Hydrogeochemical Assessment of Groundwater Along the Central Kerala Coast: Implications for Aquifer and Water Resource Management

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Abstract

Background: Hydrochemistry of groundwater is variable with location in Central Kerala dominated by sedimentary groundwater aquifers. Groundwater chemistry is also greatly influenced by activities to which humans engage in, like rock weathering during contact. Hydrochemical analysis is a basic tool to identify water types and their chemical compositions, as well as to determine whether a water is of a certain quality, which is an important requirement in any water use licensing project. **Aim:** This study aims to assess the hydrochemical data of groundwater samples. **Methods:** Sample collected from 70 open wells in and around the Thrissur Ponnani Kol in Central Kerala, through integrated statistical, Piper trilinear diagram, and spatial interpolation methods. **Results:** The results of this study show that Ca + and Cl− are the dominant cations and anions in the groundwater with mean concentrations of 267.39 mg/l and 574.81 mg/l, respectively. The pre-monsoon Piper: Hydrochemical facies of groundwater in the study area are depicted by plotting the relative concentration of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (SO_4^{2-}, Cl^{-}, HCO_3^{-}) in the Fig. Most groundwater samples in the study sequences belong to the calcium-bicarbonate (Ca-HCO_3) type, and most of the data points are located close to the Ca^{2+}-Mg^{2+} and CO_3^{2-}-HCO_3^{-} vertices, suggesting the predominance of carbonate weathering processes. Indicates little exchange of Na^{+}, K^{+}, Cl^{-}, and SO_4^{2-}, weak anthropogenic impact, like agricultural runoff or industrial discharge. **Conclusion:** Thus, the clustering of grouped samples denotes localized groundwater chemistry variations likely due to differences in geology and/or recharge conditions.

Keywords: electrical conductivity; groundwater; piper diagram; sodium absorption ratio

Introduction

Groundwater of Central Kerala, where sedimentary aquifers are prevalent, exhibits diverse hydrochemistry in different localities. However, processes like rock weathering during contact and anthropogenic activities exert considerable influence on the chemical composition of the groundwater. Groundwater chemistry needs to be established for aquifer preservation and groundwater utilization. Hydrochemical is an important approach used to characterize water types, composition and suitability for specific use which is necessary in water use licensing applications (Chekirbane et al., 2009)(Rumuri & Manivannan, 2020)(Sivakarun et al., 2020)(Elumalai et al., 2020).

Hydrochemistry of groundwater is an essential factor in water resources management tradeoff, as it indicates water's suitability for use for other uses, such as domestic, agricultural, and industrial uses (Rumuri & Manivannan, 2020). The sedimentary groundwater aquifers are common in Central Kerala, India and vulnerable to the impact of rock weathering and anthropogenic influences. Various intrusion of mineral dissolution, ion exchange and seawater on the chemical quality of the water can be found in the groundwater of the region (Sivakarun et al., 2020) (Rumuri & Manivannan, 2020).

A hydrochemical study is a key element to infer the characteristic type of water, its chemical quality, and suitability for different purposes. This information is vital to water use licensing applications, as determined by the SAP, in the efficient management and apportionment of water supplies. The present study is to evaluate the suitability of groundwater for domestic purposes in this region and to map the spatial distribution of certain water quality parameters in the study area by employing integrated statistical, geostatistical and spatial interpolation techniques using the 70 open well samples from the Thrisur Ponnani Kol in Central Kerala (Sivakarun et al., 2020) (Efobo et al., 2020) (Acharya et al., 2018) (Rumuri & Manivannan, 2020).

A number of studies have attempted to elucidate the hydrochemistry of groundwater in different parts of the world. Geographic Information Systems mapping, statistical analysis and geochemical modeling were used in conjunction to elucidate controlling factors on the groundwater chemistry in these studies.

Methods

Location of study area

The geographical area of central Kerala, India exhibits a variation in land-forms, such as midland, lowland and highland areas. Groundwater is widely used in this area for domestic, agricultural and industrial purposes. The availability of water in the region does not quite meet the increasing demand and a good and reliable groundwater resource evaluation is essential for sound management of the resource (Das et al., 2020).

The well-field area is located in the central part of Kerala, a tropical and geologically diverse state. Seasonal effect was investigated by sampling of groundwater from 70 accessions of wells during the months of July, November 2022, and March 2023. (Kolli et al., 2020) The objective of the study was to check the groundwater scenario in the area and propose management strategies toward a sustainable approach.

Hydrochemical Analysis

This work was carried out in central Kerala (India), an area depending on groundwater for domestic and agricultural requirements. Seventy open wells were selected for the hydro-chemical investigation in and around Thrissur-Ponnani Kol region. The groundwater samples were obtained from the selected open wells in the Pre-monsoon period. The samples were analyzed for various physio-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).

Descriptive, correlation and factor analysis have been used for statistical interpretation of the data to determine the hydrochemical characteristics and the factors controlling the groundwater quality (Jagadeesh & Agrawal, 2015). Geostatistical and spatial interpolation approaches like inverse distance weighting were used for mapping the spatial variability of major ions, sodium adsorption ratio, electrical conductivity and water quality index over the entire study area. The groundwater quality was assessed for its portability for domestic (drinking) and agricultural (irrigation) uses according to the standards prescribed by the World Health Organization and Bureau of Indian Standards (Raymahashay et al., 1987)(Kale et al., 2020)(Chegbeleh et al., 2020).

