Comparative Geospatial Analysis of Hydrogeochemical Characteristics of Water in the Northern Part of Mizoram.

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Abstract: This study attempts to evaluate the hydrogeochemical properties of groundwater in Aizawl district, Mizoram, India. To evaluate groundwater quality, 60 water samples were collected from both surface and subsurface sources over two seasons: pre-monsoon and southwest monsoon. The water samples were analysed for several hydrogeochemical parameters, including pH, electrical conductivity (EC), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), bicarbonate (HCO_3), sulphate (SO_4), phosphate (PO_4), nitrate (NO_3), fluoride (F), and silicate (H_4SiO_4) following a standard procedure. The analytical findings indicate that the majority of the physical characteristics, with the exception of pH, were within the allowed limits established by WHO and BIS. The spatial distribution map, generated from the water chemistry data, indicates that most parameters with higher concentrations are concentrated in the central region of the research area, which also exhibits a high population density. The comprehensive findings indicate that the water quality in the research region is suitable for household, agricultural, and industrial purposes.

Keywords: Spatial Distribution, Water quality, Aizawl district, WHO, BIS.

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Introduction

In recent years, there has been an evident increase in the number of countries with groundwater as one of the most important natural resources. The global importance of groundwater as a major source of fresh water for agricultural and domestic uses cannot be overemphasised. Also, groundwater constitutes an important component of the water cycle and it is partly used to maintain soil moisture, stream flow and wetlands, as well as being the source of drinking water, agricultural and industrial supplies in many parts of the world (Viviroli et al., 2011). Groundwater is a vital resource that must be protected and managed sustainably. Groundwater depletion and contamination are growing concerns that require careful monitoring and regulation to ensure their long-term availability. Sustainable management practices, such as recharging aquifers and reducing pollution, are essential to safeguard this valuable resource for future generations (Stavenhagen et al., 2018). By implementing proper conservation measures and promoting responsible water usage, we can help preserve groundwater for years to come. Governments, industries, and individuals must work together to protect this essential resource and ensure its availability for both current and future needs (Angelakıs et al., 2020).

Groundwater is the primary source of potable water in both urban and rural regions of India. Over the years, the water demand has escalated, resulting in water scarcity in several regions of the country. The issue of water pollution or contamination exacerbates the predicament. India is approaching a freshwater crisis, mostly owing to inadequate management of water resources and environmental deterioration, resulting in millions lacking access to a clean water supply (Chidambaram et al., 2022; Chockalingam et al., 2021). The freshwater issue is already apparent in several regions of India, differing in magnitude and severity, primarily depending on the season. India is the foremost global consumer of groundwater for irrigation purposes (Shukla & Saxena, 2020).

The groundwater conditions in Mizoram are predominantly marked by restricted potential, chiefly attributable to the state's mountainous topography and the low availability of valley fill regions suitable for groundwater storage. Mizoram has sufficient rainfall; nonetheless, a considerable amount is lost as surface runoff, restricting groundwater recharge. The state's groundwater extraction is quite low, with the majority of the extracted water utilised for potable and other residential applications (CGWB, 2024). Studying groundwater quality in

Mizoram is crucial due to escalating population growth, urbanisation, and environmental issues. As urban areas like as Aizawl grow, there is increasing pressure on groundwater supplies, potentially resulting in pollution. Agricultural practices and industrial operations lead to pollution, compromising water quality for drinking and residential use. Moreover, certain areas have shown elevated levels of heavy metals, such as manganese, above acceptable thresholds, hence necessitating consistent monitoring (Zonunthari et al., 2023). Numerous rural populations in Mizoram rely on natural spring water for their daily requirements, rendering groundwater evaluations essential for public health. Sustainable management strategies, such as phytoremediation and enhanced filtration systems, can assist in sustaining water quality for long-term usage (Malsawmtluanga et al., 2021). By performing extensive research and adopting remedial actions, groundwater may be safeguarded, assuring safe and reliable access for future generations.

Study Area

Aizawl district is located in the central and northern part of Mizoram, encompassing the state capital, Aizawl city, which is situated on the north of the Tropic of Cancer in the northern part of Mizoram and situated on a ridge 1,132 meters (3715 ft) above sea level, with the Tlawng River valley to the west and the Tuirial river valley to the east. Aizawl district is surrounded by Kolasib to the north and north-east by sections of Manipur state, Mamit to the west, Serchhip to the south, and Champhai to the east. It encompasses an area of 2138.62 sq km. Geographically, the district is located in 28’18’24.04” N to 24’24’47.23” N latitudes and 92’37’27.62” E to 93’02’26.71” E longitudes (Lalnarammawia Krista & Anandhan Paluchamy, 2024). The area receives substantial rainfall between May to late September, with an average annual rainfall of 2,794 mm under the influence of the southwest monsoon (CGWB, 2024). Fig. 1 illustrates the study area map.

