an overall improvement in water quality. This study underscores the need for continuous groundwater monitoring and sustainable water management practices in the Kovilpatti region to mitigate contamination risks and ensure safe drinking water, while also supporting sustainable agricultural practices.

1. Introduction

Groundwater quality assessment has become a crucial part of ensuring sustainable water resources for drinking and irrigation. Sivakumar et al. (2023) employed GIS-based hydro-chemical and health risk studies in Kovilpatti Taluk, Tamil Nadu, highlighting the importance of GIS tools in evaluating groundwater sustainability for drinking and agricultural purposes. Similarly, Selvam et al. (2024) assessed water quality changes in the Thamirabarani River, employing hydrochemical and environmental isotopes (HFE-D studies) to understand temporal changes and their implications on water management. In coastal regions, hydrochemical characteristics significantly influence groundwater quality. Singaraja et al. (2014) investigated groundwater hydrochemistry in Thoothukudi district, identifying the repercussions on water quality due to natural and anthropogenic factors. Additionally, Selvam et al. (2013) conducted a GIS-based assessment in the coastal aquifers of

Tuticorin, illustrating the integration of spatial analysis with hydrochemical data to evaluate water quality. Studies have also focused on the spatial and temporal variability of groundwater quality. Lanjwani et al. (2021) analyzed the hydrogeochemical characteristics of groundwater in Larkana, Sindh, Pakistan, and demonstrating significant spatial variability. Sarkar and Shekhar (2015) studied the controls on the spatial and temporal variations of hydrochemical facies in South West District, Delhi, underscoring the complex interaction between geology and human activities. Integrated approaches combining various analytical techniques have been pivotal in groundwater studies. Mohamed et al. (2022) used water quality index, multivariate statistics, and GIS to assess the spatio-temporal variation in groundwater hydrochemistry in Arba Minch Town, Ethiopia. Khokhar et al. (2023) employed similar techniques to analyze the spatial variability and hydrochemical quality in Hyderabad Rural, Sindh, Pakistan. The application of multivariate statistical analyses has provided deeper insights into groundwater quality. Silva and Lima (2023) applied multivariate statistics in a semi-arid basin to understand the hydrogeochemistry under increasing exploitation. Owoyemi et al. (2019) and Dashora et al. (2022) used similar techniques to evaluate groundwater quality in Delta State, Nigeria, and a desertic region in India, respectively. Understanding seasonal variations is crucial for effective water management. Aksever and Büyükşahin (2017) and Addis (2023) explored seasonal changes in water quality, using statistical techniques to identify patterns and impacts. Wagh et al. (2019) developed a Water Quality Index (WQI) model to study groundwater hydrochemistry and drinking suitability in the Kadava river basin, India, emphasizing the influence of seasonal variations. Geospatial techniques have proven effective in groundwater studies. Selvam et al. (2018) and Selvam et al. (2017) utilized graphical and numerical methods alongside GIS to evaluate groundwater quality in Tuticorin and Ottapidaram Taluk, Tamil Nadu. Palaniselvan et al. (2024) applied similar techniques to assess water quality in the Tuticorin district, underscoring the utility of geospatial tools in regional water quality assessment. Several studies have focused on specific regions to provide localized insights. Duraisamy et al. (2019) characterized groundwater in Kangayam taluk, Tirupur district, using GIS techniques, while Sajil Kumar (2020) assessed pollution sources in the lower Bhavani River basin. Katla et al. (2021) and Lalitha et al. (2021) conducted hydrogeochemical characterizations in Southern Telangana and the Cauvery deltaic plains, respectively, illustrating regional differences in groundwater quality. Recent methodological advances have furthered groundwater research. Ramachandran et al. (2021) identified potable groundwater zones using WQI and GIS techniques in the Adyar River basin, Chennai. Sakthivel and Manjula (2022) used geo-statistical approaches to study groundwater quality in the Tuticorin coastal region, highlighting the importance of advanced statistical methods. Assessing seasonal and temporal changes is vital for comprehensive groundwater management. Venkatesan et al. (2022) evaluated seasonal variations in groundwater quality in the Salem region, while Hassan and Ersoy (2022) focused on Çarşamba coastal plain, Samsun, Turkey, illustrating the widespread interest in understanding seasonal impacts on groundwater. Studies by Sahu et al. (2018) and Singh et al. (2023) in Raebareli District and central Punjab, India, respectively, further emphasize the importance of temporal assessments. Global perspectives on groundwater quality have been enriched by studies in diverse geographical settings. Chinedu et al. (2024) assessed groundwater quality in the vicinity of dumpsites in Southeastern Nigeria, while Oki and Ombu (2017) evaluated seasonal variation impacts in Yenagoa, Niger Delta, Nigeria. Tum et al. (2023) investigated seasonal changes in groundwater quality in northern Japan, contributing to the global understanding of groundwater dynamics.

2. Study Area

The study area is the Kovilpatti region, located in the southern part of Tamil Nadu, India (**Fig. 1**). This region encompasses a diverse landscape characterized by agricultural fields, rural settlements, and varying geological formations. The Kovilpatti area is particularly significant for assessing water quality due to its reliance on groundwater resources for agricultural and domestic use. The region experiences distinct seasonal variations, including pre-monsoon and post-monsoon periods, which influence water quality parameters such as pH, electrical conductivity, total dissolved solids, and major ion concentrations. The hydrological and geochemical characteristics of the Kovilpatti region make it an ideal location for studying the impact of seasonal changes on water quality and understanding the implications for water resource management. The geological formation is predominantly consisting of metamorphic rocks like gneisses and granites. This geological setting significantly influences the region groundwater chemistry (**Fig. 2**). The groundwater often exhibits elevated levels of calcium and magnesium due to the weathering of feldspar minerals. Sodium, chloride, and bicarbonates are also present, contributing to the water hardness (Sivakumar et al, 2023). Quality issues such as high fluoride concentrations and potential nitrate contamination from agricultural runoff are notable concerns. Due to the limited and localized nature of the aquifers in this hard rock terrain, effective groundwater management and regular quality monitoring are crucial to ensure safe and sustainable water resources for this region.

3. Methodology

In the Kovilpatti region, a comprehensive methodology was employed to evaluate water quality by analyzing 50 water samples collected during both pre-monsoon and post-monsoon periods in 2023. The analysis focused on key parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO_4), and bicarbonate (HCO_3). Hydrogeochemical evaluation utilized Aquachem software to generate Piper, Ternary, and Wilcox diagrams, which facilitated the interpretation of major ion compositions and their implications for water quality, including general water type, ion dominance, and irrigation suitability. Spatial analysis in ArcGIS included the creation of spatial distribution maps to visualize the variation of water quality parameters across the study area and the application of Gibbs plots to understand the influence of rock-water interactions on water chemistry. The data were interpreted to assess water quality indices such as Sodium Adsorption Ratio (SAR), Sodium percentage (%Na), and Residual Sodium Carbonate (RSC), with seasonal variations and spatial patterns analyzed to identify areas of concern and guide water management practices.

