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Groundwater Hydrochemistry in Central Kerala: Implications for Aquifer Infrastructure and Environmental Water Management

Samreena Mohammed[1*]; K. S Arunkumar[2]
Department of PG Studies & Research in Geology
MES Ponnani College (Calicut University)
South Ponnani P.O, Malappuram-679586, Kerala, India

Corresponding Author:- Samreena Mohammed[1*]

Abstract:- The hydrochemistry of groundwater varies significantly across different locations in Central Kerala, where sedimentary groundwater aquifers are predominant. Factors such as rock weathering during contact and anthropogenic activities have a significant impact on groundwater chemistry. Hydrochemical analysis is an essential tool for identifying water types, chemical composition, and suitability for specific purposes, which is a critical requirement for water use licensing applications. This study analyzes the hydrochemical data of groundwater from 70 open wells near the Thrissur Ponnani Kol in Central Kerala using integrated statistical,Piper trilinear diagram, and spatial interpolation methods. The results reveal that Ca+ and Cl- are the most abundant cations and anions in the groundwater, with mean concentrations of 267.39 mg/l and 574.81 mg/l, respectively. water chemistry and spatial interpolation analysis for major cations (Na+) and major anions(Cl-), Sodium Adsorption Ratio, Electrical Conductivity, and Water Quality Index were performed using the inverse distance weighting method. The hydrochemical data were analyzed to classify the groundwater for domestic use (drinking) and agriculture (irrigation) purposes based on the recommended guidelines of the WHO and BIS. The study area is characterized by high salinity of three water types: Ca-Cl reverse ion-exchange water, Mixed Type of water, and Mg-HCO3 base ion-exchange water. Approximately 70-80% of the open wells in Central Kerala meet the requirements for irrigation application.

Keywords:- *Groundwater, Piper Diagram, Sodium Absorption Ratio, Electrical Conductivity, WQI.*

I. INTRODUCTION

The hydrochemistry of groundwater in Central Kerala, where sedimentary groundwater aquifers are predominant, varies significantly across different locations. Factors such as rock weathering during contact and anthropogenic activities have a significant impact on groundwater chemistry. It is crucial to determine the groundwater chemistry for aquifer protection and groundwater management. Hydrochemical analysis is an essential tool for identifying water types, chemical composition, and suitability for specific purposes, which is a critical requirement for water use licensing applications (Chekirbane et al., 2009) (Rumuri & Manivannan, 2020)(Sivakarun et al., 2020)(Elumalai et al., 2020).

The hydrochemistry of groundwater is a crucial aspect of water resource management, as it determines the suitability of water for various purposes, such as domestic, agricultural, and industrial use (Rumuri & Manivannan, 2020). In Central Kerala, India, the predominant groundwater aquifers are of sedimentary origin, which are highly susceptible to the impacts of rock weathering and anthropogenic activities. Factors such as mineral dissolution, ion exchange, and seawater intrusion can significantly influence the chemical composition of groundwater in this region. (Sivakarun et al., 2020) (Rumuri & Manivannan, 2020)

Hydrochemical analysis is an essential tool for understanding the water types, chemical composition, and suitability of groundwater for specific uses. This information is critical for water use licensing applications, as it helps in the effective management and allocation of water resources. This study aims to analyze the hydrochemical data of groundwater from 70 open wells near the Thrissur Ponnani Kol in Central Kerala, using integrated statistical, geostatistical, and spatial interpolation methods. (Sivakarun et al., 2020) (Efobo et al., 2020) (Acharya et al., 2018) (Rumuri & Manivannan, 2020)

Several studies have been conducted to understand the hydrochemistry of groundwater in various regions of the world. These studies have employed a range of analytical techniques, including geographic information systems, statistical analysis, and geochemical modeling, to identify the factors controlling the groundwater chemistry.

II. METHODOLOGY

➢ *Location of Study Area*

The central region of Kerala, India, is a diverse landscape characterized by coastal plains, wetlands, and hilly terrain. Groundwater is extensively utilized in this

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region for various purposes, including domestic use, agriculture, and industrial activities. However, the region has faced challenges in meeting the growing demand for water, and a comprehensive assessment of groundwater resources is necessary to develop sustainable management strategies. (Das et al., 2020)

The study area is situated in the central region of Kerala, which is known for its tropical climate and diverse geological settings. To capture seasonal variations, groundwater samples were collected from 70 well locations during July, November 2022, and March 2023. (Kolli et al., 2020) This study aims to evaluate the groundwater resources in the region and identify strategies for sustainable management.