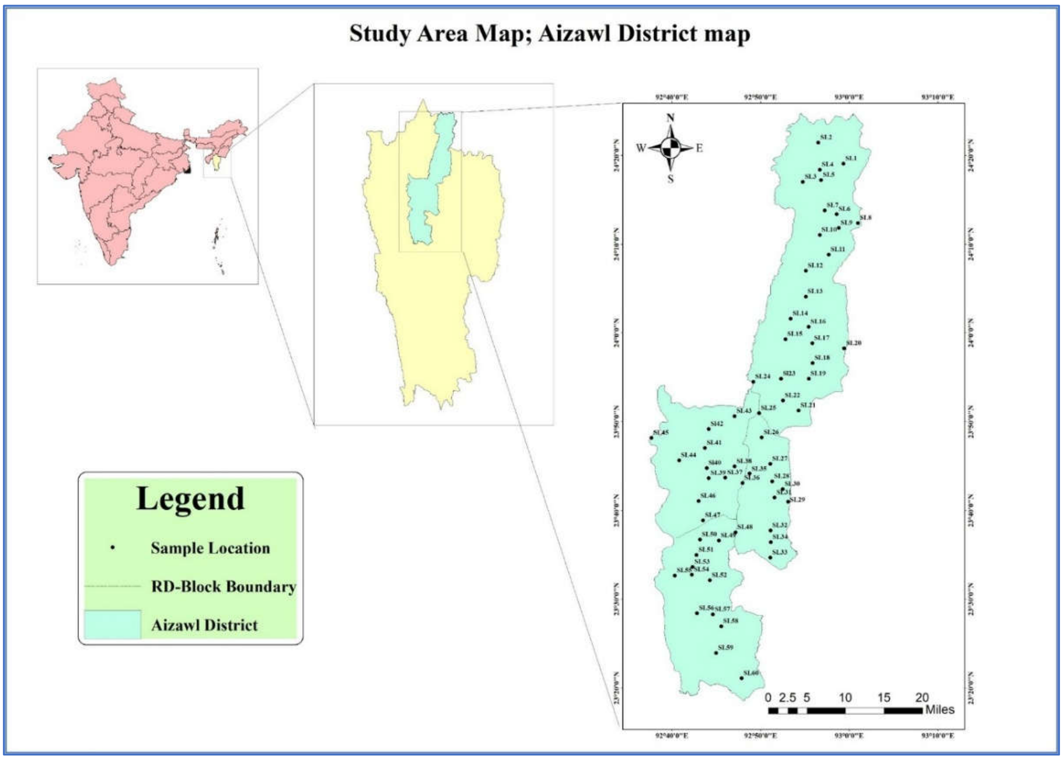

Fig 1. Study area map

Materials and Methods

Water samples were collected from 60 different locations for two seasons pre-monsoon and Southwest monsoon (January 2023 and July 2023), and tested for physicochemical. The water was analyzed for major ions such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Chloride, Carbonate, Bicarbonate, Calcium, Magnesium, Sodium, Potassium, Silica, Nitrate, Fluoride and Phosphate. The analysis was carried out with the standard made by the American Public Health Association (2012) procedure, and suggests precautions are taken to avoid contamination. The analyzed data were digitized and analysis of spatial interpolation was done using GIS software like Google Earth Pro, QGIS and ArcMap. The spatial variation maps of the major water quality parameters were produced as a thematic layer following BIS guidelines.

Results and Discussions

The minimum, maximum and average value of the chemical analysis of the physicochemical parameters of the study area for PRM and SWM are shown boxplot (Fig. 2). The average concentration of the physicochemical parameters of the two seasons is compared with the World Health Organization (WHO) and Bureau of Indian Standards (BIS) as shown in table 1. The comparison of spatial variation of the physicochemical analysis in the study area shows that majority of the parameter's concentration decrease during SWM which can be due to the dilution of water during the monsoonal rainfall.

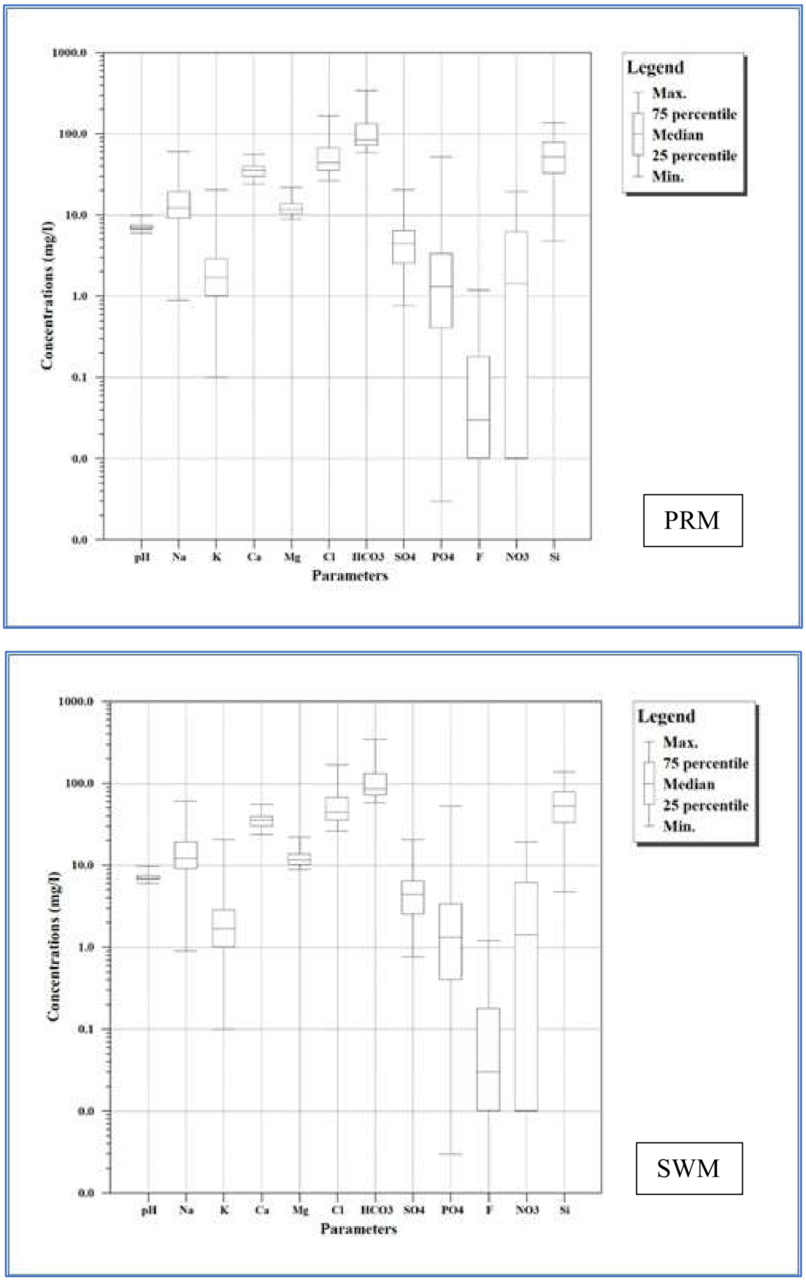

Fig 2. Boxplot for all parameters except EC and TDS, during Pre-monsoon and Southwest monsoon

Table 1. Comparison of an average value of different parameters with WHO (2011) and BIS (2012) for two seasons.