Results and Discussion

The hydro-chemical data analysis indicates that the water in the investigated area is saline, and Ca+ and Cl- are the dominant cation and anion, respectively. The average contents of Ca+ and Cl- were 267.39 and 574.81 mg/l, respectively, which suggested the impact of rock weathering and ion exchange with groundwater in the aquifer.

The Pre-monsoon Piper (Figure 2) depicts the hydrochemical face of groundwater in the investigation region in relation to concentrations of major ions. Most of the data points are gathered around the Ca^{2+}-Mg^{2+} and CO_3^{2-}-HCO_3^- vertices, revealing the prevalence of carbonate weathering (Diop and Tijani, 2014). The small proportion of Na^+, K^+, Cl^-, and SO_4^{2-} indicates a restricted exchange of ions and low impact of anthropogenic activities, such as agricultural wash or industrial effluent. The grouping of samples as clusters reveals regional differences in groundwater chemistry, which may reflect differences in geologic units or recharge areas (Pandit, Shakya and Shrestha, 2019).

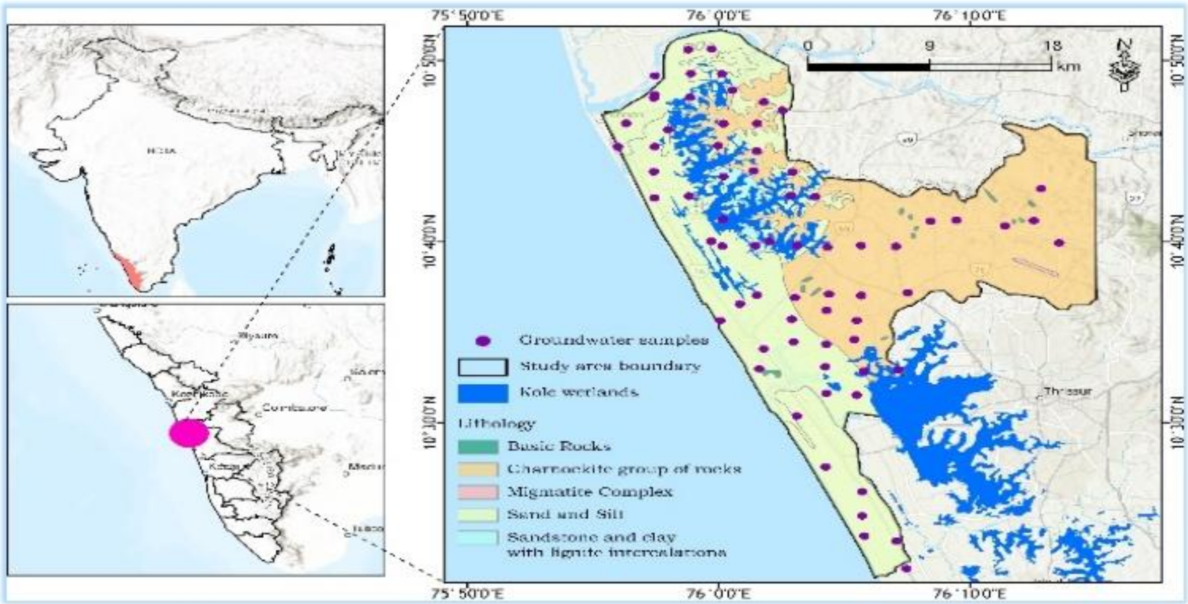

Figure1. Location of the study area with lithological variations and groundwater sampling locations

The data from this hydro-chemical examination offer information about the natural occurrence and seasonal effect on groundwater quality. The predominance of the Ca-HCO_3 hydro-chemical facies indicates that the water chemistry is predominantly controlled by the dissolution of carbonate minerals, proposed earlier in past studies discussing the groundwater quality of similar geological formations (Laloo,Chandrakantha & Deshbhandari, 2020). Clustering of samples into separate groups also implies that there could be a localized influence for example aquifer lithology or the recharge conditions that could be contributing to the spatial variation of the groundwater chemistry in the study area.

The left triangle of the graph, however, the isodose of calcium (Ca^{2+}) is dense, followed by magnesium (Mg^{2+}), and these isotopes vary little for sodium (Na^+) and potassium (K^+) in the cationic composition. Also, the right triangle implies that bicarbonate and carbonate are the primary anions, and chloride and sulfate provide for minor contributions. The results are in agreement with previous hydro-chemical studies, which revealed the importance of geological and seasonal control on the groundwater quality (Laloo, Chandrakantha and Deshbhandari, 2020; Diop and Tijani, 2014; Palmajumder et al., 2021; Chegbeleh, Aklika and Akurugu, 2020).

The main diamond ranging cationic and anionic information in Piper diagram reveals that most samples belong to the Ca-HCO_3 variety. This means that carbonate formations experience refuge zone effects with respect to chemical dissolution.