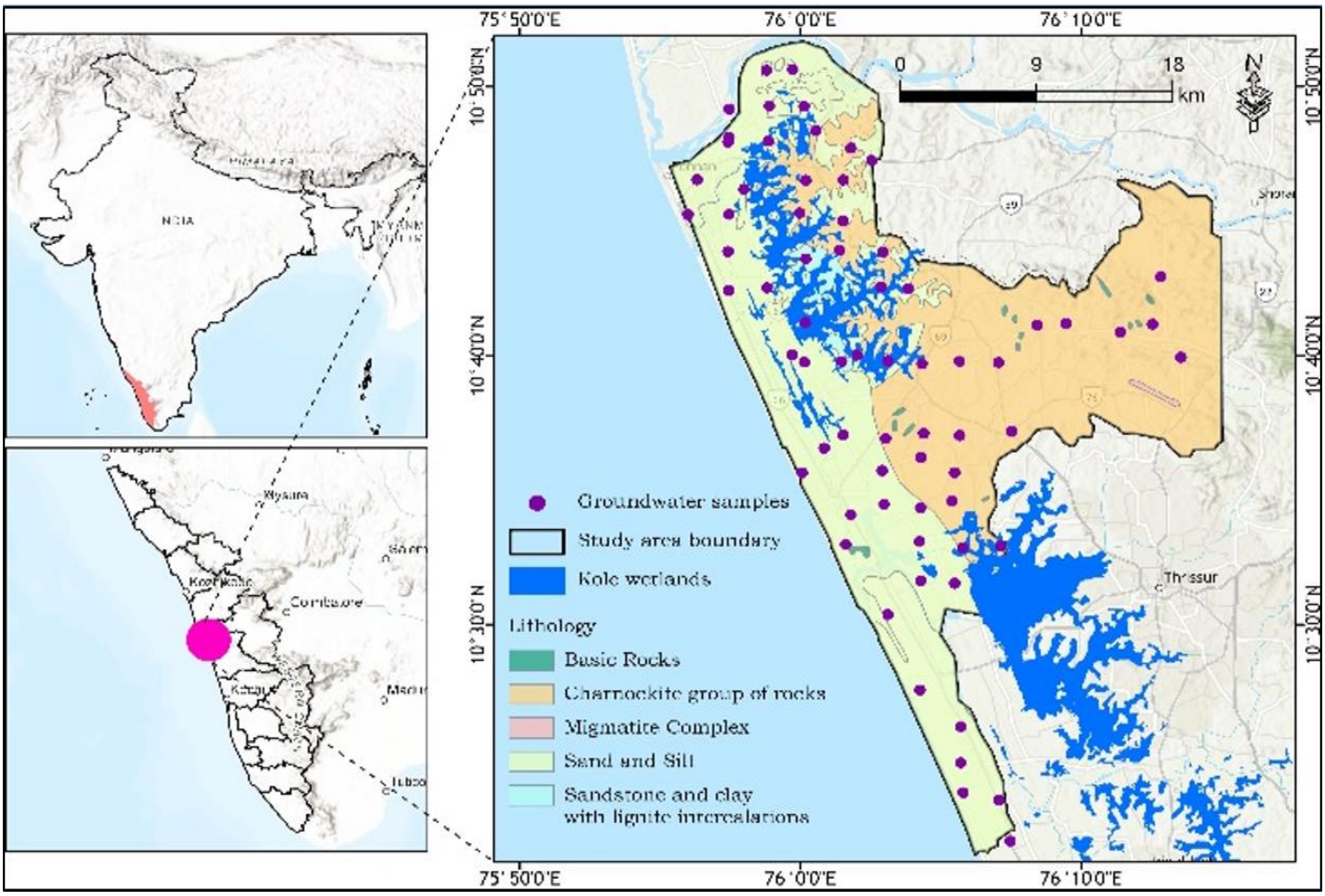

Fig 1 Location of the Study Area with Lithological Variations and Groundwater Sampling Locations

➢ *Hydrochemical Analysis*

The study was conducted in the central region of Kerala, India, where groundwater is the primary source of water for domestic and agricultural purposes. A total of 70 open wells near the Thrissur-Ponnani Kol region were selected for the hydrochemical analysis. Groundwater samples were collected from the selected open wells during the pre-monsoon season. The samples were analyzed for various physico-chemical parameters, including pH, electrical conductivity, total dissolved solids, major cations (Ca2+, Mg2+, Na+, K+) and major anions (CO32-, HCO3-, Cl-, SO42-) using standard analytical methods (Kale et al., 2020) (Kadam et al., 2021).

The data was subjected to statistical analysis, including descriptive statistics, correlation analysis, and factor analysis, to understand the hydrochemical characteristics and the factors influencing groundwater quality (Jagadeesh & Agrawal, 2015). Geostatistical and spatial interpolation techniques, such as the inverse distance weighting method, were employed to map the spatial distribution of major ions, sodium adsorption ratio, electrical conductivity, and water quality index across the study area. The groundwater quality was evaluated for its suitability for domestic (drinking) and agricultural (irrigation) purposes based on the guidelines recommended by the World Health Organization and Bureau of Indian Standards (Raymahashay et al., 1987)(Kale et al., 2020)(Chegbeleh et al., 2020).

III. RESULTS AND DISCUSSION

The results of the hydrochemical analysis reveal that the groundwater in the study area is characterized by high salinity, with Ca+ and Cl- being the most abundant cations and anions, respectively. The mean concentrations of Ca+ and Cl- were 267.39 mg/l and 574.81 mg/l, respectively, indicating the influence of rock weathering and ion exchange processes in the aquifer.

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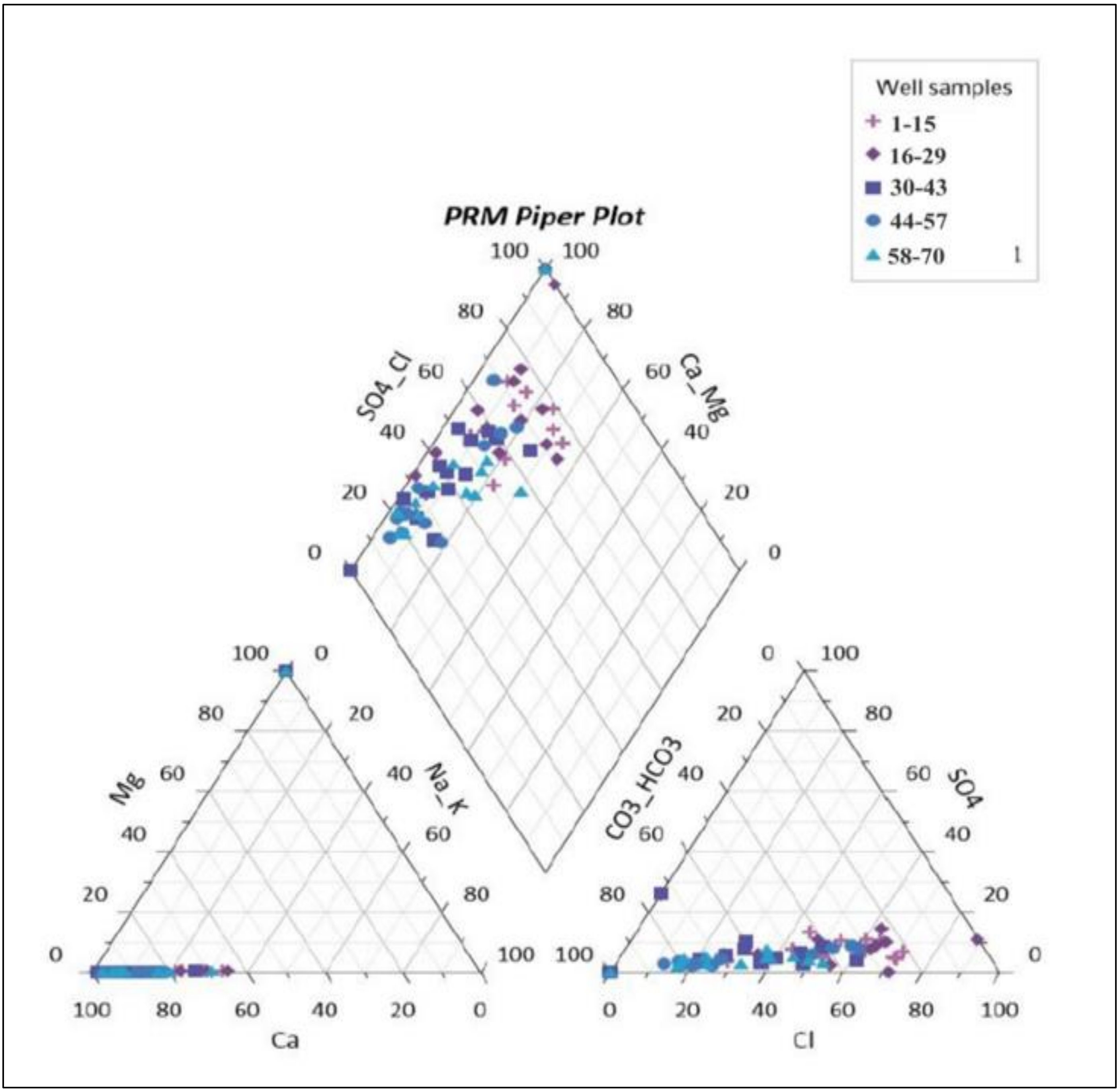