Parameters	WHO acceptable limit	BIS acceptable limit	Average concentrations of the sample	
			PRM	SWM
pH	6.5-8.5	6.5-8.5	7.17	7.00
EC	500-1500	500-1500	274	295
TDS	500-1500	500-1500	310	236
Bi-carbonate	30-1500	***	114.50	56.30
Chloride	200-1000	250-1000	54.52	55.20
Fluoride	0.5-1.5	0.5-1.5	0.11	0.18
Nitrate	45	45	4.57	4.63
Sulphate	200-400	150-400	5.03	2.99
Calcium	75-200	75-200	36.03	28
Magnesium	50-150	30-100	15.85	9.86
Sodium	50-200	***	17.00	12.20
Potassium	200	***	3.46	2.40
Phosphate	200	***	4.53	1.57

pH

The pH denotes the concentration of hydrogen ions shown in logarithmic terms. The activity of hydrogen ions is regulated by chemical reactions that generate or deplete hydrogen ions. Thus, pH serves as an indicator of the equilibrium reaction in water. pH in the study area varies from 6.01 to 9.92 during PRM and 6.10 to 9.56 during SWM, with an average value of 7.17 and 7.00 during PRM and SWM. The spatial variation of pH in the study area is shown in Fig. 3, which shows that the value exceeds the acceptable limit and is clustered in the central part of the study area.

Electrical Conductivity (EC)

EC is the ability of a substance to conduct an electric current. The measure of conductivity is directly proportional to the strength of the water. The EC for purest water is 0.05 μs/cm^2 (Hem, 1991). EC value ranges from 23 to 825 μs/cm^2 during PRM and 31 to 831 μs/cm^2 during SWM, with an average value of 274 μs/cm^2 and 295 μs/cm^2 in PRM and SWM.

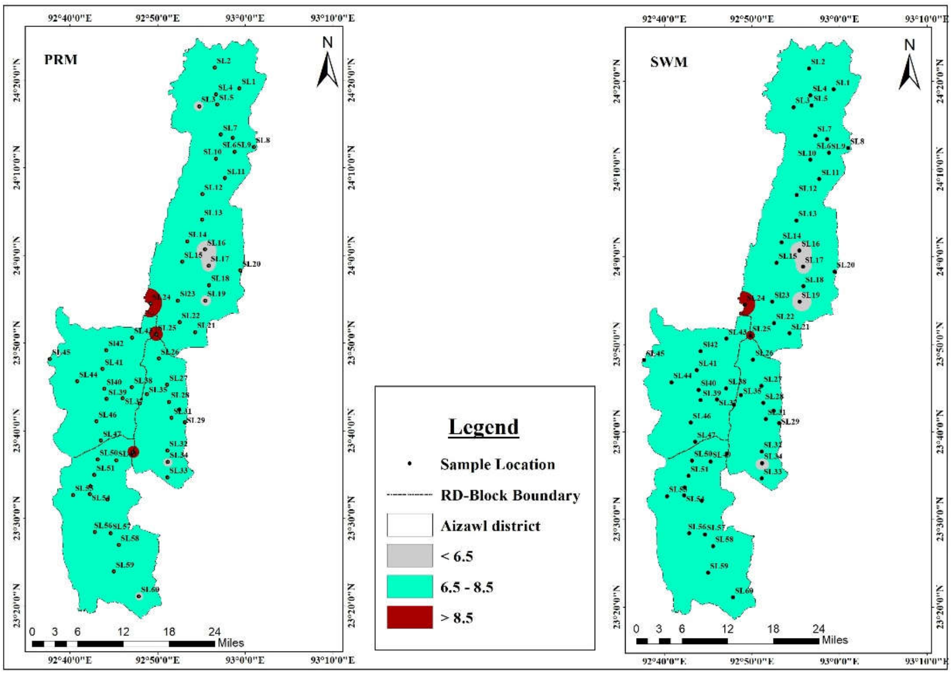

Fig 3. Spatial variation of pH in the study area during PRM and SWM.

Chloride (Cl)

Chloride is generally present as disassociated chloride (Cl^-) ions in groundwater. The chloride concentration in excess of 100 mg/l causes physiological damage. Some industries like textile processing, paper manufacturing and synthetic rubber manufacturing desire less than 100 mg/l. The common source of chloride is sedimentary rock (evaporates); minor sources are igneous rocks. The concentrations of chloride in the study area ranges from 26.58 to 168.38 mg/l during PRM and SWM with an average concentration of 54.52 mg/l and 55.20 mg/l. Figure 4 shows the spatial distribution of chloride in the study area during PRM and SWM indicating the higher concentration in the central and northern part of the study area during PRM. During southwest monsoon the higher concentration is spotted only in the central part of the study area.

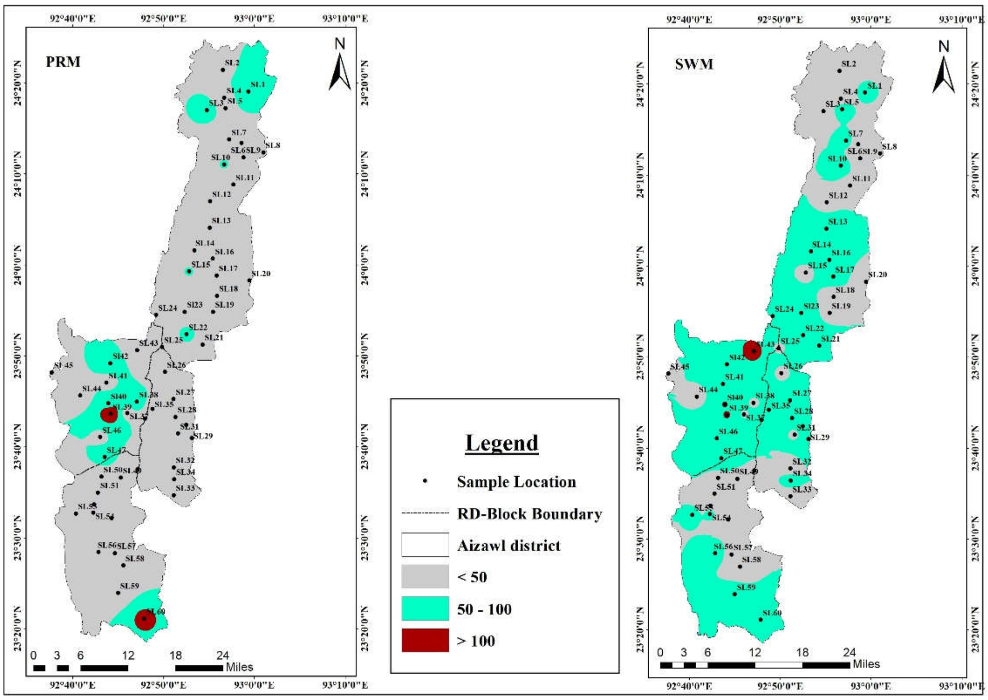

Fig 3. Spatial variation of Chloride in the study area during PRM and SWM.