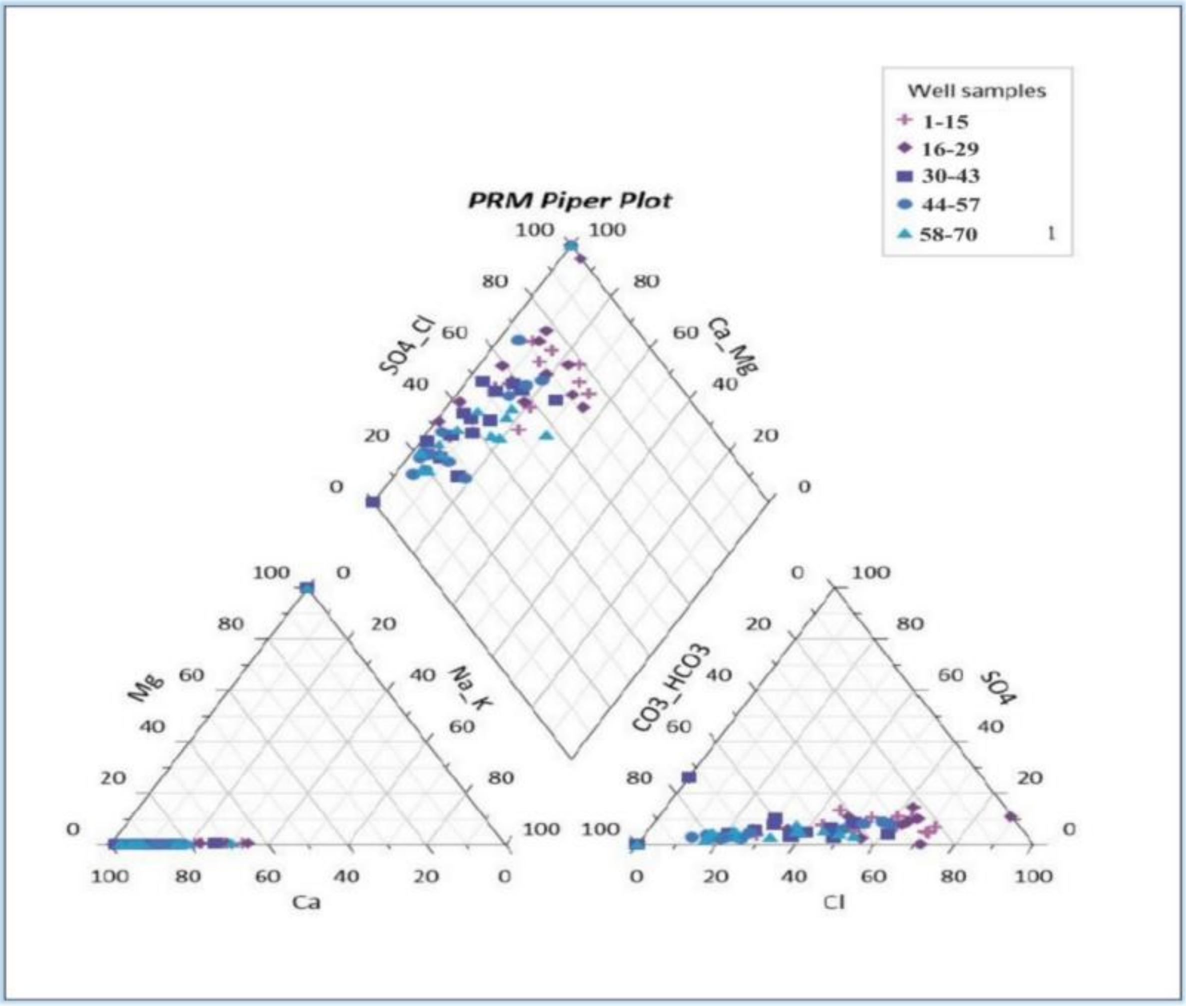

Figure 2. Piper Trilinear Plot of Pre-monsoon (PRM) Season

Zone of differences among different groups of samples revealed that some groundwater samples with close composition grouped together, indicating in-situ processes like ion exchange/mixing activities which occur as an effect of post monsoon recharge. The interpretations of the results can be comprehended when the partial evidence due to literature are described as one or several stages from short term which is caused by geology and/or periodic evapotranspiration induced effects on the hydro-chemical character of the groundwater (Reddy et al., 2021; Diop and Tijani, 2014; Laloo et al., 2020).

Figure 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. The PSM Piper diagram (Figure 4) has been used to trilobite the groundwater samples and show the geographic and chemical variability in the post summer monsoon period groundwater samples. The cationic triangle is grossly dominated by Ca^{2+} and Mg^{2+} , with some participation from Na^{+} and K^{+}The anion triangle is dominated by bicarbonate and carbonate, along with traces of chloride and sulfate. The top left diamond plot shows the combined data and reveals that most groundwater samples were of the Ca-HCO_3 types, dominated in recharge type characterized by carbonate rock weathering (Table 5). Within well variability (1–15, 16–29, etc.) depicts localized reactions such anion exchange, mineral dissolution or anthropogenic impacts. These hydro-chemical 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).