Fig 2 Piper Trilinear Plot of Pre-monsoon(PRM) Season

The pre-monsoon Piper (Fig 2) diagram illustrates the hydrochemical facies of groundwater in the study area by plotting the relative concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions. The majority of groundwater samples are classified as calcium-bicarbonate (Ca-HCO_3) type, with most data points concentrated near the Ca^{2+}-Mg^{2+} and CO_3^{2-}-HCO_3^{-} vertices, indicating the dominance of carbonate weathering processes (Diop and Tijani, 2014). Minimal contribution from Na^{+}, K^{+}, Cl^{-}, and SO_4^{2-} suggests limited ion exchange and lower influence of anthropogenic activities such as agricultural runoff or industrial discharge. The clustering of samples into groups highlights localized variations in groundwater chemistry, potentially linked to differences in geological formations or recharge conditions. (Pandit, Shakya and Shrestha, 2019)

This hydrochemical assessment provides insights into the natural processes and seasonal impacts affecting groundwater quality. The dominance of the Ca-HCO_3 hydrochemical facies suggests that the groundwater chemistry is primarily influenced by the weathering of carbonate minerals, consistent with the findings reported in previous studies on groundwater quality in similar geological settings (Laloo, Chandrakantha and Deshbhandari, 2020). The clustering of samples into distinct groups further suggests that localized factors, such as differences in aquifer lithology or recharge conditions, may play a role in shaping the spatial variability of groundwater chemistry within the study area.

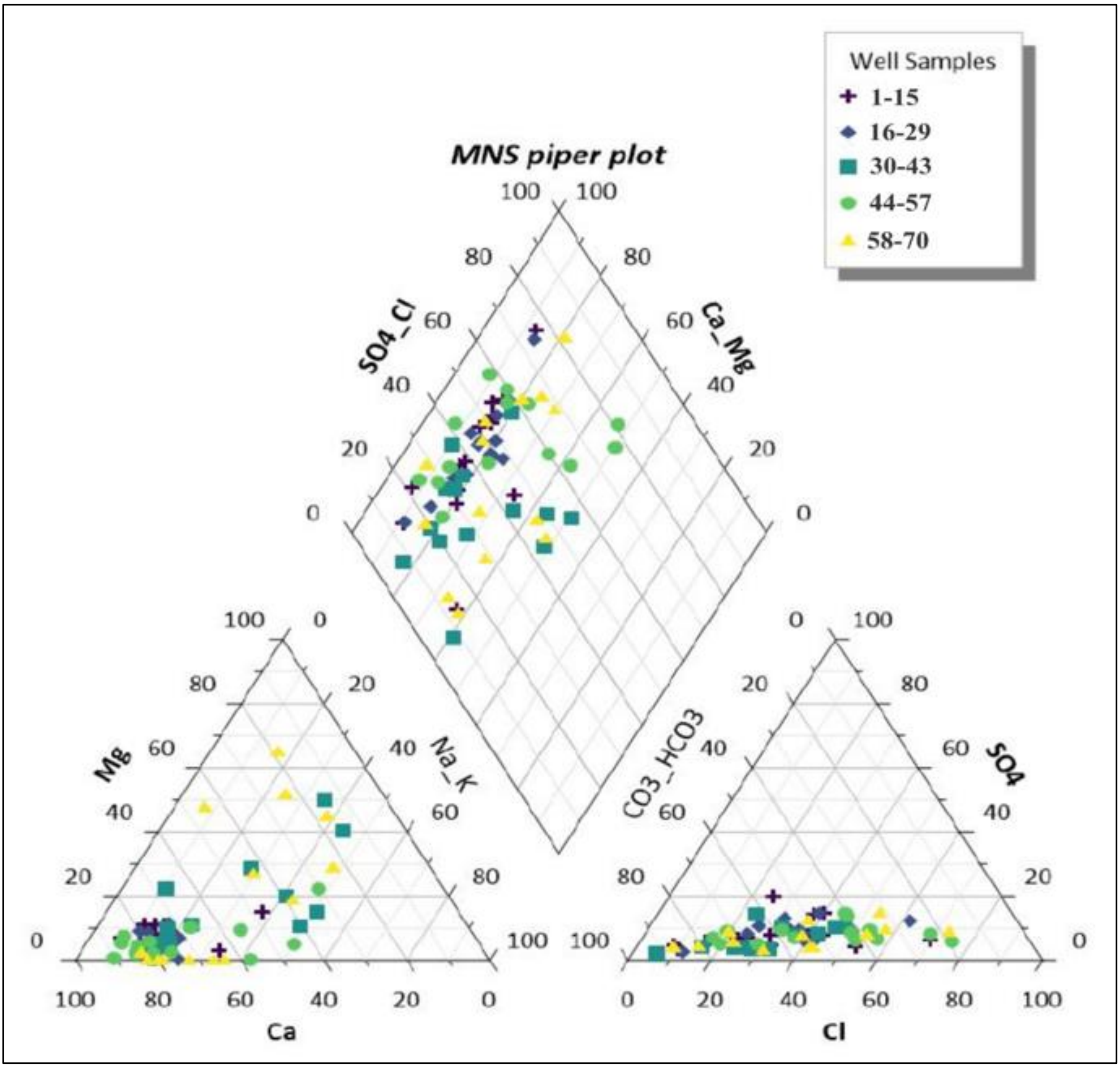

Fig 3 Piper Trilinear Plot of Monsoon(MNS) Season

Fig 3 depicts the Post-Monsoon hydrochemical facies of groundwater samples (Based on well samples ID [1–15, 16–29, Etc.]) as represented in the MNS Piper diagram.