Bicarbonate (HCO_3)

Bicarbonate (HCO_3^-) is a crucial component in playing a significant role in buffering pH level and maintaining equilibrium in a natural water system. It forms when carbon dioxide (CO_2) dissolves in water and interacts with carbonate minerals. The carbonate combines with alkaline earth's, principally calcium and magnesium to form a scale of calcium carbonate that retards flow of heat through pipe, walls and restricts flow of fluids in pipes (Anandhan et al., 2016). The concentration of bicarbonate in the study area varies from 58.60 mg/l to 347.10 mg/l, with an average of 114.50 mg/l during pre-monsoon. During the southwest monsoon, the bicarbonate concentration varies from 13.4 mg/l to 152.3 mg/l, with an average of 56.30 mg/l, which shows a significant decrease in concentration during SWM. Bicarbonate is the dominant anion of water chemistry in the study area. The spatial variation of bicarbonate during PRM and SWM is shown in Fig. 5, which shows that the concentration is high in the central and southern part of the study area during PRM. In contrast, during SWM, high concentration is not shown.

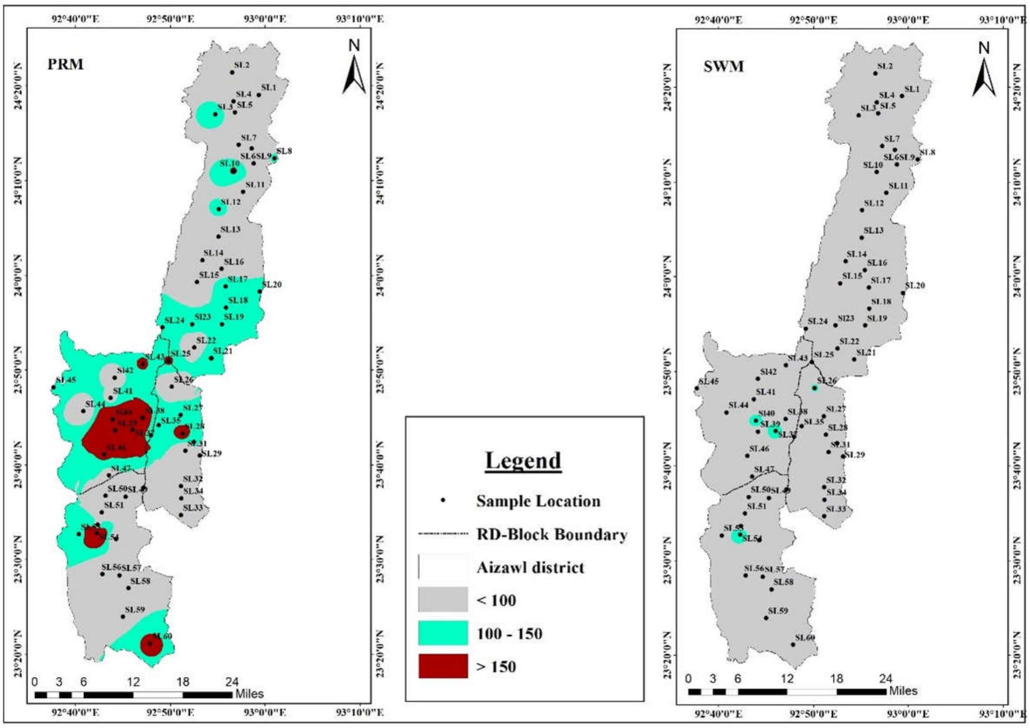

Fig 5. Spatial variation of Bicarbonate in the study area during PRM and SWM.

Fluoride (F)

The presence of fluoride in groundwater is a critical concern, especially in areas where natural geological formations lead to elevated fluoride concentrations. Although fluoride is advantageous for oral health in minimal quantities, high levels can result in health issues such as dental fluorosis (discolouration and damage to teeth) and skeletal fluorosis (weakening of bones) (Nungula et al, 2025). Fluoride in groundwater may originate from natural sources, such as the weathering of fluoride-rich rocks, or anthropogenic activity, including industrial waste and agricultural runoff (Chaudhuri et al. 2024; Kumar, 2017). The concentration of fluoride in the study area ranges from 0.01 to 1.20 mg/l during PRM and 0.01 to 1.43 mg/l during SWM, with the average value of 0.11 mg/l and 0.18 mg/l in the study area. The overall concentration of fluoride in the study area falls within the allowable limit recommended by WHO and BIS. The spatial distribution of fluoride in the study area is shown in Fig. 6, indicating higher concentration during SWM in the northeastern part of the study area.