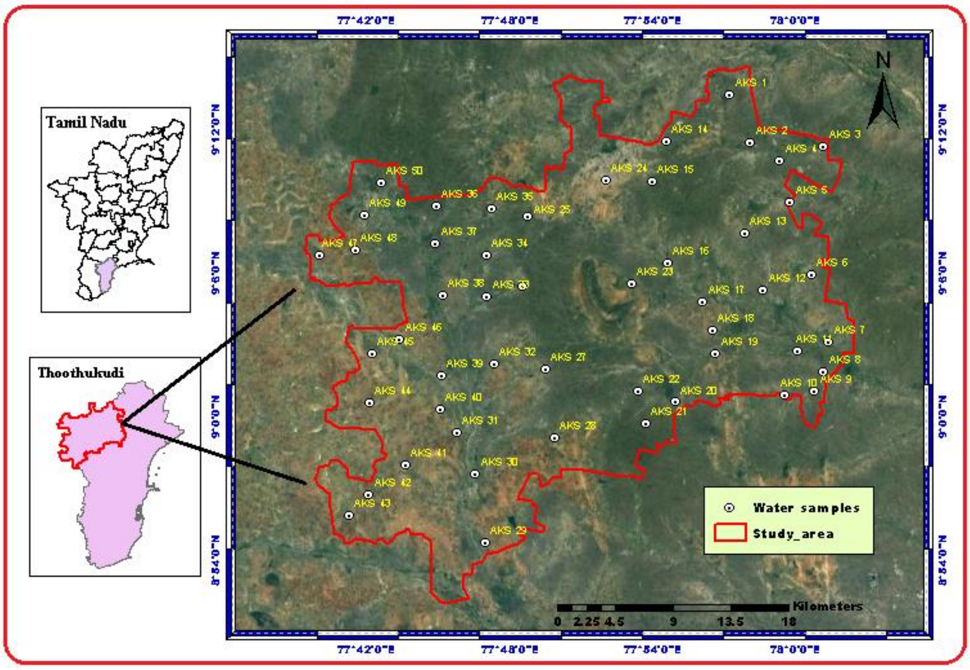

Fig. 1 Water sample location map of the study area

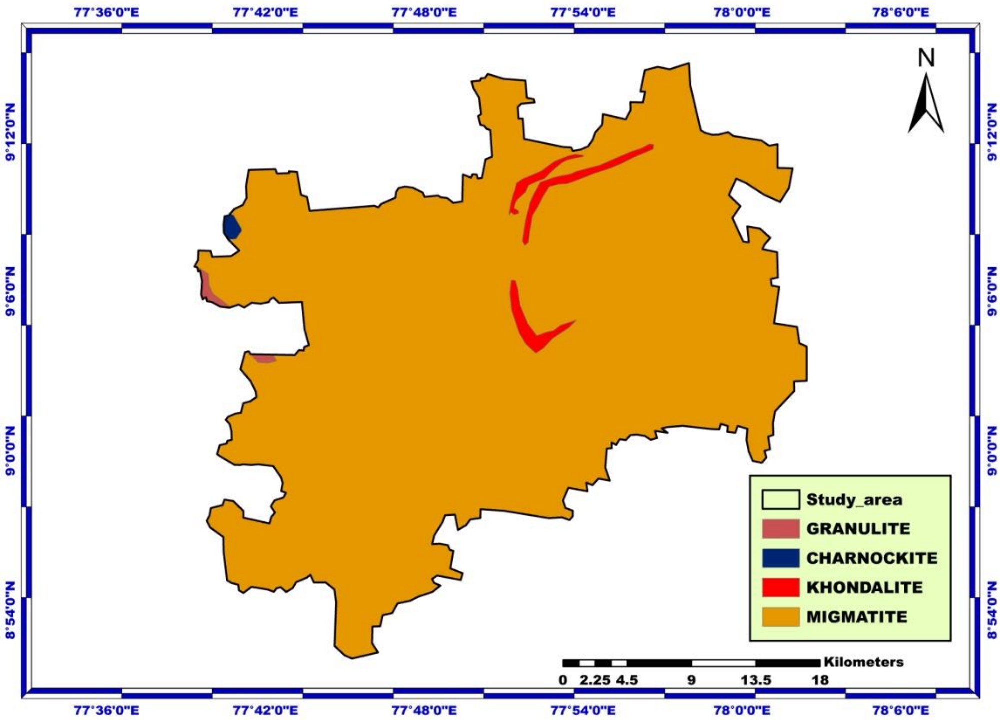

Fig. 2 Geology map of the study area

Water quality index calculation

The Water Quality Index (WQI) was developed to assess the impact of both natural and human-caused changes on numerous important chemical properties of groundwater. The WQI is calculated by weighting various physical and chemical criteria influencing total drinking water quality from 1 to 5 (Singh, 2020). The relative weight of each parameter, as shown in equation 1, is the first step in estimating WQI.

Table 1 The weight (w_i) and relative weight index (W_i) of each chemical parameter (Jesuraja, K., 2021) in WHO 2017 guidelines

Parameters	Weight (w_i)	Relative Weight (W_i)	WHO 2017
pH	3	0.097	8.5
TDS	5	0.161	500
Ca^{2+}	3	0.097	75
Mg^{2+}	3	0.097	50
Na^{+}	4	0.129	200
K^{+}	2	0.065	10
HCO_3^-	1	0.032	300
Cl^-	5	0.161	250
So_4^{2-}	5	0.161	400
Total	$\sum w_i = 31$	$\sum W_i = 1$	

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where,
W_i is the relative weight
w_i is the weight of each parameter
n is the number of parameters.
The quality rating scale (q_i) is calculated by section for each parameter; its density was multiplied by 100 in each water sample by the corresponding WHO Standard 2017 (**Table 1**).

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

Where,
q_i is the quality rating
C_i The concentration of each chemical parameter in each sample is in milligrams per liter
S_i Milligrams per liter for chemical parameters according to the World Health Organization standard (2017) guidelines. The total water quality index can be calculated by the quality rating with the specific gravity according to the equation (3).
To calculate the endpoint of the WQI, the SI for each parameter is first determined. The sum of SI values provides a water quality indicator for each sample.

$$SI_i = w_i + q_i \quad (3)$$

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

Where,
SI_i is the sub-index for i^{th} parameter
q_i the rating based on the concentration for i^{th} parameter
n is the number of parameters

The concentration and chemical components dissolved in water are used to determine the quality of irrigation water for agricultural usage. Water quality must be considered when assessing salinity or alkalinity in an irrigation area. Appropriate water quality can help increase production (as well as good soil and water management methods). The suitability of water for irrigation is determined by the sodium concentration of TDS (salinity) and calcium and magnesium, or SAR. Stanley R. et al., 2021 examined water quality parameters in the research region, including salt absorption ratio (SAR), soluble sodium percentage (SSP), kelly ratio (KR), sodium percentage (percent Na), magnesium risk (MH), and permeability index (PI).

Sodium Adsorption Ratio (SAR)

SAR is used to examine the acceptability of groundwater for irrigation since it provides alkaline and saline harmful readings for agriculture. The sodium absorption coefficient is determined as the percentage of sodium to calcium and magnesium. It aids in the diagnosis of groundwater sodium excess. The rate of water penetration into the soil is inversely related to SAR.
Richards (1954) suggested the following formula, Equation (5), to find this:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (5)$$

Sodium percentage

The concentration of sodium in irrigation water is usually expressed as a percentage of sodium ions. Na% can be calculated by using equation (8) by Acharya, S. et al 2018.

$$Na\% = \frac{Na^{+} + K^{+} \times 100}{(Ca^{2+} + Mg^{2+}) + (Na^{+} + K^{+})} \quad (6)$$

Residual Sodium Carbonate (RSC)
It is an important parameter in water quality studies, especially in assessing irrigation water. It's used to evaluate the suitability of water for agricultural purposes. RSC is calculated using the formula:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (7)$$

4. Result and discussion

Piper Diagram:
In a Piper diagram, which is a trilinear diagram used to visualize the composition of water samples, the central diamond field provides insights into the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}). The upper part of the diamond indicates a dominance of alkaline earth metals (Ca^{2+} and Mg^{2+}), while the lower part indicates a dominance of alkali metals (Na^{+} and K^{+}). The left side indicates a dominance of weak acids (HCO_3^{-} and CO_3^{2-}), and the right side indicates a dominance of strong acids (Cl^{-} and SO_4^{2-}). In the Kovilpatti region, the pre-monsoon samples predominantly fall in the lower part, indicating a dominance of alkaline earth metals (Ca^{2+} and Mg^{2+}), and on the right side, indicating a dominance of strong acids (Cl^{-} and SO_4^{2-}). Post-monsoon samples show a similar trend, but a few samples exhibit slight evaporation and ion exchange processes (**Fig. 3**). This suggests that, in both seasons, alkaline earth minerals outnumber alkali metals.

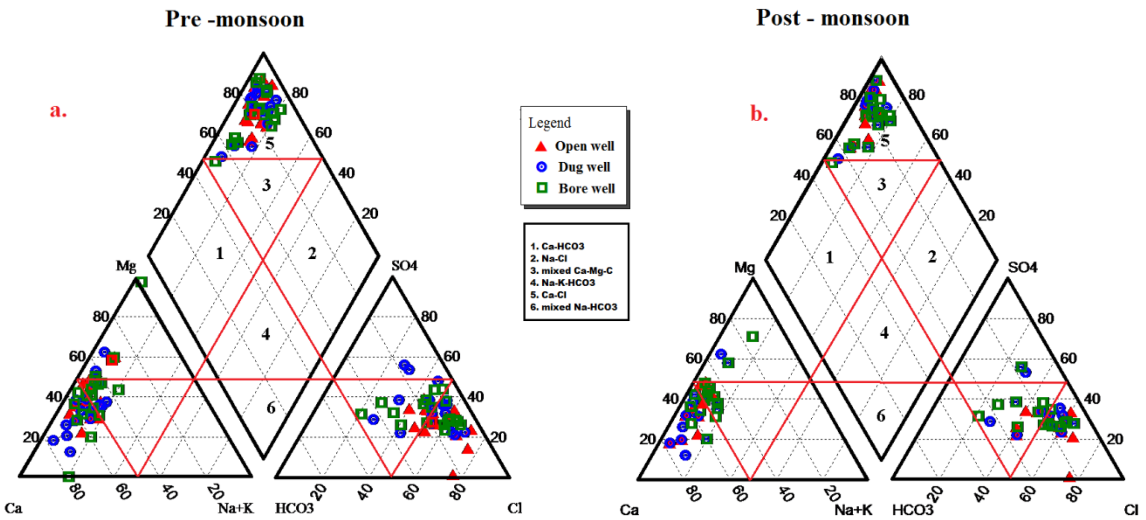

Fig. 3 Piper diagram (a. pre-monsoon and b. post-monsoon)

Wilcox Diagram:
The Wilcox diagram, commonly used in similar studies, evaluates water suitability for irrigation by plotting sodium hazard (sodium adsorption ratio, SAR) against salinity hazard (electrical conductivity). Low SAR and low conductivity indicate water suitable for irrigation, while high SAR and high conductivity suggest water that may pose soil permeability issues. The Wilcox plot assesses the suitability of water for irrigation based on the sodium adsorption ratio (SAR) and electrical conductivity (EC). Water in the Low Salinity (C1) and Low Sodium (S1) category is generally suitable for all types of crops and soils with little risk of salinity or sodium hazards. Conversely, water in the High Salinity (C4) and High Sodium (S4) category poses a significant risk to crops and requires careful management to avoid soil degradation and reduced crop yields. The distribution of samples in the Wilcox plot

indicates how sodium content and salinity vary among different water sources and their suitability for agricultural use (**Fig. 4**). By comparing the positions of samples, one can assess the potential risks and necessary management practices to ensure sustainable agricultural practices in the Kovilpatti region.