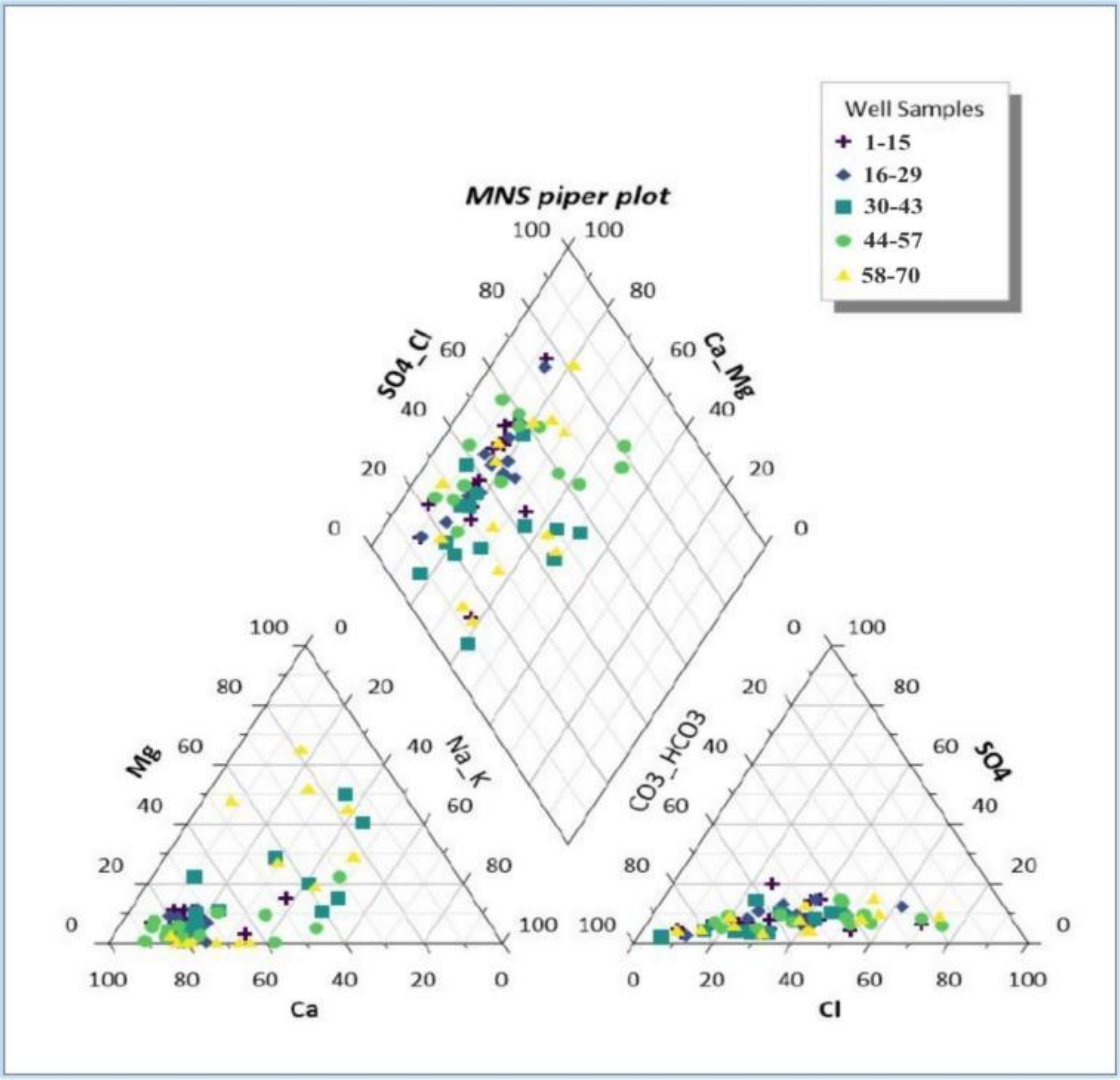

Figure 3. Piper Trilinear Plot of Monsoon (MNS) Season

The molecular composition of groundwater is also an invaluable carrier of hydrogeochemical signal of cosmospheric origin to earth surface weathering, and consequently the identification of solute components can facilitate the reconstruction of the principal chemical reactions during groundwater mineralization (Diop and Tijani, 2014). The isotopic composition of the spring waters did not vary seasonally over the period of this study, over and above our previously published values from 12 years ago, suggesting that, the spring recharge sources and ground water flow paths supporting the spring flow probably have little temporal variation (Alvarez-Campos et al., 2022).