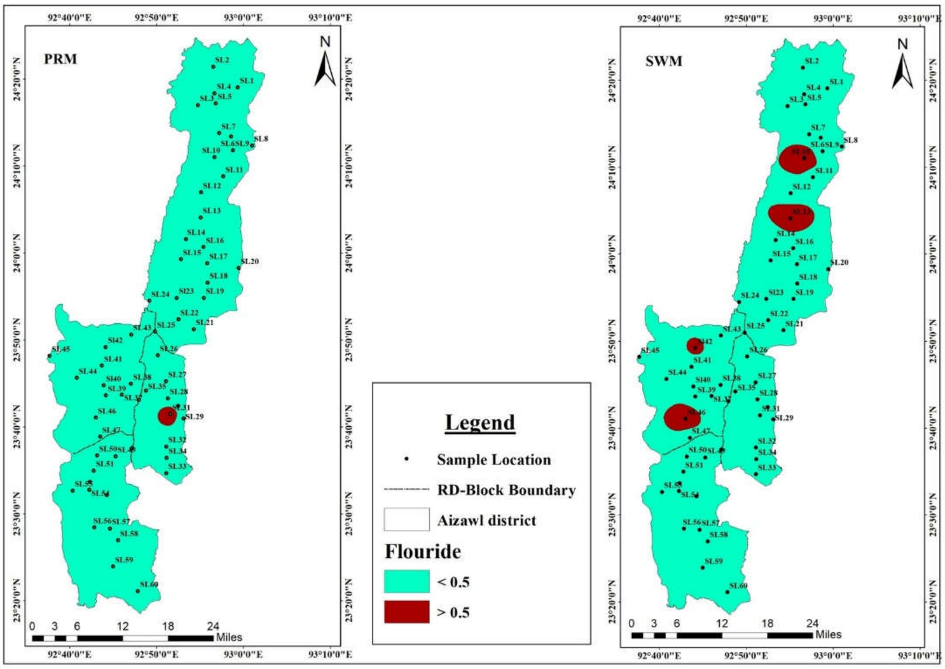

Fig 6. Spatial variation of Fluoride in the study area during PRM and SWM.

Nitrate (NO_3)

Nitrate pollution in groundwater is an increasing issue, especially in agricultural areas where fertilisers and wastewater boost nitrate concentrations. Elevated nitrate levels in drinking water pose health hazards, including methemoglobinemia, or "blue baby syndrome," which impairs oxygen delivery in the blood, particularly in babies (Brella et al., 2023). In India, the number of districts exhibiting elevated nitrate levels in groundwater has increased from 359 in 2017 to 440 in 2023, affecting almost 56% of the nation's districts. The Central Ground Water Board (CGWB) has been assessing this matter, revealing that 19.8% of analysed samples in 2023 had nitrate concentrations above permissible limits. The nitrate concentration in the study area varies from 0.90 to 19.50 mg/l during pre-monsoon, with an average of 4.57 mg/l. During the southwest monsoon, the value ranges from 0.01 to 18.92 mg/l, with an average of 4.63 mg/l. Figure 7 shows the spatial distribution of Nitrate in the study area, which indicates that the concentration is high in the western and central parts of the study area during PRM, while during SWM, it shows that the concentration is high in the central and southern parts of the study area.

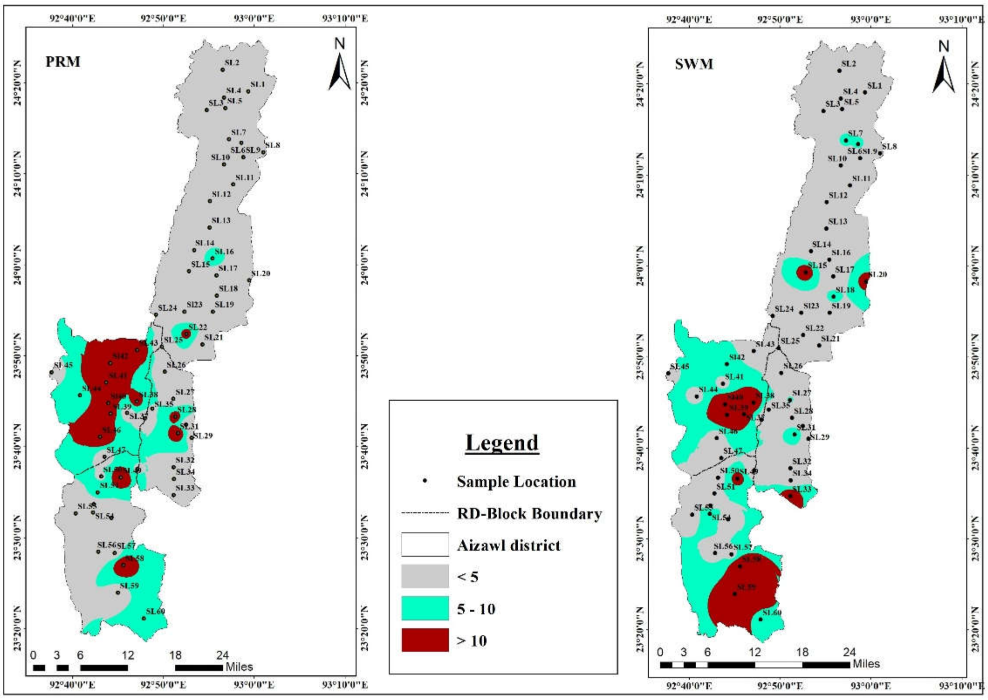

Fig 7. Spatial variation of Nitrate in the study area during PRM and SWM.

Calcium (Ca)

Calcium is a common mineral found in groundwater, mostly because of the dissolution of limestone, dolomite, and gypsum in subsurface rock formations. It plays a significant role in determining water hardness, which can impact plumbing systems, soap efficiency, and even flavour (Srinivasamoorthy et al., 2009). While calcium is vital for human health, high quantities in groundwater can contribute to limescale buildup in pipes and appliances. In places with high calcium concentrations, water softening procedures such as ion exchange or reverse osmosis are commonly employed to minimise hardness. The concentration of calcium in the study area ranges from 24.00 to 56.00 mg/l, with an average of 36.03 mg/l during pre-monsoon, while a slight decrease in the concentration occurs during the southwest monsoon, ranging from 20.00 to 46.00 mg/l, with an average concentration of 28.23 mg/l. The spatial distribution map shows that a higher concentration is in the central, northern and southern parts of the study area during PRM, while during SWM, a higher concentration is not indicated except for few locations (Fig 8).