Gibbs Plot

In the Kovilpatti region, the Gibbs plot analysis reveals that evaporation and rock–water interaction are the dominant processes influencing groundwater chemistry in both pre- and post-monsoon seasons. Prominent samples are identified in these fields, indicating significant groundwater percolation with rock infiltration, particularly for chloride (Cl^-) and sodium (Na^+) ions. The pre-monsoon season shows more pronounced weathering and evaporation conditions, leading to higher concentrations of Cl^- and Na due to prolonged rock–water interactions (**Fig. 5**). In the post-monsoon season, there is a noticeable reduction in weathering effects, although some samples still reflect ongoing rock-water interactions and evaporation processes. This suggests that while rock–water interaction and evaporation continue to play a key role in determining groundwater composition, their influence is slightly diminished after the monsoon.

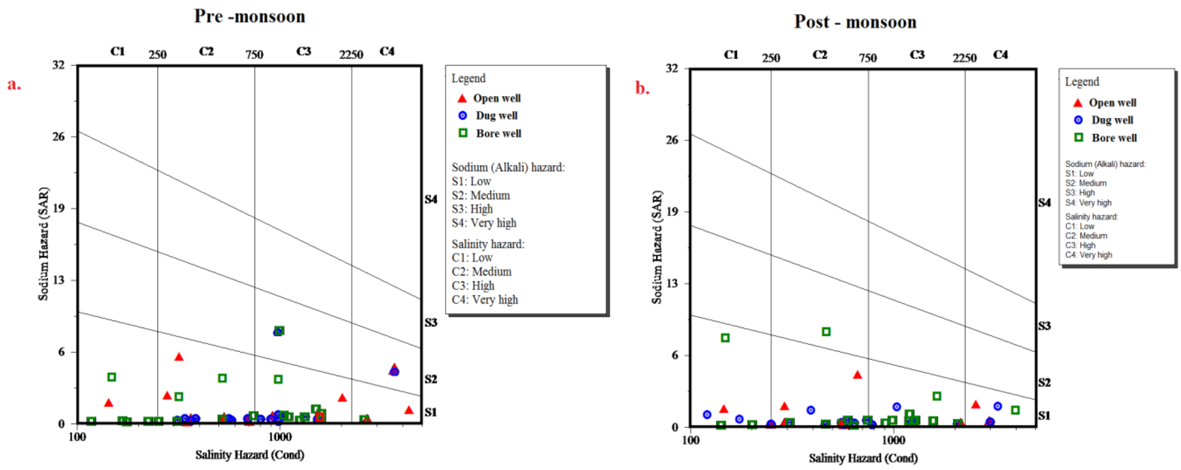

Fig 4. Wilcox diagram (a. pre-monsoon and b. post-monsoon)

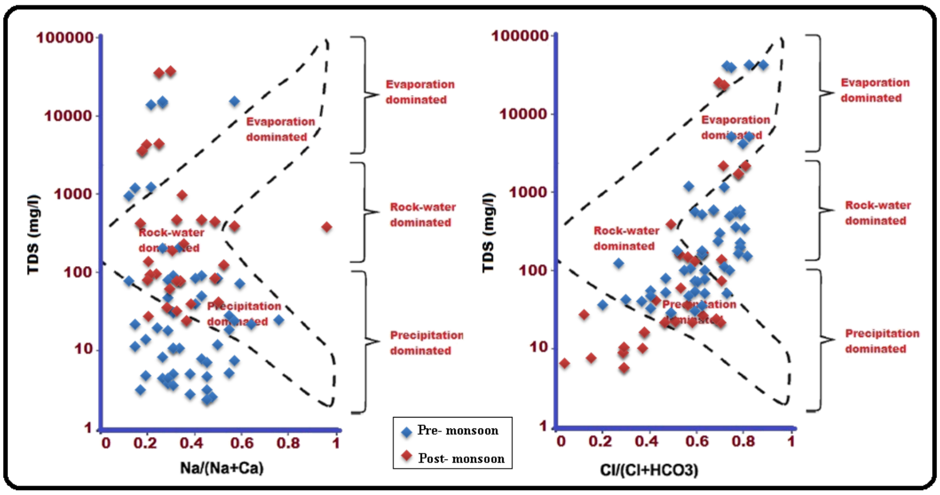

Fig. 5 Gibbs diagram (a. pre-monsoon and b. post-monsoon)

Assessment of spatial analysis

Using ArcGIS, spatial analysis techniques were employed to evaluate water quality in the Kovilpatti region during pre-monsoon and post-monsoon seasons of 2017. Parameters such as pH, electrical conductivity, total dissolved solids (TDS), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO4), and bicarbonate (HCO3) were analyzed (**Table 2**). The pre-monsoon data revealed a pH range of 7 to 8 with an average of 8, which is within the WHO standard of 5.5 to 9.5 (**Fig. 6**). Conductivity values ranged from 48 to 3750 µS/cm with an average of 1125 µS/cm (**Fig. 7**). TDS ranged from 75 to 5860 mg/L, averaging 1758 mg/L, exceeding the WHO guideline of 500 mg/L in several instances (**Fig. 8**). The average sodium concentration was 29 mg/L (range: 2-96 mg/L), well below the WHO limit of 200 mg/L (**Fig. 9**). Potassium levels ranged from 1 to 36 mg/L, with an average of 11 mg/L, slightly exceeding the WHO recommendation of 10 mg/L in some samples (**Fig. 10**). Magnesium concentrations varied from 3 to 582 mg/L, with an average of 103 mg/L, surpassing the WHO limit of 50 mg/L (**Fig. 11**). Calcium levels ranged from 8 to 680 mg/L, with an average of 180 mg/L, exceeding the WHO guideline of 75 mg/L in many samples (**Fig. 12**). Chloride concentrations varied from 24 to 2484 mg/L, with an average of 497 mg/L, frequently surpassing the WHO standard of 250 mg/L (**Fig. 13**). Sulfate levels ranged from 7 to 1085 mg/L, with an average of 368 mg/L, also exceeding the WHO guideline of 400 mg/L in several cases (**Fig. 14**). Bicarbonate levels ranged from 24 to 448 mg/L, averaging 202 mg/L, within the acceptable range of the WHO standard of 300 mg/L (**Fig. 15**). Post-monsoon analysis showed a pH range of 7.5 to 8.2 with an average of 7.8, still within WHO standards. Conductivity ranged from 94 to 2984 µS/cm with an average of 1073 µS/cm. TDS values ranged from 146 to 4672 mg/L, averaging 1677 mg/L, consistently exceeding the WHO guideline. Sodium concentration averaged 25 mg/L (range: 3-76 mg/L), below the WHO limit. Potassium levels averaged 10 mg/L (range: 1-27 mg/L), meeting the WHO standard. Magnesium concentrations averaged 91 mg/L (range: 8-447 mg/L), surpassing the WHO guideline. Calcium levels averaged 188 mg/L (range: 16-544 mg/L), again exceeding the WHO standard. Chloride concentrations averaged 456 mg/L (range: 30-1021 mg/L), frequently exceeding the WHO limit. Sulfate levels averaged 333 mg/L (range: 6-758 mg/L), within the WHO guideline. Bicarbonate levels averaged 211 mg/L (range: 51-358 mg/L), also within the WHO standard (**Figure 6A, B and C**). The spatial distribution maps generated in ArcGIS highlighted regions with water quality issues, particularly elevated TDS, Mg, Ca, and Cl levels, which pose potential health risks. These findings underscore the importance of continuous monitoring and the implementation of sustainable water management practices to mitigate contamination and ensure safe drinking water for the local population.