Indeed, the left triangle of the diagram shows a strong concentration of calcium (Ca^{2+}) followed by magnesium (Mg^{2+}), and some variation from sodium (Na^+) and potassium (K^+) in the cationic composition. Also, the right triangle shows that bicarbonate and carbonate are the major anions and chloride and sulfate contribute slightly. These results are consistent with earlier hydrochemical investigations, which highlighted the significance of geological and seasonal control mechanism of groundwater quality (Laloo, Chandrakantha and Deshbhandari, 2020)(Diop and Tijani, 2014)(Palmajumder et al., 2021)(Chegbeleh, Aklika and Akurugu, 2020).

The core diamond of the Piper diagram incorporates these cationic and anionic information shows that most samples are Ca-HCO_3 type. This implies that the recharge zones are affected by the weathering of carbonate rocks.

Spatial variation between sample groups suggests localized hydrochemical processes, such as ion exchange or mixing, driven by post-monsoon recharge dynamics. The insights gleaned from the findings could be understood with owing evidence from the literature, which are varied intervals interval from geological and / or periodic influence of evapotranspiration on the hydrochemical characteristics of groundwater (Reddy et al., 2021) (Diop and Tijani, 2014) (Laloo et al., 2020).

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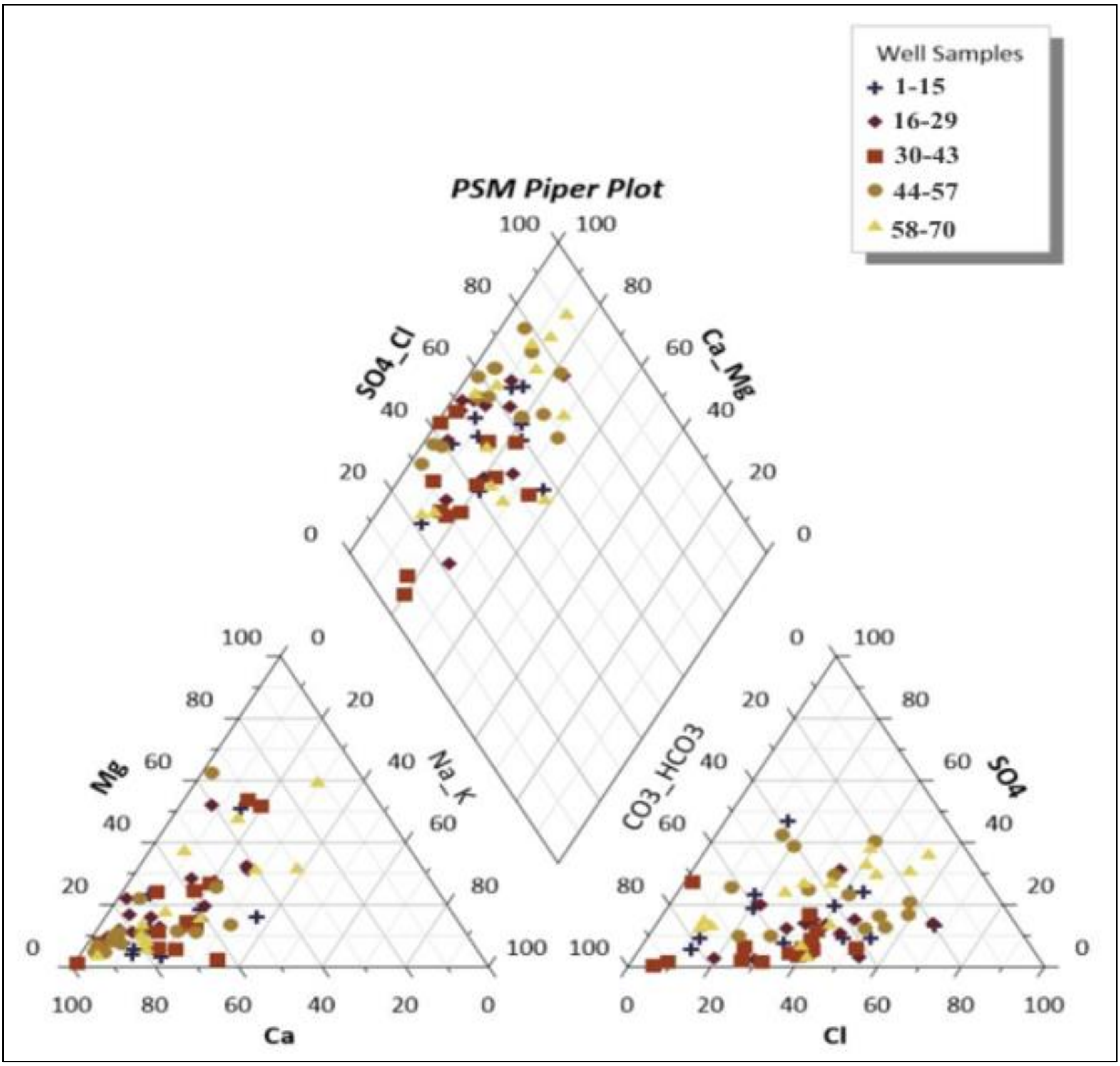

Fig 4 Piper Trilinear Plot of Post-Monsoon(PSM) Season

The PSM Piper diagram(Fig 4) represents groundwater samples showing the spatial and chemical variability of groundwater samples in post-summer monsoon period. Ca^{2+} and Mg^{2+} dominate the cationic triangle, with some influence from Na^{+} and K^{+}. Bicarbonate and carbonate dominate in the anionic triangle, along with trace amounts of chloride and sulfate. The upper left diamond plot combines those data and shows that most of the groundwater samples were Ca-HCO_3 types, which is indicative of the types of recharge influenced by carbonate rock weathering (Table 5). Differences within well samples (1–15, 16–29, etc.) illustrate localized processes like ion exchange, mineral dissolution, or anthropogenic effects. These hydrochemical patterns reinforce the findings of studies that examined the impact of monsoons on aquifer systems, which found that the geological formations and seasonal recharge on groundwater quality (Laloo, Chandrakantha and Deshbhandari, 2020)(Diop and Tijani, 2014)(Pandit, Shakya and Shrestha, 2019)(Alvarez-Campos et al., 2022).