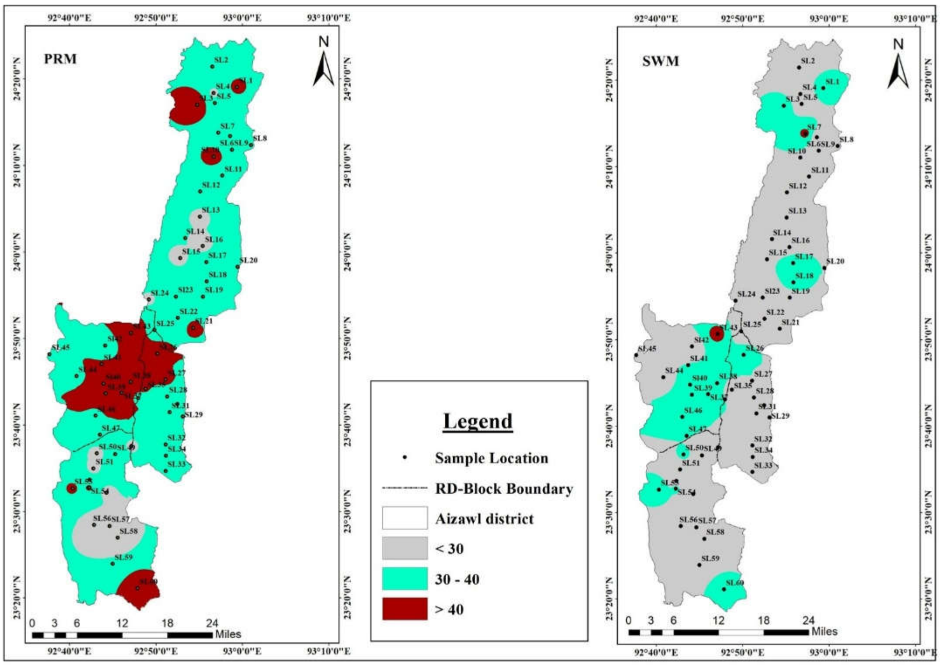

Fig 8. Spatial variation of Calcium in the study area during PRM and SWM.

Magnesium (Mg)

Magnesium is a naturally occurring mineral in groundwater, largely obtained from the weathering of rocks such as dolomite and limestone. It plays a vital part in water hardness, with calcium, and can alter plumbing systems, soap efficiency, and even flavour. Recent research has studied the isotopic composition of magnesium in groundwater, which can assist identify water cycle activities and interactions between groundwater and rock formations (Chen, Wang, and Su 2024). In the study area, the magnesium concentration varies from 9.00 to 22.20 mg/l during PRM with an average of 12.85 mg/l. During SWM, the magnesium concentration ranges from 6.2 to 24.2 mg/l, with an average concentration of 9.86 mg/l. The spatial variation map of magnesium in the study areas indicates that a high concentration is detected in the southern part of the study area during SWM (Fig. 9).

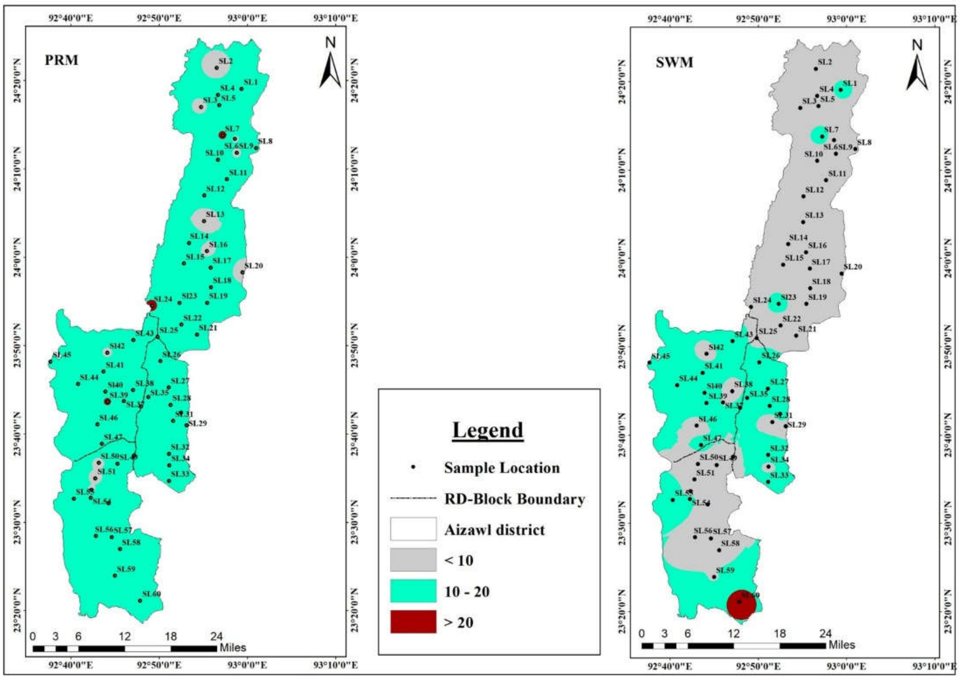

Fig 9. Spatial variation of Magnesium in the study area during PRM and SWM.

Sodium (Na)

Sodium is a naturally occurring element in groundwater, mostly derived from rock weathering, seawater intrusion, and anthropogenic activity such as irrigation and industrial effluent. Sodium is vital for human health; yet, excessive amounts in groundwater can result in health difficulties such as high blood pressure and kidney issues, along with water quality concerns, including increased salinity. Sodium concentration in the study area ranges from 0.90 to 60.70 mg/l during pre-monsoon with an average value of 17.00 mg/l. During the southwest monsoon, the concentration varies from 1.2 to 57.5 mg/l, with an average value of 12.20 mg/l. The spatial variation of sodium is illustrated in Fig. 9, which indicates that a higher concentration was detected in the central and southern parts of the study area during PRM, while during SWM high concentration is detected only in the central part of the study area.