Table 2 Statistical summary of physicochemical parameter for pre monsoon and post monsoon

Season	Pre-monsoon				Post-monsoon				WHO standard 2017
Parameters	Min	Max	Avg	St.dev	Min	Max	Avg	St.dev	
pH	7	8	8	0	7.5	8.2	7.8	0.2	5.5
Cond	48	3750	1125	944	94	2984	1073	809	-
TDS	75	5860	1758	1475	146	4672	1677	1266	500
Na	2	96	29	22	3	76	25	18	200
K	1	36	11	8	1	27	10	6	10
Mg	3	582	103	133	8	447	91	104	50
Ca	8	680	180	176	16	544	188	170	75

Cl	24	2484	497	431	30	1021	456	300	250
SO4	7	1085	368	255	6	758	333	187	400
HCO3	24	448	202	110	51	358	211	94	300

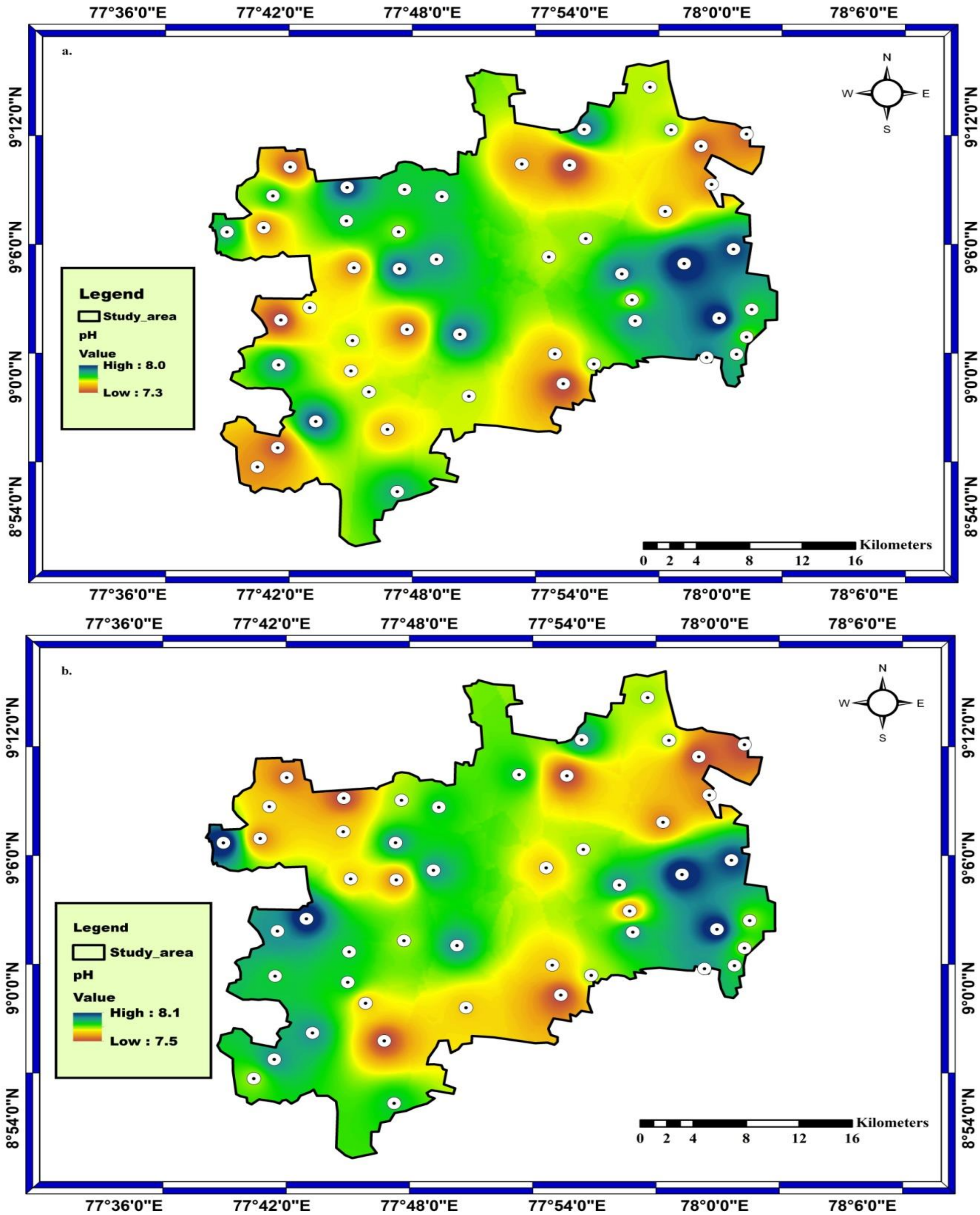

Fig. 6 The spatial analysis map of pH (a. pre-monsoon and b. post-monsoon)

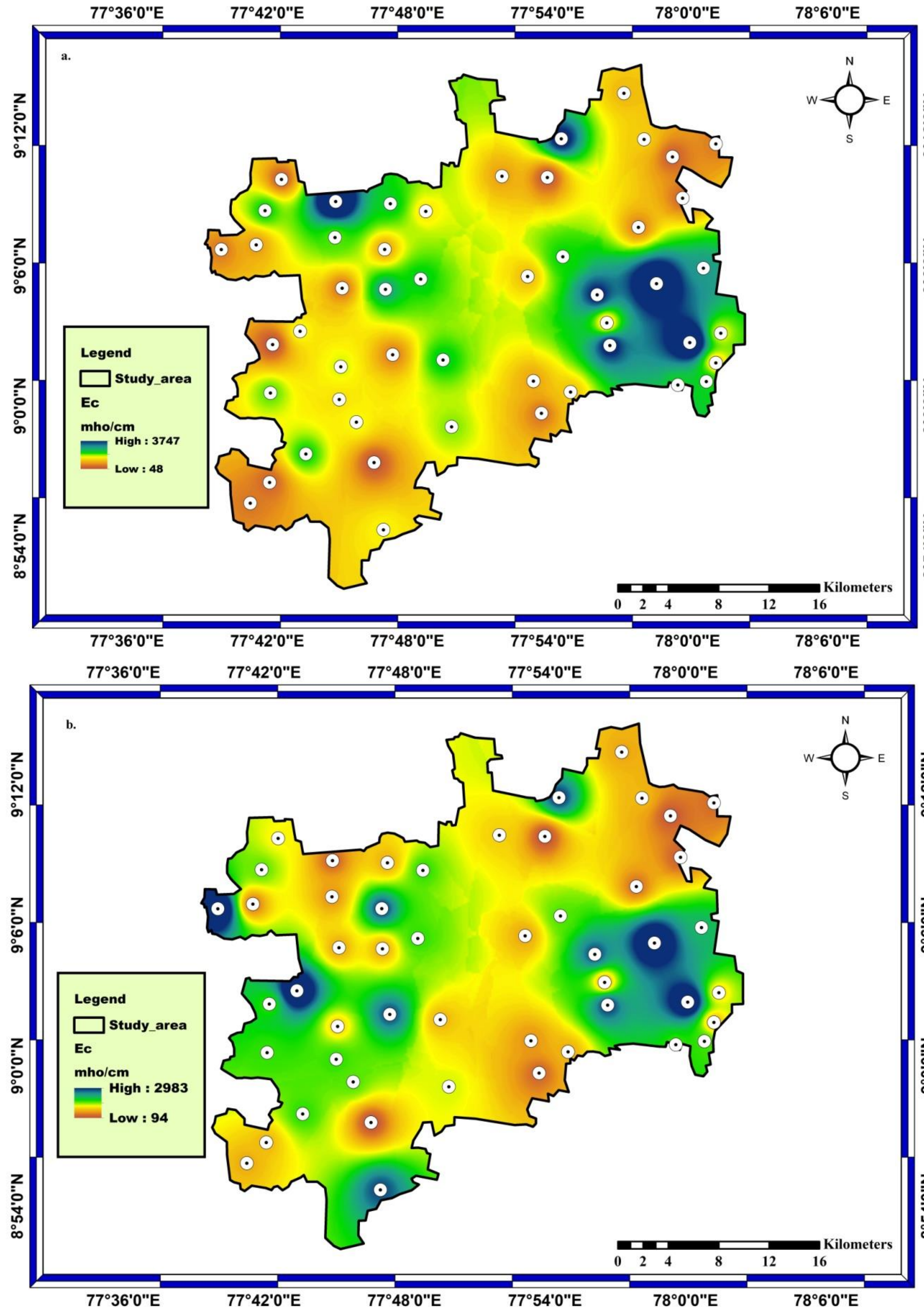

Fig. 7 The spatial analysis map of Ec (a. pre-monsoon and b. post-monsoon)