Groundwater molecular composition is an important source of hydrogeochemical signature of earth surface weathering processes, and understanding solute constituents can simplify reconstruction of the major chemical interactions involved in groundwater mineralization. (Diop and Tijani, 2014) The isotopic composition of spring water was unchanged seasonally for the duration of this study and our previous published values from over a decade ago, indicating sources of recharge and groundwater flowpaths in support of springflow, seem to be relatively fixed in time (Alvarez-Campos et al., 2022).

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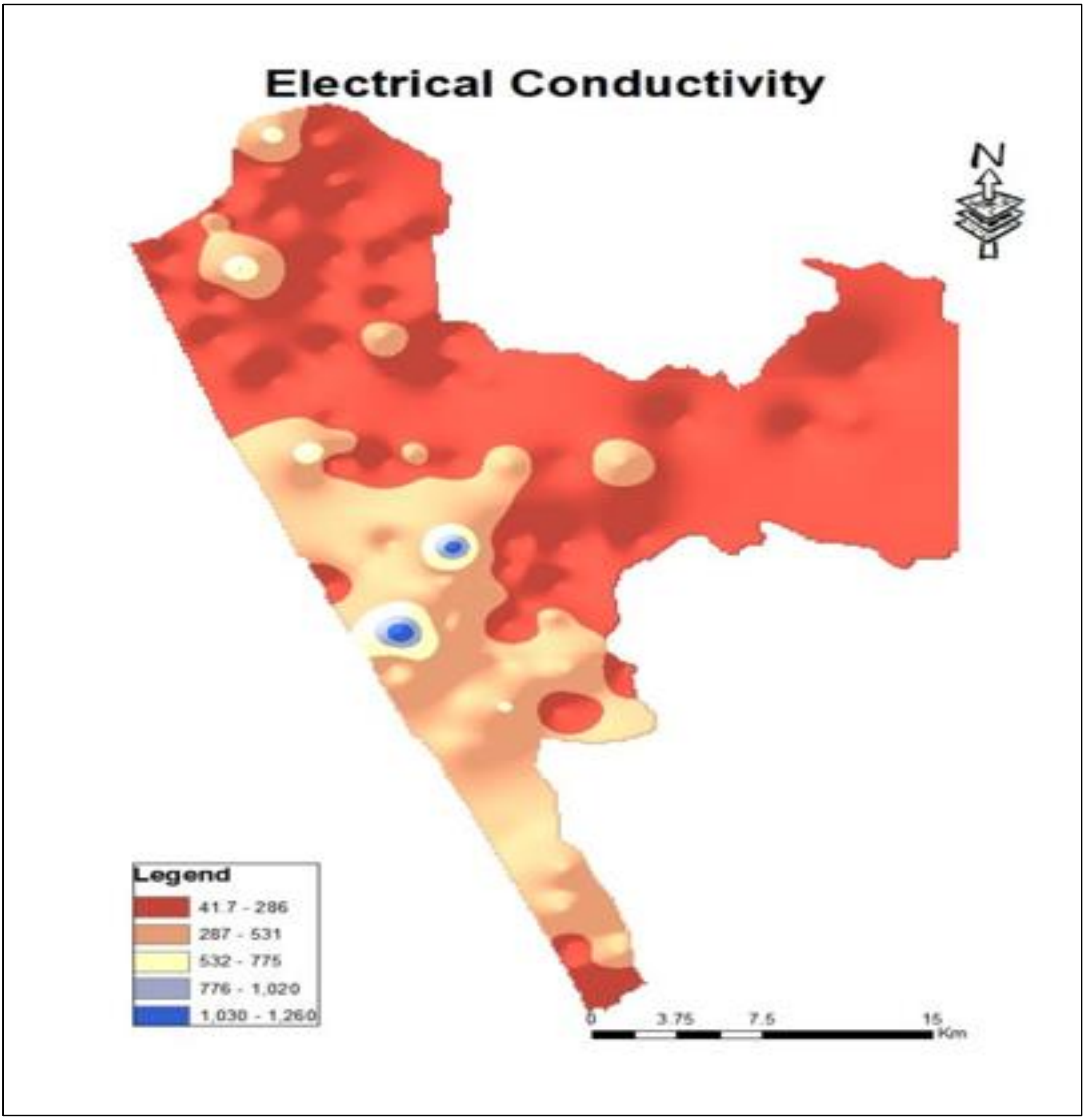

Fig 5 Spatial Distribution of Electrical Conductivity (EC)

Fig 5 Map of the spatial distribution of the Electrical Conductivity throughout the mapped region, illustrating its variability, caused either by geological or anthropogenic characteristics. Higher EC values (up to 1260 µS/cm) in the southern part of the region indicate high levels of dissolved ionic species, which may result from saline water intrusion or agricultural practices that leach salts. The phenomenon leads to the salinization of groundwaters characterized by higher concentration of the major groundwater constituent that is Na, Mg, Cl, and SO 4, and the value of electrical conductivity or total dissolved solids is high (1, 2). (Jeen et al., 2021) The adverse impact of salinity on plant growth is hydraulic as well as ion dependent toxicity(Mugai, E.N., 2004), giving rise to a reduction in the water potential of the soil solution and inhibiting plant roots from taking up water and nutrients. In contrast, the northern and central zones show relatively lower EC values, suggesting better water quality or reduced mineral dissolution. Such high EC levels in certain areas may render groundwater unsuitable for drinking or irrigation purposes without treatment, underscoring the need for targeted groundwater management strategies to mitigate salinization and improve water sustainability (Slama et al., 2023)(Jeen et al., 2021)(Mugai, 2004)(Ikuyinminu et al., 2023).