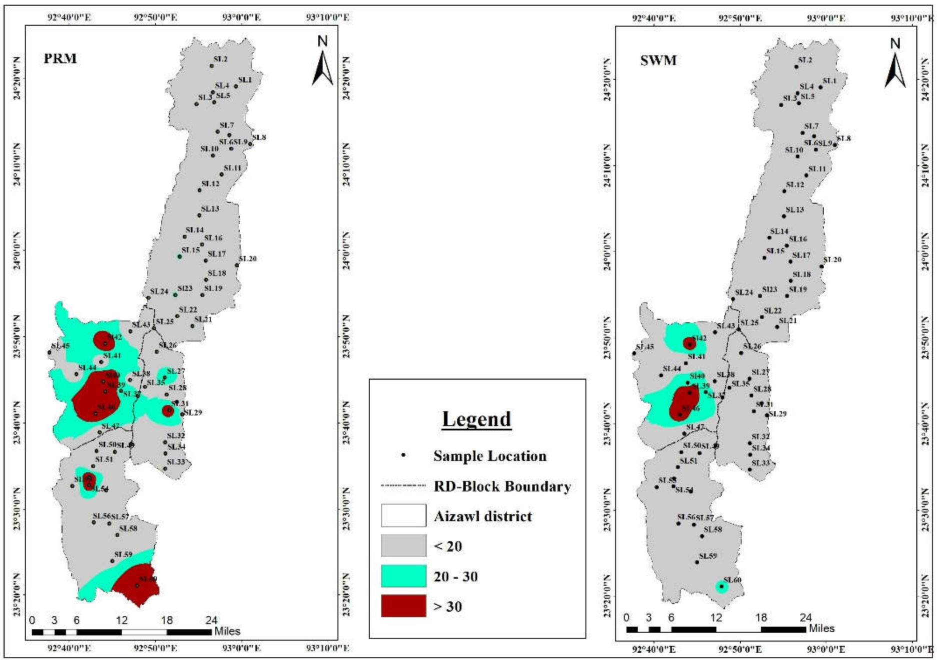

Fig 10. Spatial variation of Sodium in the study area during PRM and SWM.

Potassium (K)

Potassium is a naturally occurring element in groundwater, mostly derived from rock weathering, agricultural runoff, and industrial effluent. Although potassium is vital for human health, its concentration in groundwater is often lower than that of other principal ions such as sodium and calcium (Marsh & Gough, 1997). Excessive potassium concentrations in groundwater may be affected by fertiliser application, wastewater pollution, and geological structures. While potassium is typically not a significant issue for drinking water safety, monitoring its concentrations is essential for preserving water quality and ecological balance (Ravenscroft & Lytton, 2022). Potassium in the study area varies from 0.10 to 20.50 mg/l and 0.1 to 18.3 mg/l during pre-monsoon and southwest monsoon, with an average value of 3.46 mg/l and 2.40 mg/l. The spatial variation map shows that (Fig. 11) the higher concentration is detected in the central and southern parts during pre-monsoon, while in the southwest monsoon, high concentration is detected only in the central part of the study area. All the potassium concentration in the study area falls in the safe category prescribed by WHO and BIS.

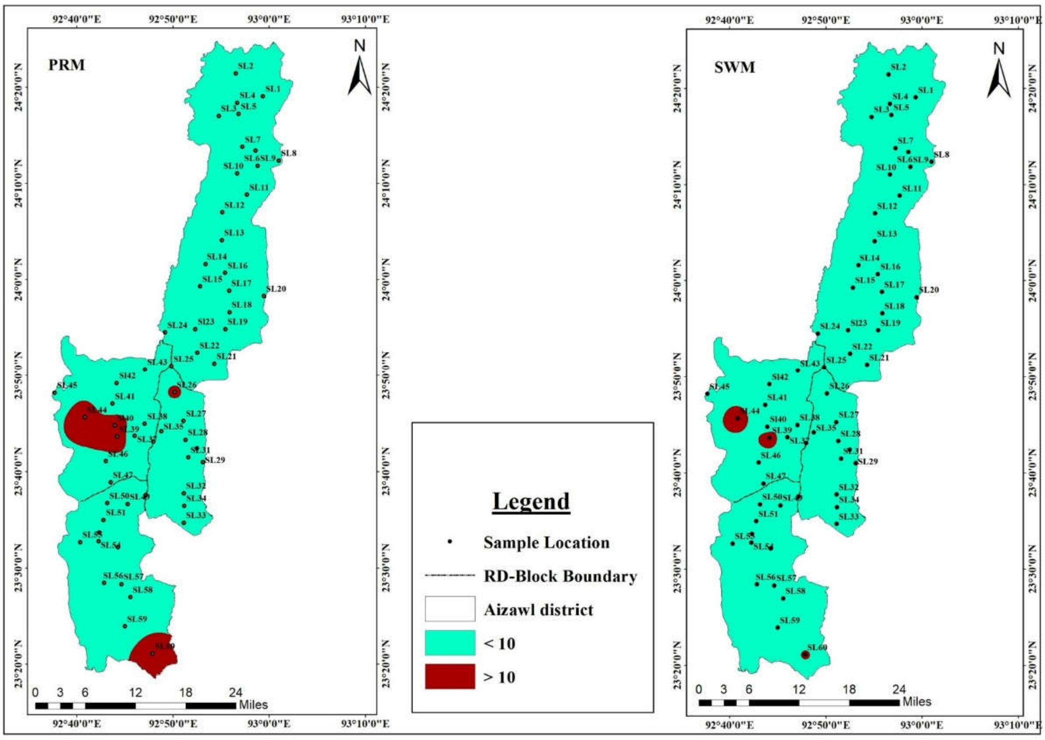

Fig 11. Spatial variation of Potassium in the study area during PRM and SWM.

Sulphate (SO_4)

Sulphate in groundwater derives from natural sources, including mineral dissolution (notably gypsum), and human activities such as mining and fertiliser application. While sulphate alone is not very dangerous, excessive quantities can induce dehydration, diarrhoea, and changes in blood composition when consumed in large amounts. Due to its high solubility, sulphate is found in substantial proportions in many groundwater systems. Thermochemical sulphate reduction (TSR) plays a role in naturally lowering sulphate levels in some situations (Sharma and Kumar 2020). In the study area, the concentration of sulphate varies from 0.77 to 20.69 mg/l during PRM and 0.30 to 15.1 mg/l during SWM, with an average value of 2.03 mg/l and 2.99 mg/l. The spatial distribution map (Fig. 12) shows that the sulphate concentration in high in central part of the study area during both PRM and SWM.