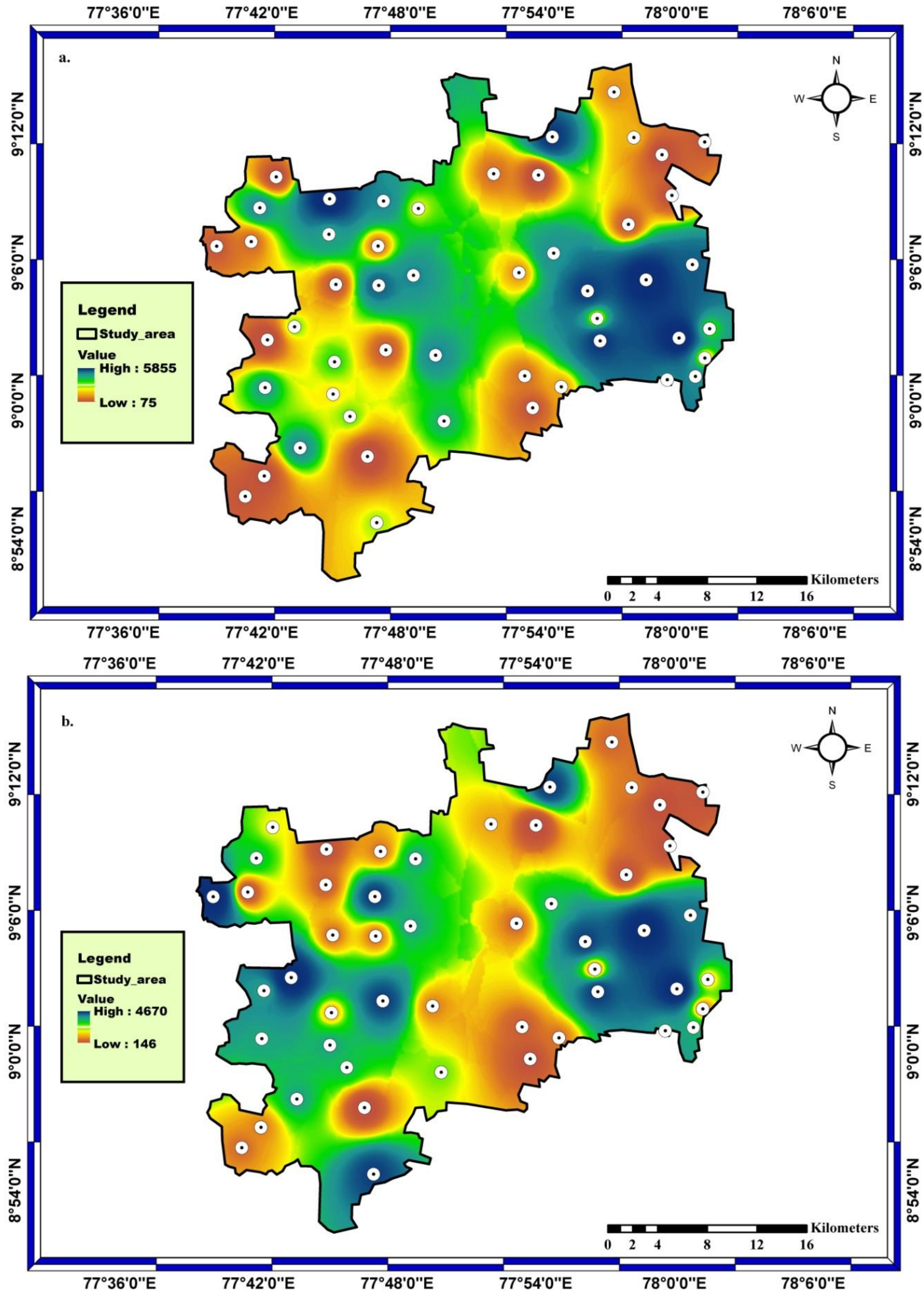

Fig. 8 The spatial analysis map of TDS (a. pre-monsoon and b. post-monsoon)

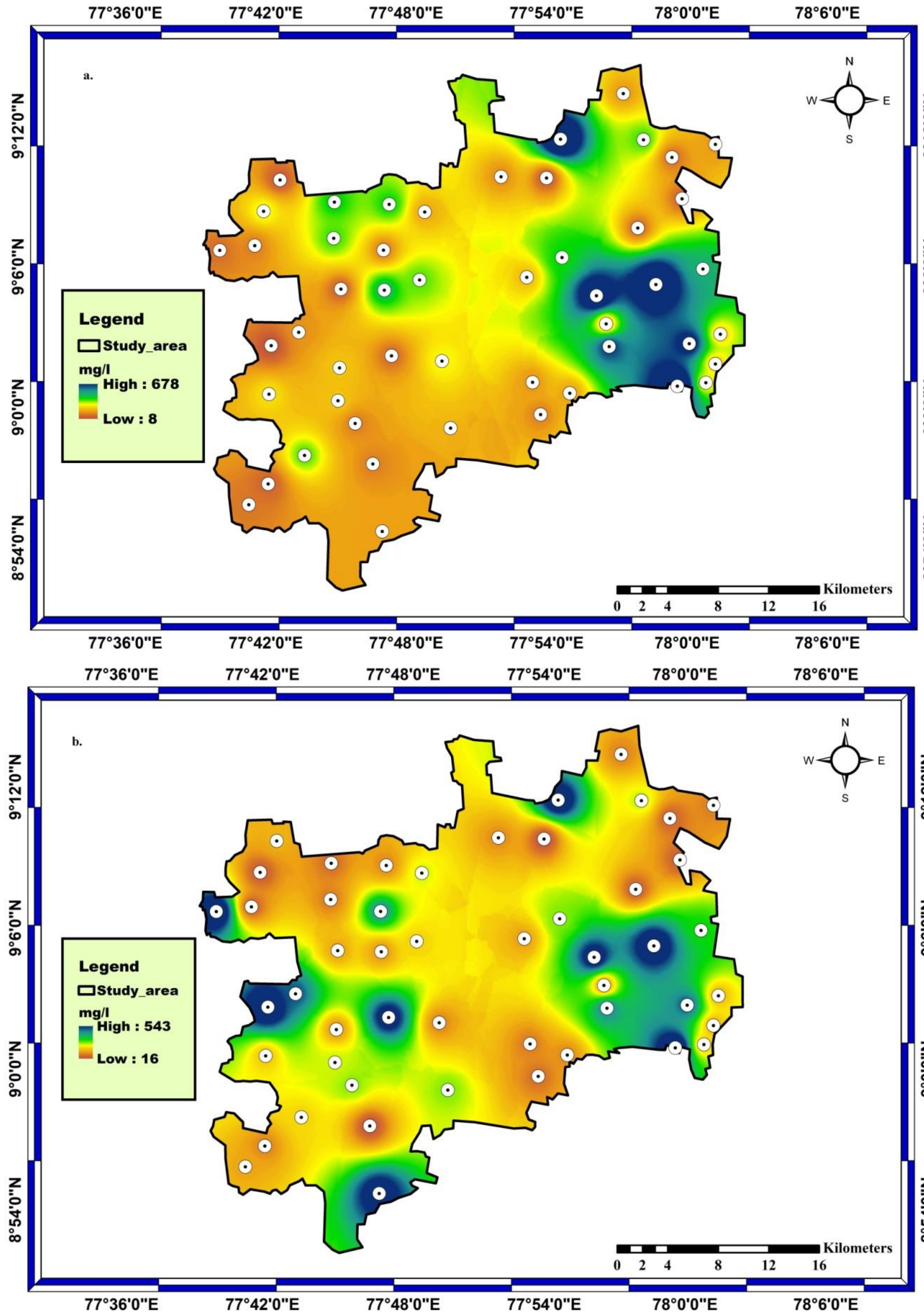

Fig. 9 The spatial analysis map of Ca^{2+} (a. pre-monsoon and b. post-monsoon)