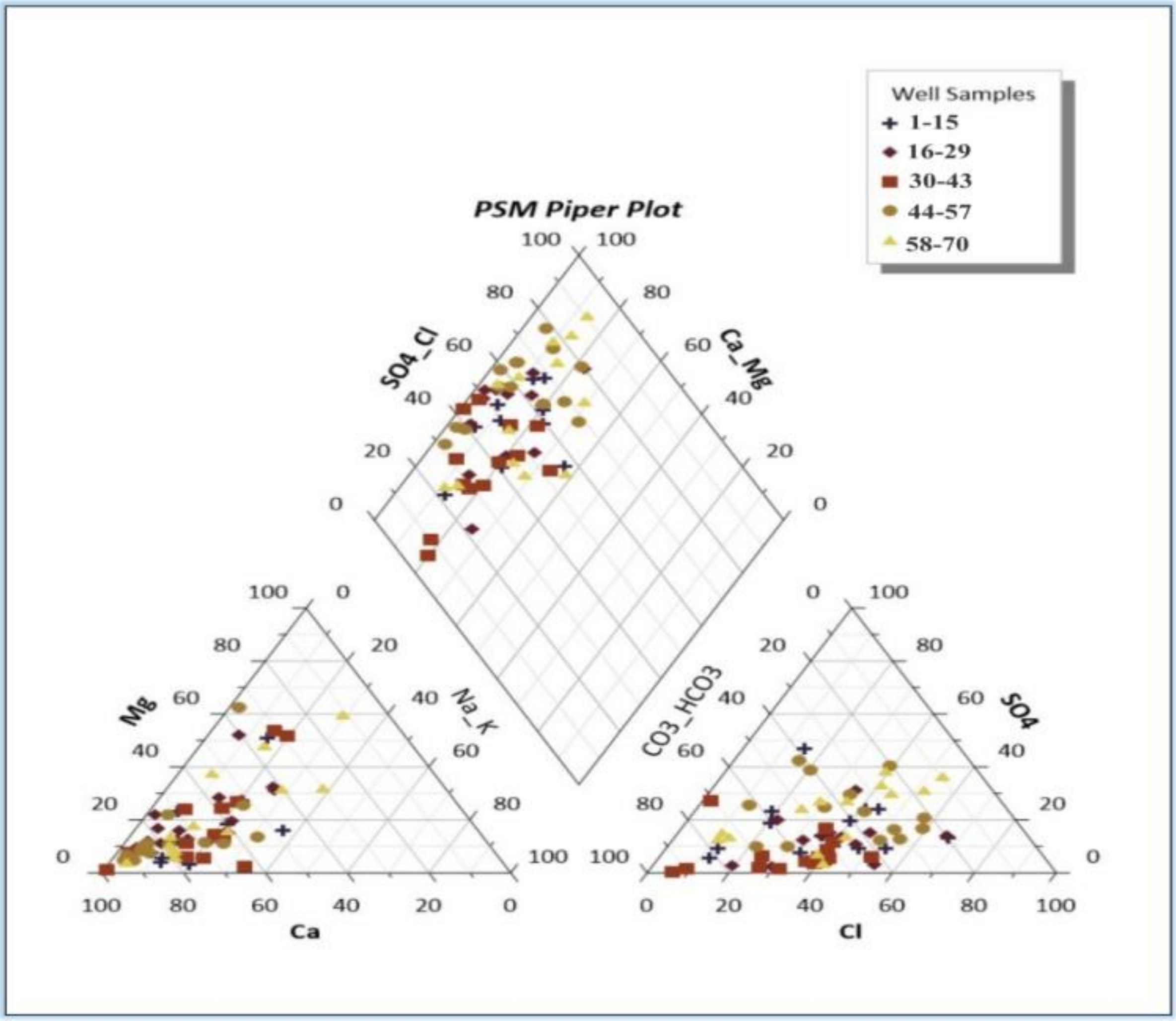

Figure 4. Piper Trilinear Plot of Post-Monsoon (PSM) Season

Figure 5, Map of the spatial pattern of the Electrical Conductivity over the mapped area, showing variation, which could be due to geological or human influences. Greater EC values (approximately 1260 μS/cm) for the southern part of the study area suggest high dissolved ionic species, potentially attributed to seawater intrusion or agricultural processes that leach salts. The phenomenon results in the salinization of the groundwater with higher concentrations of dominating groundwater constituents, i.e., Na, Mg, Cl, SO 4, and then water becomes fit for agricultural use when the value of electrical conductivity or TDS (alkaline, saline) is high (1, 2) (Jeen et al., 2021). The detrimental effect of salinity on plant growth is both hydraulic and 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).

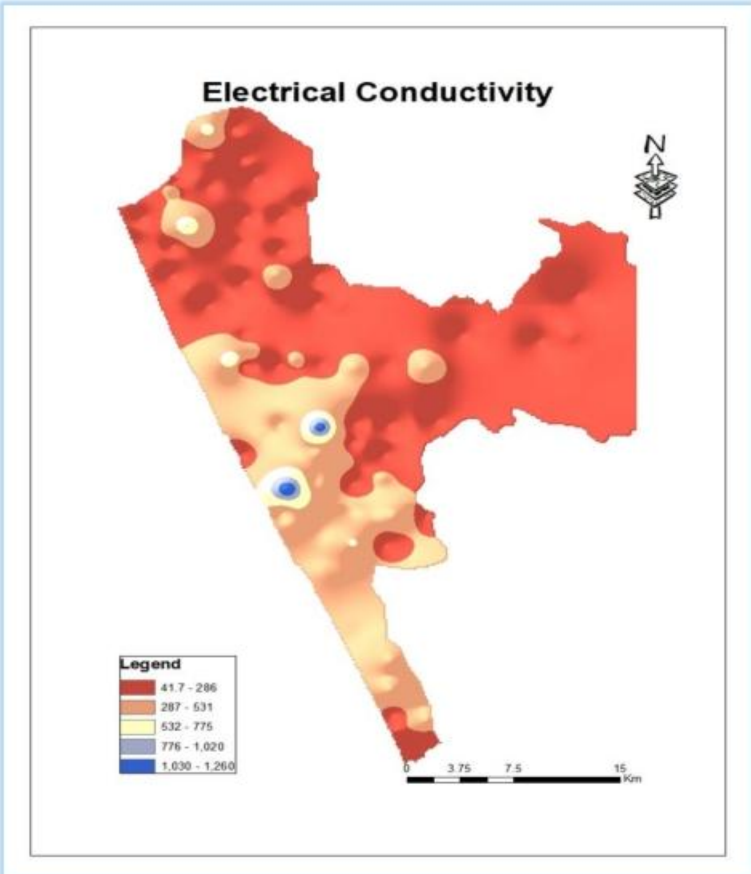

Figure 5. Spatial Distribution of Electrical Conductivity (EC)