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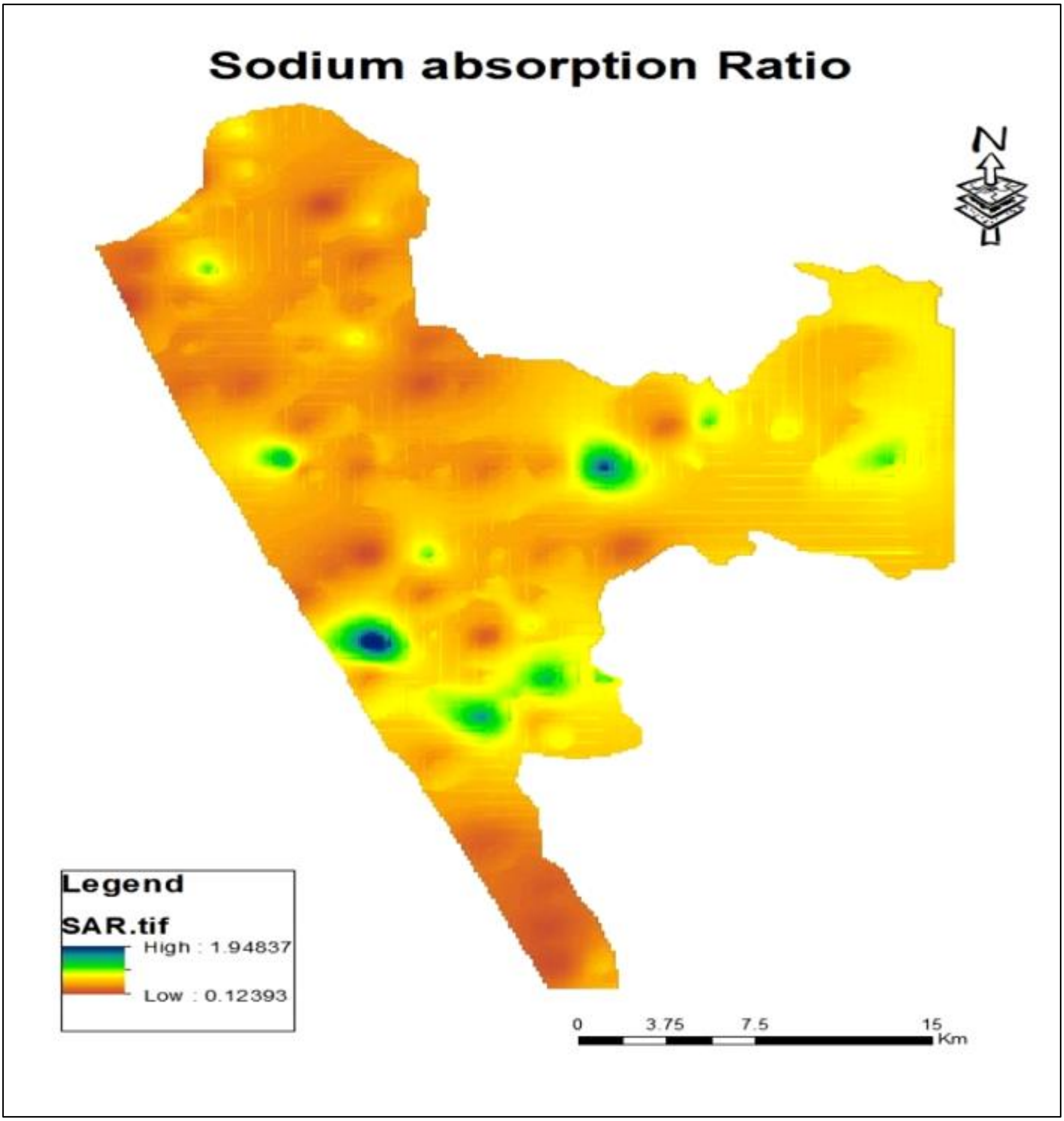

Fig 6 Spatial Distribution of Sodium Absorption Ratio

The spatial distribution of Sodium Absorption Ratio (**Fig 6**) in the study area identifies areas that can target irrigation uses. Low SAR regions, high density observed in central and southeast part, demonstrate an excellent quality of groundwater for irrigation since soil sodicity risk decreases with lower SAR, increased permeability of soil (Morway & Gates, 2011) (Elnashar et al., 2021). On the other hand, high concentrations of sodium (SAR) which are only detected in patches in both northern and southern zones can be potential indicators for excessive sodium accumulation in the soil with subsequent low soil fertility and yield of crops. Given that salinization and the diminished suitability of groundwater for irrigation can occur as a consequence of the overexploitation and poor management of water resources, the monitoring and management of underground SAR levels are vital for sustainable agricultural practices implemented in the region. (Shi, 2022) (Morway & Gates, 2011)

Spatial Interpolation analysis by inverse distance weight method highlights distinct spatial patterns for major cations, major anions, Sodium Adsorption Ratio, Electrical

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Conductivity and Water Quality index. The results suggest that the hydrochemistry of the groundwater in the study area is influenced by a combination of natural and anthropogenic factors(Gayathri, .A., Raj, V.T., Sreelash, . *et al*,2021), mineral dissolution, ion exchange, seawater intrusion, etc.

The assessment of groundwater quality for domestic and agricultural use revealed that about 70-80% of the open wells in Central Kerala were appropriate for irrigation use. But because of high salinity levels, a lot of this groundwater cannot be safely used for drinking. (Sivakarun et al., 2020) (Acharya et al., 2018) (Rumuri & Manivannan, 2020) (Susaiappan et al., 2021)

➢ *Overall Season Trend*

The box plot shown is comparing Water Quality Index across three seasons: Post-Monsoon, Monsoon and Pre-Monsoon(Fig. 3). The post-monsoon season median WQI value is around the median of WQI interquartile range, means the water quality is very stable. However, the outliers above the threshold of 100 indicate that some areas can see an increase in seasonal water pollution, which may be caused by agricultural runoff or low water levels (Dalal and Gupta, 2017). The median WQI during the Monsoon season is not much different from the Post-Monsoon season, although, the complete range looks less spread out with lesser extreme values. This might indicate a relatively more stable (less variable) water quality during Monsoon period. Nevertheless, there are still some outliers, though they are fewer and lower in value compared to the Post-Monsoon season. The WQI values in the Pre-Monsoon season exhibit a range similar to the other seasons, with the median slightly higher than the Monsoon season. Notably, there are several outliers exceeding 200, indicating poor water quality in certain locations prior to the Monsoon.

Most of the WQI points in the three seasons were remained consistently less than 100 providing a relatively lower water quality overall. Seasonality is seen but extreme values and outliers increase in Pre-Monsoon and Post-Monsoon seasons. Factors like agricultural runoff, decreasing water levels or other seasonal variations that impact water quality could be responsible for this trend (Shahnawaz, Kriplani and Iqbal, 2019)(Kumar et al., 2020). Overall, the water quality of the studied area shows some level of seasonal variation, with the Pre-Monsoon and Post-Monsoon seasons having the most fluctuation and issues with water quality, in contrast to the Monsoon season which has a much steadier and moderate range of water quality (Kumar et al., 2020) (Dalal and Gupta, 2017) (Mitra, Pal and Das, 2018) (Shahnawaz, Kriplani and Iqbal, 2019).