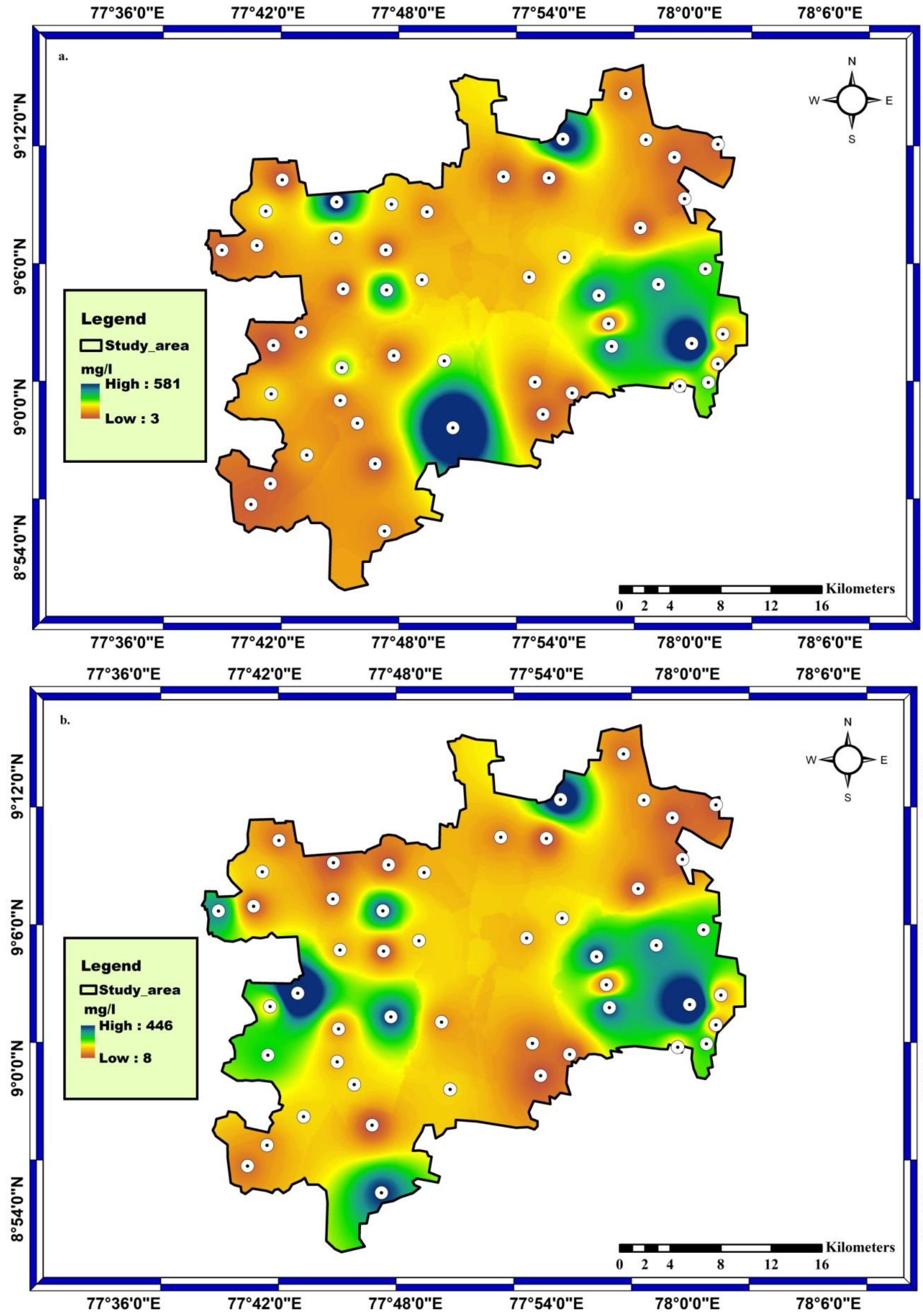

Fig. 10 The spatial analysis map of Mg^{2+} (a. pre-monsoon and b. post-monsoon)

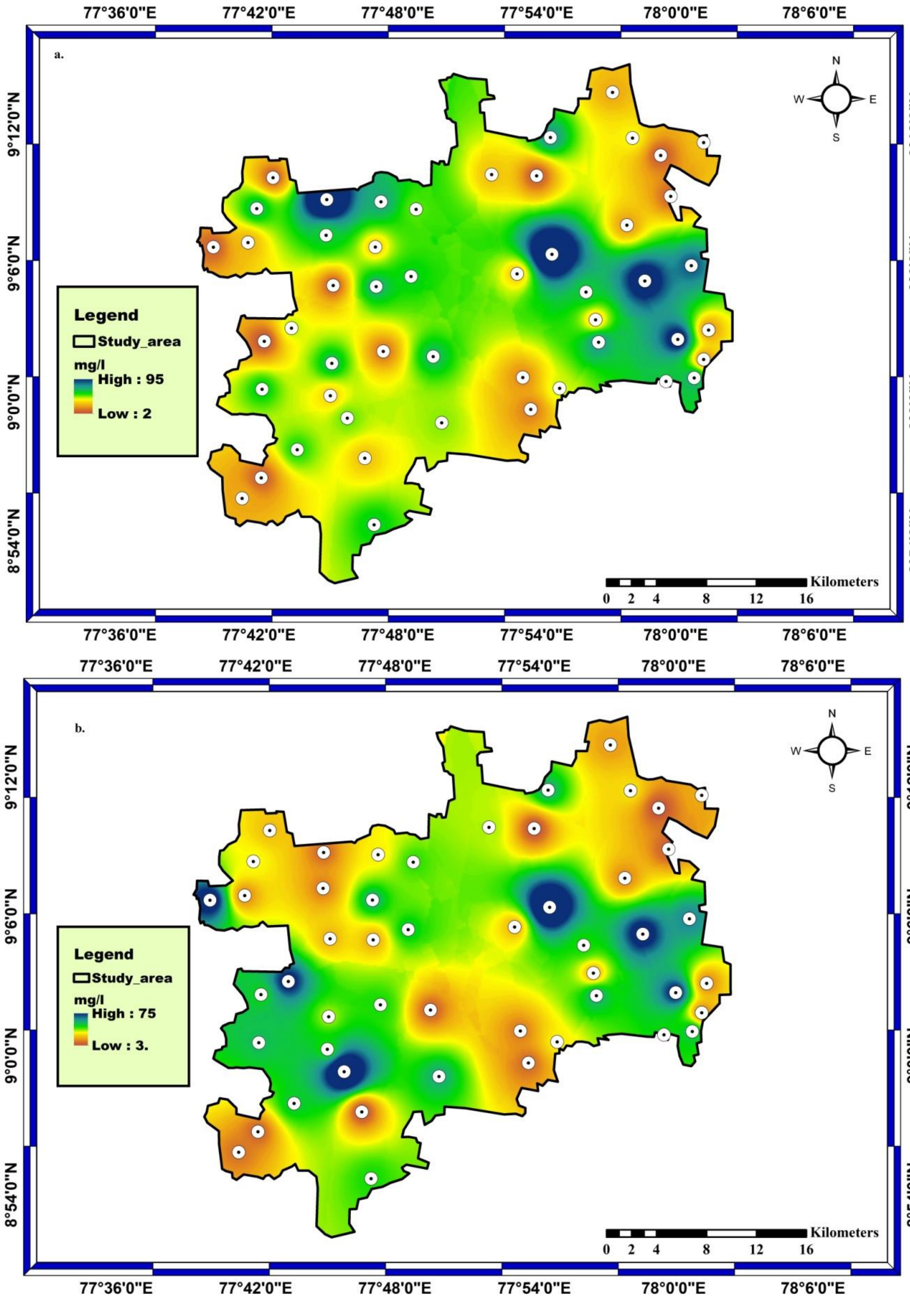

Fig. 11 The spatial analysis map of Na^{+} (a. pre-monsoon and b. post-monsoon)