The spatial variation of Sodium Absorption Ratio (Figure 6) shows the locations which can utilize waters for irrigation purpose. Low SAR regions (high density which represents central and southeast part) indicate good groundwater quality for irrigation, as the risk of soil periodicity decreases with SAR being lower in soil (Morway & Gates, 2011; Elnashar et al., 2021). On the contrary, high SAR levels, which are observed in points both in the north and the south zones, may indicate excessive sodium accumulation in soil and a consequence of low soil fertility and crop yield. Given that salinization and the diminished suitability of groundwater for irrigation can occur as a consequence of the over-exploitation 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 using inverse distance weight method reveals distinct spatial patterns of major cations, major anions, Sodium Adsorption Ratio, Electrical Conductivity and Water Quality index. The observation of the hydro-chemical characters of the groundwater reveals a complex composition resulting from natural and man-made factors(Gayathri, A., Raj, V.T., Sreelash, et al,2021) and mineral dissolution, ion exchange, seawater intrusion, etc.

The evaluation of the suitability of groundwater for domestic and agricultural purposes indicated that 70-80% of the open wells in the Central Kerala were suitable for irrigation purposes. Much of that groundwater, however, is not fit for safe drinking because of high levels of salinity (Sivakarun et al., 2020; Acharya et al., 2018; Rumuri & Manivannan, 2020; Susaiappan et al., 2021).

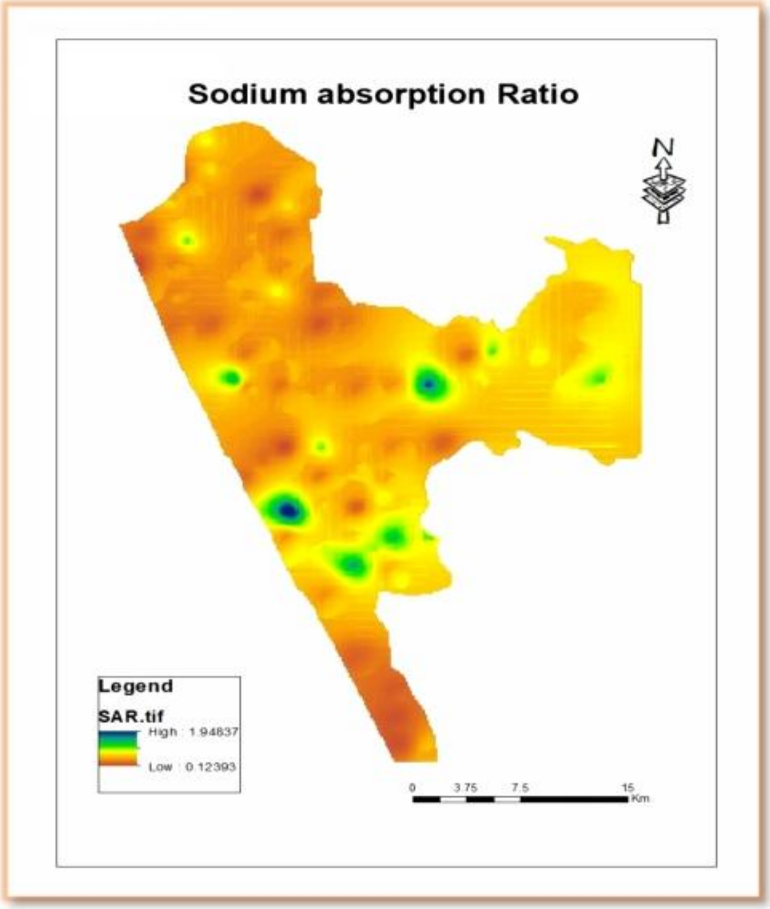

Figure 6. Spatial Distribution of Sodium Absorption Ratio

Overall Season Trend

The box plot as shown comparing Water Quality Index of the three seasons i.e., Post-Monsoon, Monsoon and Pre-monsoon (Figure 7). The post-monsoon median WQI falls on approximately the median of WQI inter-quartile range which indicates good steadiness in the water quality. Nevertheless, five points are above the threshold of 100, showing that some areas can be subject to a higher pollution level in water during the rainy season, due to either agricultural runoff or low water levels (Dalal and Gupta, 2017). The median WQI during the Monsoon is hardly different than the one from the Post-Monsoon, however, the distribution looks less spread with fewer extreme values. This could suggest a little more stable (less variable) water quality during Monsoon season. However, some exceptions remain, albeit in lower numbers and values than the PM season. The WQI values during Pre-monsoon varies within the same range and the medians are slightly higher than the Monsoon season. Importantly, there are a few outlier values greater than 200, which reflects the poor water quality in some sites before the onset of the Monsoon.

For most of the WQI points in the three seasons, the points were lower than 100, which means that the overall water quality was comparably low. Seasonality is observed but extreme and outlier values are larger in Pre-monsoon and Post-Monsoon seasons. Such kind of factors, i.e., rural run-off, reduced water level or any other seasonal changes that affect water quality can be responsible for this pattern (Shahnawaz, Kriplani and

Iqbal, 2019)(Kumar et al., 2020). In general, the water quality of the study area exhibits some seasonal variations, with the Pre-monsoon and Post-Monsoon being more varied and problematic with respect to water quality compared to the Monsoon, which has a relatively stable and less varied water quality (Kumar et al., 2020; Dalal and Gupta, 2017; Mitra, Pal and Das, 2018; Shahnawaz, Kriplani and Iqbal, 2019).