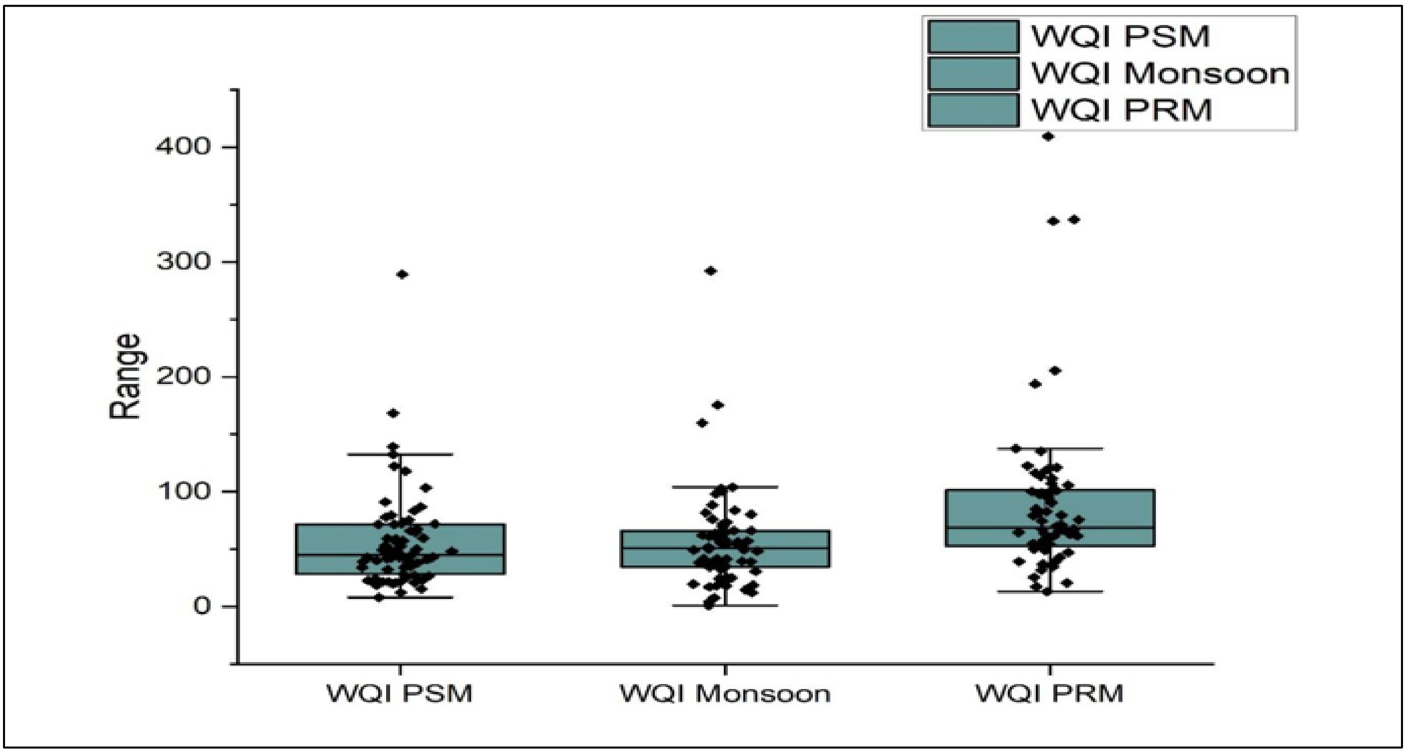

Fig 7 Overall Seasonal Trend of 3 Season.

Groundwater chemistry in coastal and agricultural areas has also been investigated in previous studies. The processes responsible for this phenomenon include water-rock interaction, cation exchange and seawater intrusion, as presented in these studies. (Sivakarun et al., 2020) For instance, a research project studying hydrogeochemical processes in a coastal alluvial aquifer determined the major factors controlling groundwater chemistry, which included dissolution, reverse ion exchange and seawater intrusion. (Sivakarun et al., 2020) In a research in Cuddalore district of India, in agricultural area, showed the groundwater chemistry was influenced by process such as mineral dissolution, cation exchange, and agricultural inputs. (Rumuri & Manivannan, 2020). These study results support the current literature findings, however also reveal into the hydrochemistry of groundwater in Central Kerala.

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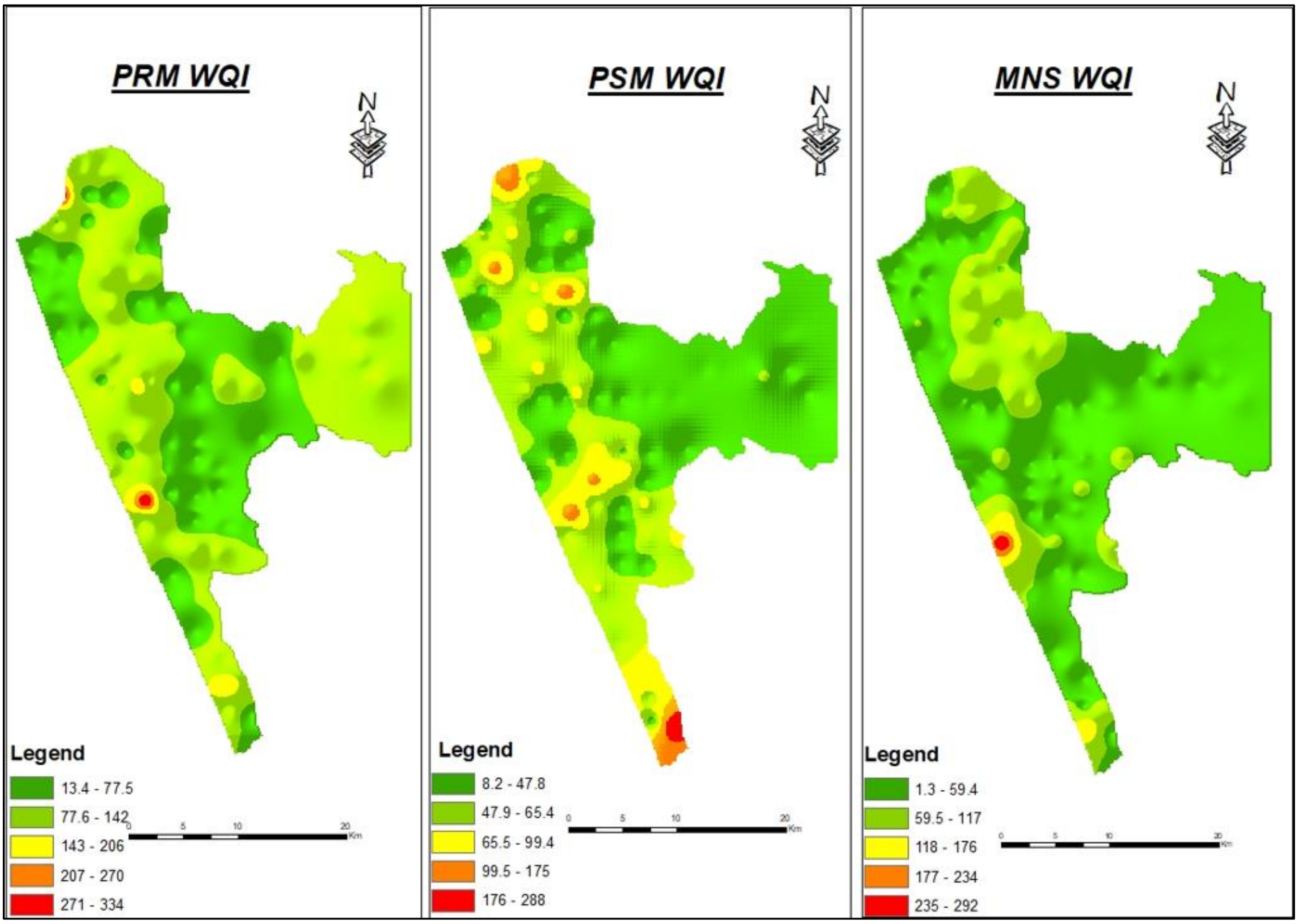