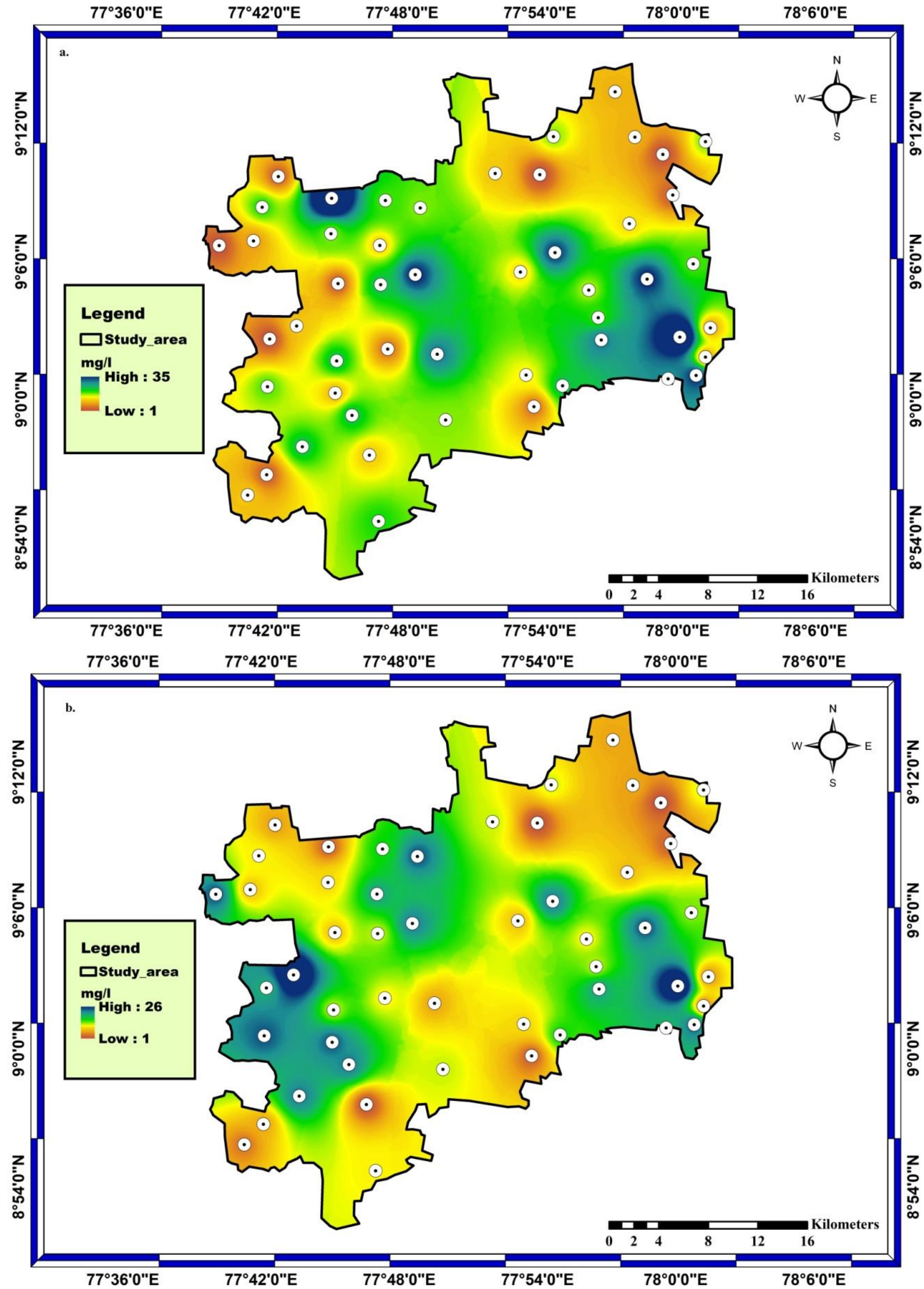

Fig. 12 The spatial analysis map of K^+ (a. pre-monsoon and b. post-monsoon)

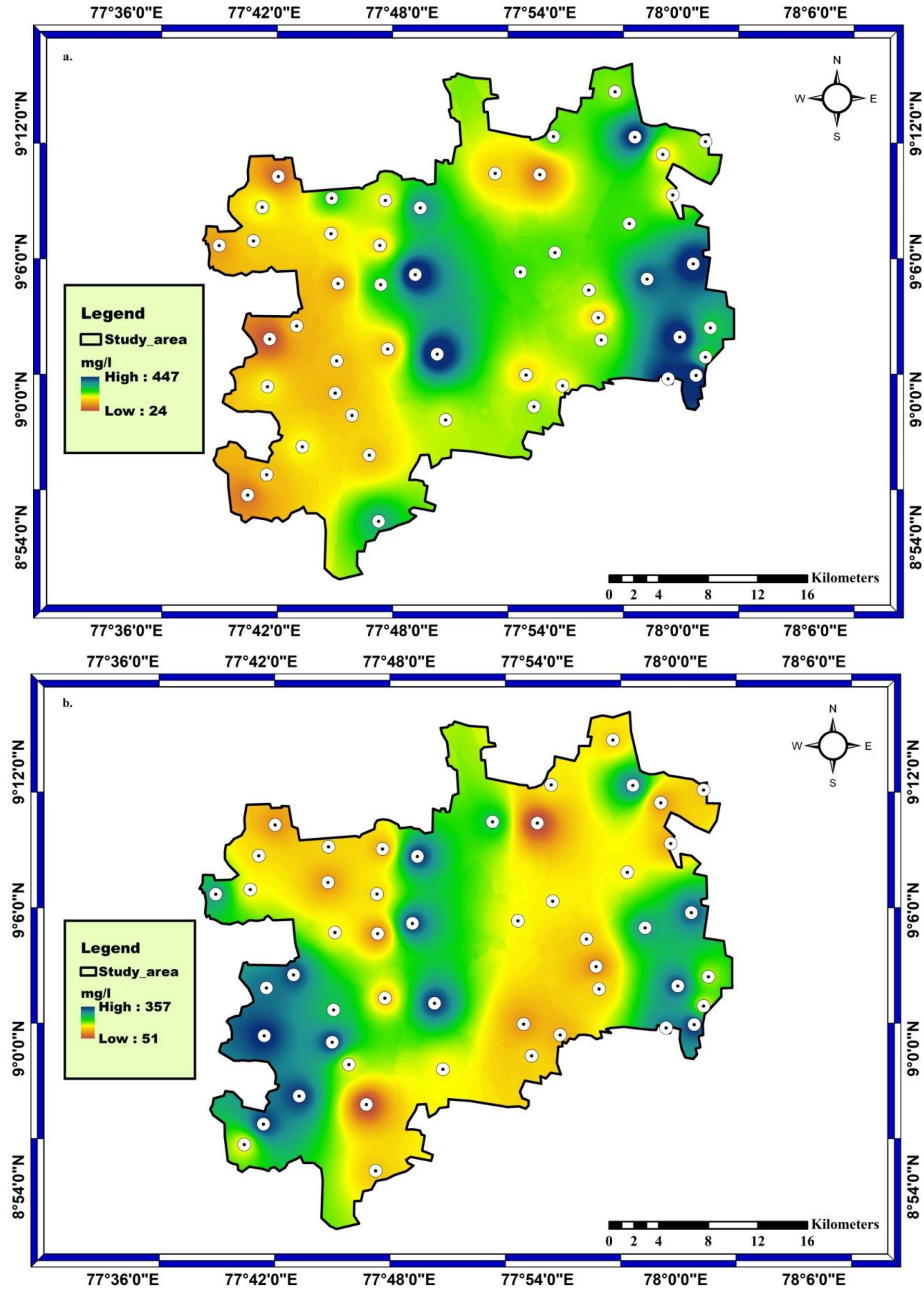

Fig. 13 The spatial analysis map of HCO_3^- (a. pre-monsoon and b. post-monsoon)

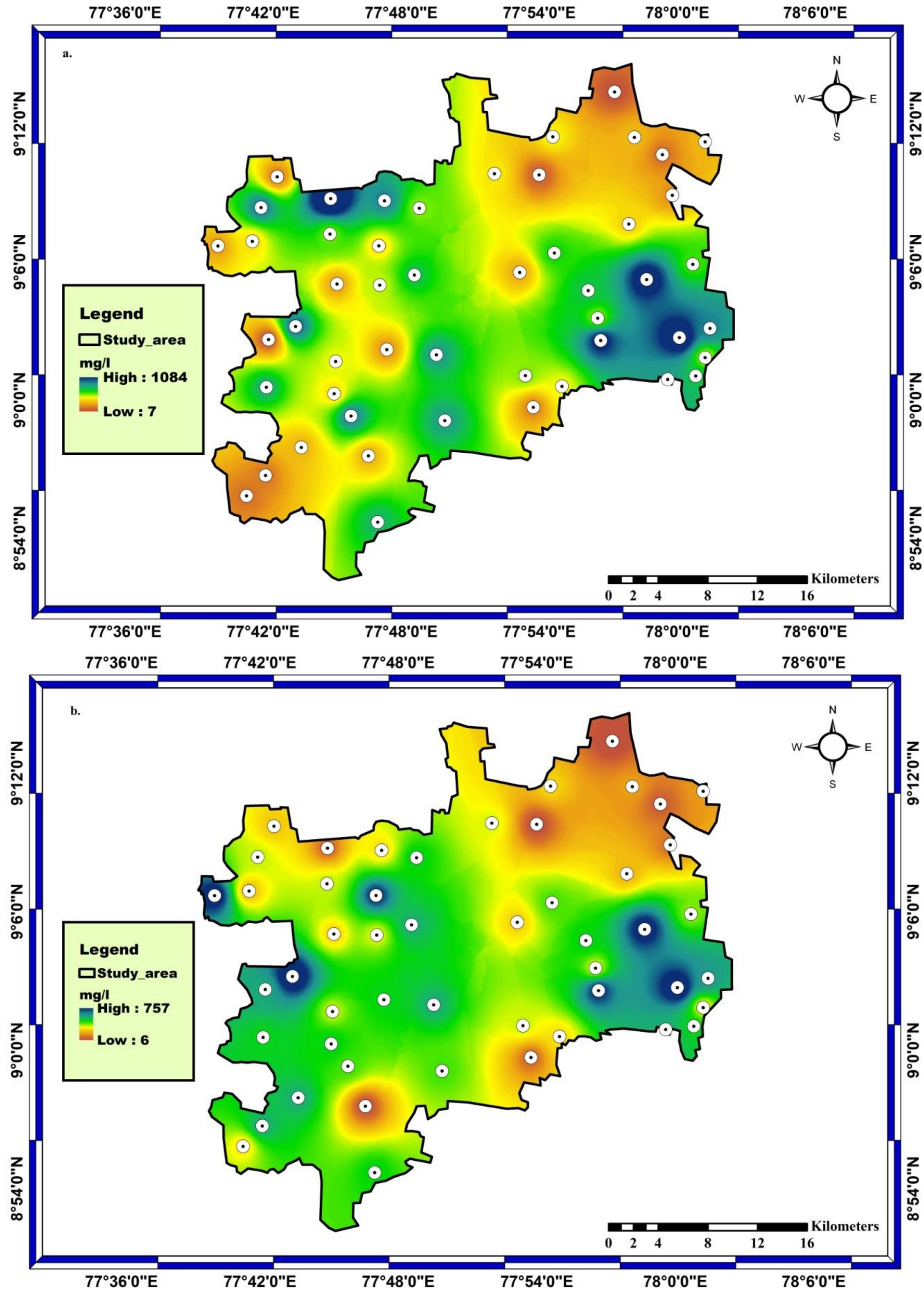

Fig. 14 The spatial analysis map of So_4^{2-} (a. pre-monsoon and b. post-monsoon)