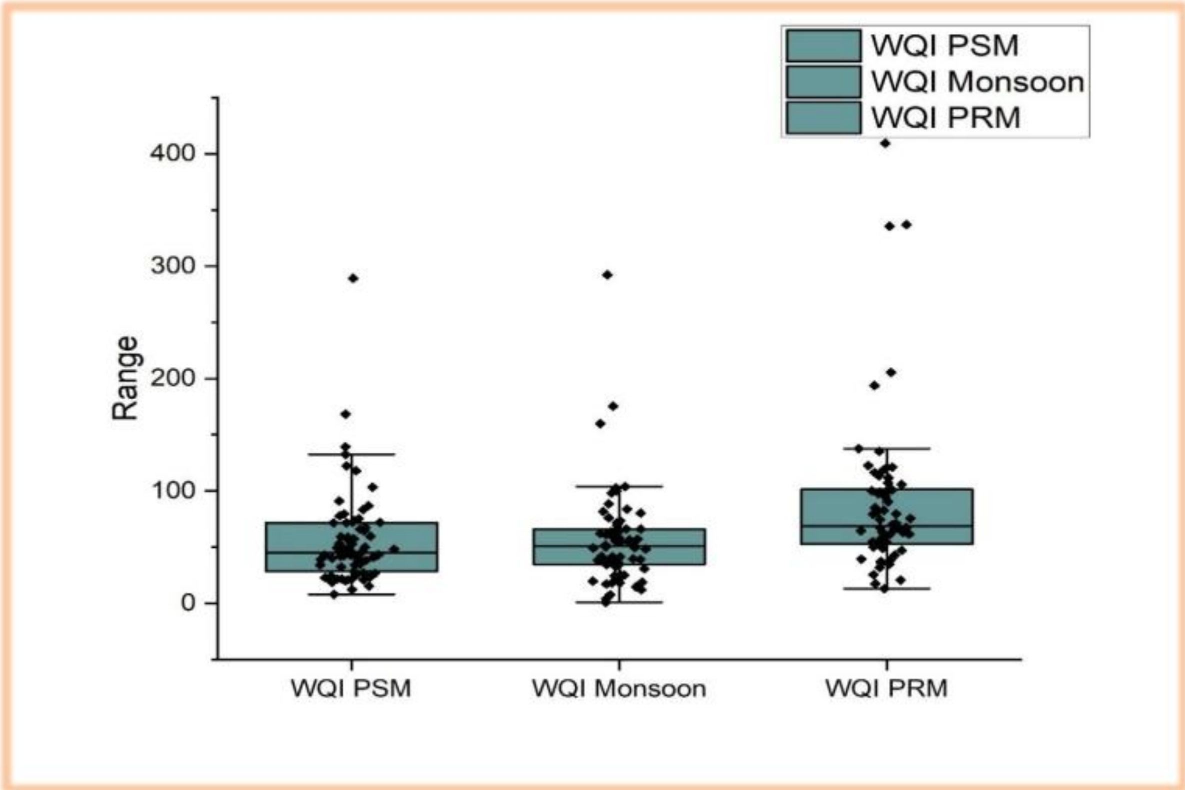

Figure 7. Overall Seasonal trend of 3 Season.

Groundwater's geochemical aspects in coastal and agricultural settings have also been studied in the past. The mechanisms driving this have been shown to include water–rock interaction, cation exchange and seawater intrusion (;) (Sivakaran et al., 2020). For example, a study of hydrogeochemical processes in a coastal alluvial aquifer identified the dominant controls over groundwater chemistry to be dissolution, reverse cation exchange and seawater intrusion (Sivakarun et al., 2020). Research in Indian Cuddalore district in agricultural area showed that the groundwater chemistry in the study area was controlled by the processes of mineral dissolution, cation exchange, and agricultural inputs (Rumuri & Manivannan, 2020). The present study findings are in accordance with literature findings and also provide insights into groundwater hydrochemistry in Central Kerala.

Seasonal variation The spatial distribution of the WQI, as shown in Figure 8 in the Thrissur-Ponnani Kole land basin, reveals seasonal characteristics during pre-monsoon, post-monsoon, and monsoon season. Few areas with increased pollution levels can be seen in southern and central regions as indicated in the Pre-monsoon WQI map above. This difference could be attributed to lesser influence of dilution and increase in anthropogenic activities in the dry season (Nayan et al. 2018). Likewise, Post-Monsoon WQI depicts a relatively better distribution of water quality due to rains recharge and dilution of pollutants (Nayan et al., 2018). Conversely, the least contamination level was noted under Monsoon WQI, which may be attributed to the beneficial effect of monsoonal rains, as it washes off pollution. These spatio-temporal patterns highlight the importance of seasonal dynamics and localized influences in shaping groundwater quality within this agriculturally dominated floodplain ecosystem, providing vital insights for sustainable water management and policymaking (Boyacıoğlu, 2009; Krishan & Singh, 2016; Nayan et al., 2018; Jagadeesh & Agrawal, 2015).