Fig 8 Spatial Distribution of Water Quality Index

Water Quality Index spatial variation (Fig 8) in the Thrissur-Ponnani Kole Land Basin delineates seasonal trends in the pre monsoon, post monsoon and monsoon season. As observed in the Pre-Monsoon WQI map shows areas that have relatively higher pollution levels, mostly in the southern and central zones. This could be due to less impact from dilution and more anthropogenic activities during the dry season (Nayan et al. 2018). Similarly, Post-Monsoon WQI shows a relatively better distribution of water quality because of rainsantosponsored recharge and dilution of contaminants. (Nayan et al., 2018) On the other hand, minimum levels of contamination were observed under Monsoon WQI indicating the beneficial effect of monsoonal rains in washing off pollution. These spatio-temporal patterns highlight the importance of seasonal dynamics and localized influences in shaping groundwater quality within this agricultural-dominated floodplain ecosystem, providing vital insights for sustainable water management and policymaking (Boyacıoğlu, 2009)(Krishan & Singh, 2016)(Nayan et al., 2018)(Jagadeesh & Agrawal, 2015).

IV. CONCLUSION

The chemical composition, salinity and its suitability towards domestic plants at the study area were found to be significantly scattered based on the hydrochemical approach of groundwater in Central Kerala. The present study demonstrates the significance of integrated hydrochemical and geostatistics, supplemented with spatial analysis to provide a clearer understanding for the better upholding of the aquifer and groundwater resources within the study region. Hydrochemical study of the groundwater from the Thrissur Ponnani Kol, Central Kerala, show that the groundwater is saline in nature, and contains mostly Ca+ and Cl- as major cations and anions respectively. Spatial interpolation using the inverse distance weighting method demonstrates the individual spatial behavior of the quantities of major ions, Sodium Adsorption Ratio, Electrical Conductivity and Water Quality Index. The major hydrochemical facies of groundwater in the sedimentary aquifers of Central Kerala show substantial variations across different locations. Groundwater chemistry is strongly affected by rock weathering during contact (Sunkari et al., 2020) and anthropogenic factors. Knowledge of groundwater chemistry is essential for aquifer protection and groundwater management (Pedley & Howard, 1997) (Kale et al., 2020) (Sunkari et al., 2020). Hydrochemical investigation proves very vital for recognization of water types: chemical determinations: and utility for specific use: which is the prime requirement for water use licensing applications. (Sunkari et al., 2020) (Kamble & Saxena, 2016).

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Groundwater hydrochemistry is critical to water resource utilization, which determines the applicability of different types of water (domestic, agricultural and/or industrial). The main groundwater aquifers in Central Kerala, India, are of sedimentary origin, which are highly vulnerable to the impacts of rock weathering and anthropogenic activities. Factors such as mineral dissolution, ion exchange, and seawater intrusion can significantly influence the chemical composition of groundwater in this region.Hydrochemical analysis acts as a very important method for comprehending the types of water, chemical composition of water and its appropriateness for diverse uses (Sunkari et al., 2020; Kale et al., 2020. Water stress data is important for water use licensing applications; lays out effective water management and allocation. The current study focuses on the analysis of hydrochemical data of groundwaters from 70 open wells collected from the Thrissur Ponnani Kol in Central Kerala using integrated statistical, geostatistical and spatial interpolation techniques.

Various studies have been reported on the hydrochemistry of groundwater in different areas including: (i) Saboba and Chereponi Districts of Ghana (Chegbeleh et al., 2020); (ii) Kwahu-Bombouaka Group of Ghana (Sunkari et al., 2020); and (iii) Kabar Tal wetland-Bihar, India (Gupta et al., 2021); A considerable number of such studies have been carried out and they emphasise the need for hydrogeochemical characterisation and assessment of groundwater quality (Sunkari et al., 2020) (Kadam et al., 2021) (Kale et al., 2020) (Gupta et al., 2021). In our study, the combination of statistical, geostatistical, and spatial interpolation methods facilitates a comprehensive processing of the hydrochemical data.The findings of this study will contribute to a better understanding of the groundwater hydrochemistry in Central Kerala and inform the development of effective aquifer protection and water resource management strategies. Hydrochemical study of the groundwater in Central Kerala's Thrissur Ponnani Kol region showed considerable spatial variation in the water quality, and the high level of Ca^+ and Cl^- is the predominating feature. The groundwater is mostly for irrigation, but many samples are unsuitable for domestic use because of the high salinity. These results have significant implications for groundwater resources management and the development of infrastructure to facilitate sustainable use of groundwater in this region.

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- *Declaration of Competing Interest*

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

- *Credit Author Statement*

Samreena Mohammed: Methodology, Data Curation, Resources, Software, Investigation, Writing- Original draft preparation.

K S Arunkumar: Conceptualization, Supervision, Writing- Reviewing and Editing.

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