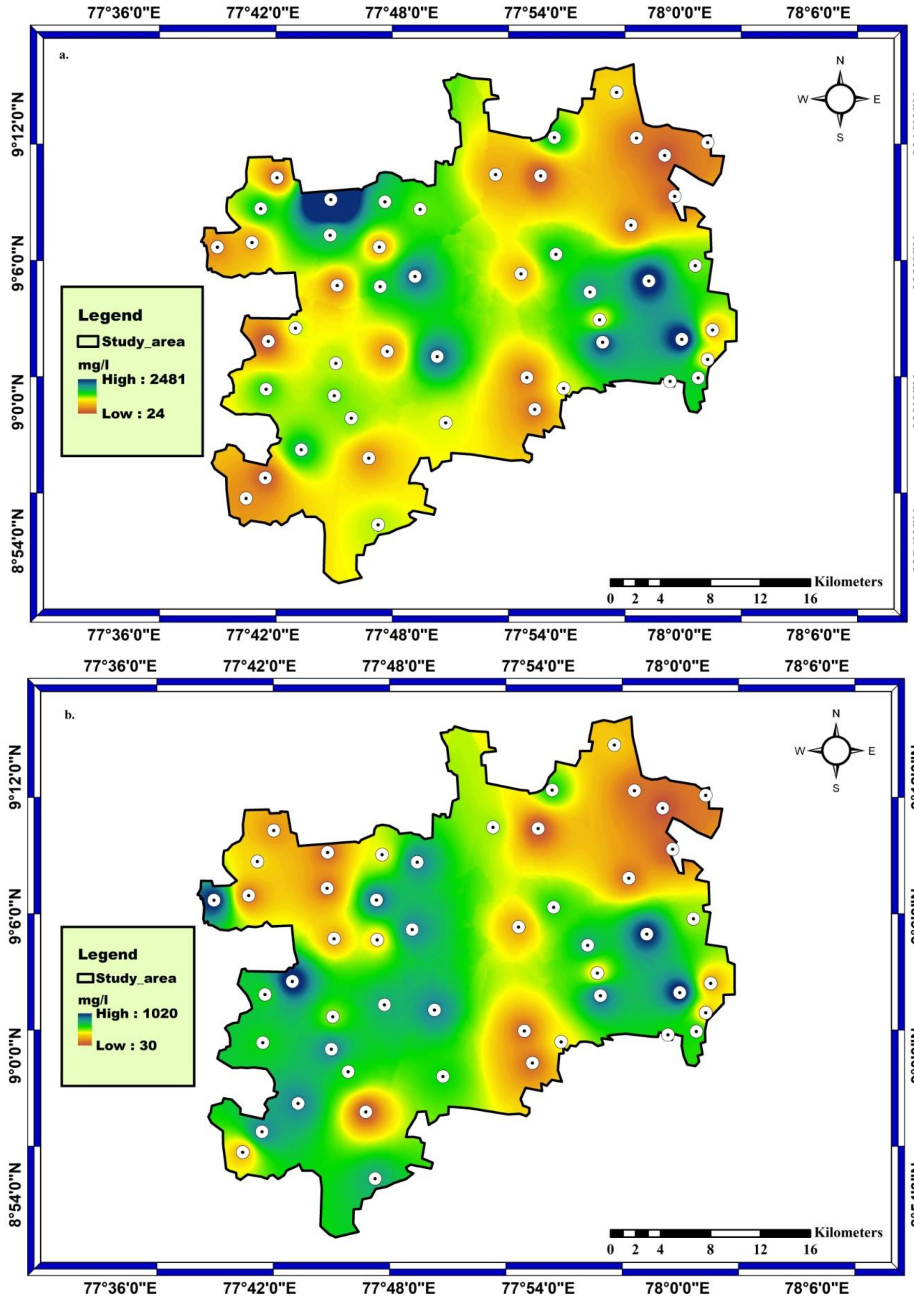

Fig. 15 The spatial analysis map of Cl^- (a. pre-monsoon and b. post-monsoon)

Water quality indices assessment

In the Kovilpatti region, water quality indices reveal distinct seasonal variations in water chemistry. During the pre-monsoon period, the Sodium Adsorption Ratio (SAR) indicates that 56% of the samples are categorized as moderate, with 24% falling into the high range and none exceeding the very high threshold. This suggests a potential for soil structure and permeability issues due to elevated SAR values. Post-monsoon, the SAR distribution shifts, with 32% of samples in the low category, 18% in the moderate range, 20% in the high, and 30% reaching the very high category. This indicates a marked increase in SAR levels after the monsoon, which could affect soil and water management practices. For sodium percentage, all pre-monsoon samples fall into the low range (20% ≤ %Na < 40%), suggesting relatively lower sodium impacts on soil quality, whereas post-monsoon data reveals 86% in the very low category and 14% in the low range, indicating improved sodium levels in the water (**Table 3**). Residual Sodium Carbonate (RSC) analysis during the pre-monsoon shows 62% of samples are unsafe, with 20% marginal and 18% safe, reflecting potential concerns for soil alkalinity and plant growth. However, post-monsoon conditions show a significant improvement, with 100% of samples classified as safe and none in the marginal or unsafe categories, suggesting that the monsoon effectively mitigates RSC levels and improves overall water quality.

Table 3 Categorization of water samples based on determined parameter standards (Wilcox LV 1955)

Parameters	Range	Class	No. of. samples		% of samples	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
SAR	0–10	Low	10	16	20	32
	10–18	Moderate	28	9	56	18
	18–26	High	12	10	24	20
	> 26	Very High	-	15	-	30
(% Na)	%Na < 20%	Very Low	-	43	-	86
	20% ≤ %Na < 40%	Low	50	7	-	14
	40% ≤ %Na < 60%	Moderate	-	-	-	-
	%Na ≥ 60%	High	-	-	-	-
Residual Sodium Carbonate (RSC)	RSC ≤ 1.25	Safe	9	50	18	100
	1.25 < RSC < 2.5	Marginal	10	-	20	-
	RSC ≥ 2.5	Unsafe	31	-	62	-

Conclusion

The comprehensive water quality analysis in the Kovilpatti region, utilizing various spatial analysis techniques and hydrogeochemical plots, reveals significant insights into the groundwater conditions during the pre-monsoon and post-monsoon seasons of 2017. The findings indicate notable seasonal variations in water quality parameters such as pH, electrical conductivity, total dissolved solids (TDS), sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), chloride (Cl), sulfate (SO4), and bicarbonate (HCO_3). The pre-monsoon season shows higher levels of conductivity, TDS, Mg, Ca, and Cl, frequently exceeding WHO standards, indicating potential health risks and the influence of prolonged rock-water interactions and evaporation processes. In contrast, the post-monsoon season reflects a dilution effect due to rainwater recharge, resulting in improved water quality for some parameters, although TDS and Mg still exceed acceptable limits. Hydrogeochemical plots, including the Piper, Ternary, Wilcox, and Gibbs diagrams, further elucidate the groundwater composition and geochemical processes at play. The Piper diagram indicates a dominance of alkaline earth metals (Ca^{2+} and Mg^{2+}) and strong acids (Cl^- and SO_4^{2-}) in both seasons. The Ternary diagram highlights the variability in Na, Mg, and Ca concentrations across different water sources, with distinct clustering patterns revealing unique hydro-geological conditions. The Wilcox plot identifies potential risks for agricultural use, emphasizing the need for careful management of water with high salinity and sodium content. The Gibbs plot underscores the roles of evaporation and rock-water interaction in shaping groundwater chemistry, with a slight reduction in these influences post-monsoon. Water quality indices reveal distinct seasonal impacts on groundwater suitability for irrigation. Pre-monsoon, elevated Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) values indicate potential soil structure and permeability issues. Post-monsoon, there is a noticeable improvement in water quality, with a significant reduction in RSC levels and a shift in SAR distribution, suggesting the monsoon's positive impact on groundwater quality. Overall, this study underscores the importance of continuous monitoring and the implementation of sustainable water management practices to mitigate contamination and ensure safe drinking water for the local population. It also highlights the need for targeted interventions to address specific water quality issues and support sustainable agricultural practices in the Kovilpatti region.

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Conflicts of Interest

They no conflicts of interest

Availability of Data and Material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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