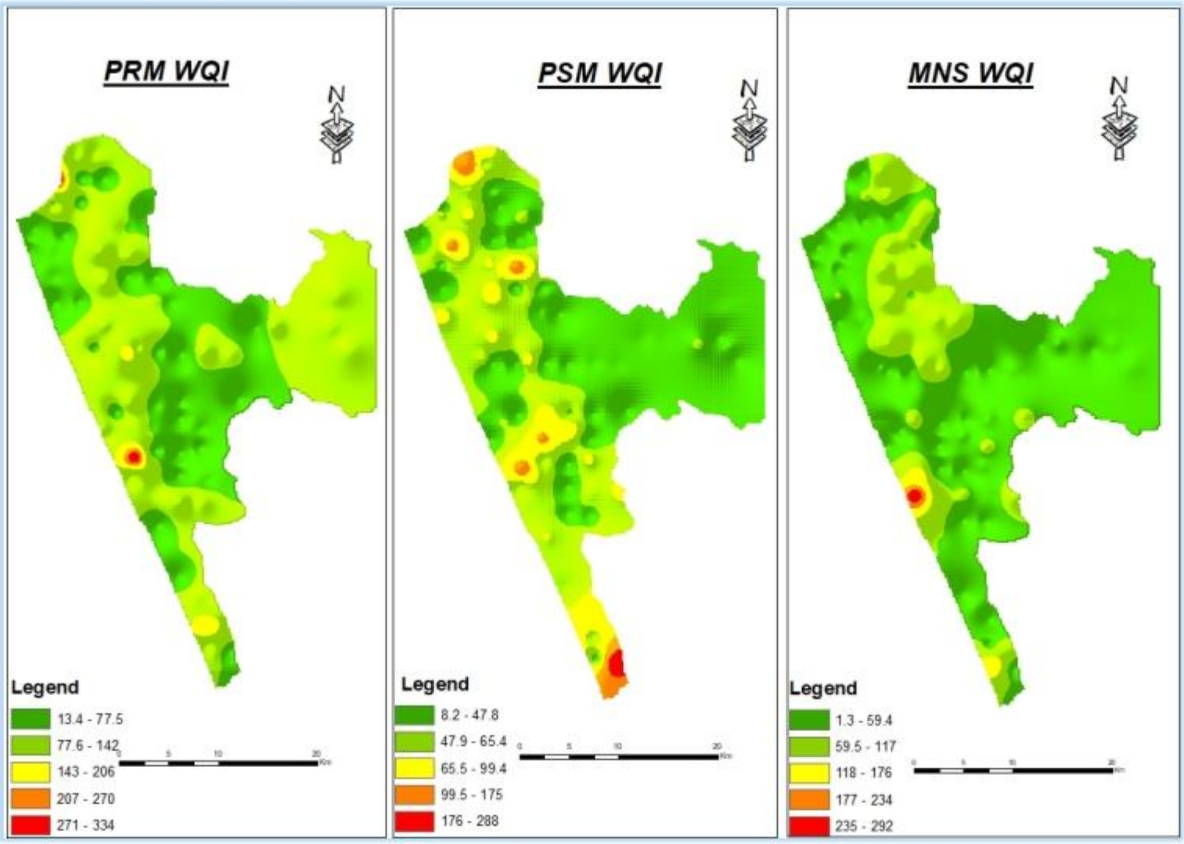

Figure 8. Spatial Distribution of Water Quality Index

Conclusion

According to the hydro-chemical classification of groundwater in Central Kerala, the chemical composition, salinity, and suitability to domestic plants in the study area were highly dispersed. The current work highlights the importance of combining hydro chemistry and geostatistics, along with spatial analysis for the better planning of the aquifer and groundwater resources in the study area. Hydrochemistry of the groundwater of 'Thrissur Ponnani Kol' region in Central Kerala, demonstrates that the groundwater is saline and it is dominated by Ca+ and Cl- as a water chemistry couple of ions, as in major cations and anions respectively. The individual spatial variation of major ions, SAR, EC and WQI is observed through the Spatial interpolation method based on the inverse distance weighting approach. The major hydro-chemical 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. Hydrochemical investigation proves very vital for recognition of water types: chemical determinations, and utility for specific use, which is the prime requirement for water use licensing applications.

The hydrochemistry of groundwater is an important factor for water resources management, particularly in the application of different types of water (domestic/agricultural and industrial). The primary aquifers in Central Kerala, India, are sedimentary sediments that are very sensitive to the weathering of rock and human interferences. Mineral dissolution, ion exchange, and seawater intrusion might have strong impacts on the chemical composition of groundwater in this area. Hydro-chemical study plays a very significant role in understanding the nature of water, its chemistry, and suitability for various purposes. Water stress information is valuable for water use licensing applications; it defines efficient water management and allocation. In the present research, the hydrochemistry data are analysed and described. The current study focuses on the analysis of hydro-chemical data of groundwater from 70 open wells collected from the Thrissur Ponnani Kol in Central Kerala using integrated statistical, geostatistical, and spatial interpolation techniques.

The results of the present study will aid in providing a better insight into the groundwater hydrochemistry of the region and will guide in the formulation of pollution control plans and water management programmes. Hydrochemistry of the groundwater of the Thrissur Ponnani Kol in the Central Kerala region revealed significant spatial variability in water quality, with high Ca^+ and Cl^- being the principal characteristics. Most of the groundwater is used for irrigation, but many samples aren't suitable for domestic use due to the high salinity. These findings have important implications for groundwater regulation and the construction of infrastructures for sustainable groundwater use in this area.

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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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