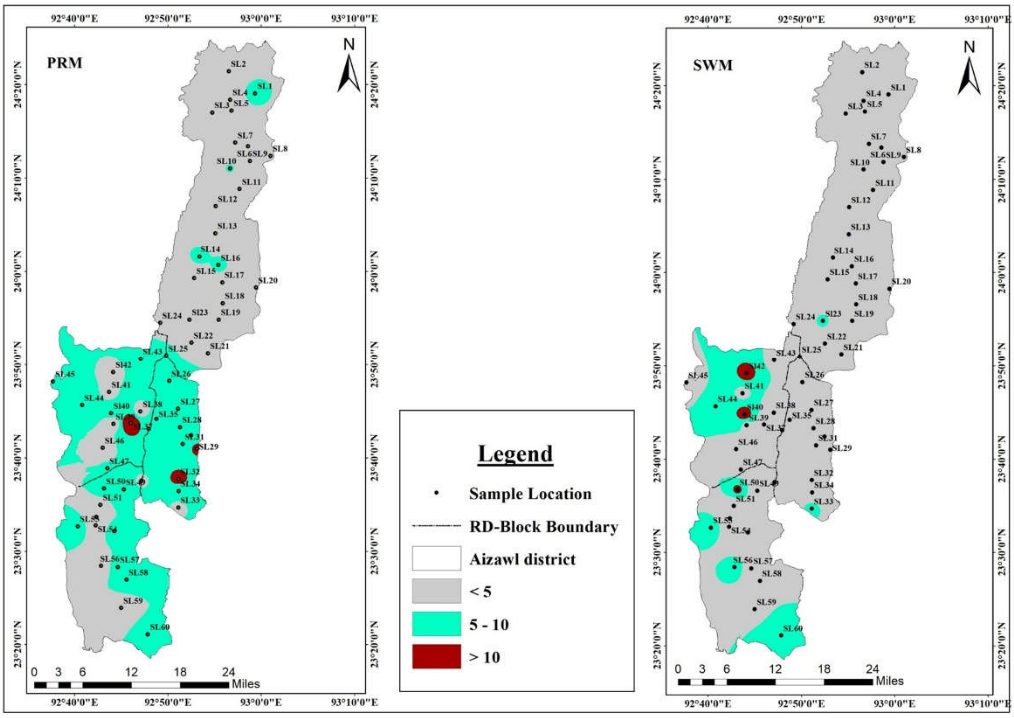

Fig 12. Spatial variation of Sulphate in the study area during PRM and SWM.

Phosphate (PO4)

Phosphate in groundwater generally results from natural sources, including rock weathering and human activities such as agricultural runoff, wastewater discharge, and industrial operations. While phosphorus is required for plant development, high phosphate levels in groundwater can contribute to eutrophication, leading to hazardous algal blooms and oxygen depletion in water bodies (Mishra, 2023). In India, research has emphasised the existence of phosphate pollution in groundwater, particularly in places with phosphate-rich geological formations and fertiliser-intensive agriculture. Research reveals that groundwater seepage can considerably contribute to phosphorus loading in lakes and rivers, harming aquatic ecosystems. In the study area, phosphate concentration falls within the permissible limit recommended by the WHO and BIS. The concentration varies from 0.12 to 52.60 mg /l and 0.30 to 11.58 mg/l during PRM and SWM, with the average of 4.53 mg/l and 1.56 mg/l. The spatial distribution (Fig. 13) classified the concentration into <5 mg/l and >5 mg/l, which shows that in the central, western and southern part shows the concentration higher than > 5 mg/l during PRM. During SWM concentration higher than 5 mg/l is detected only in a few locations.

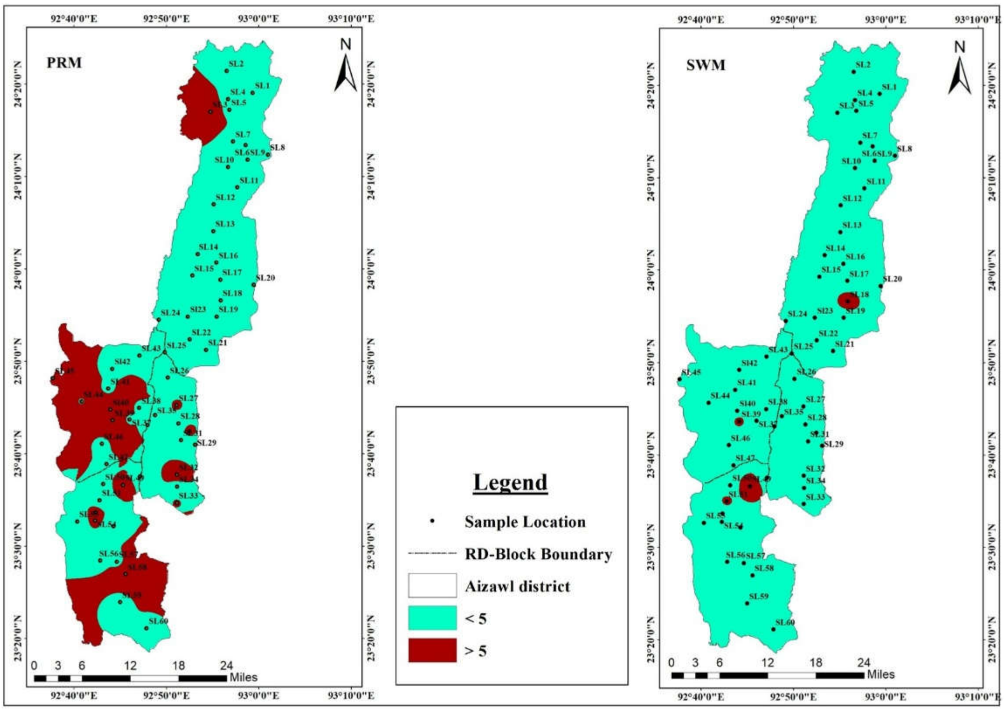

Fig 13. Spatial variation of Phosphate in the study area during PRM and SWM.

Silica (H_4SiO_4)

Silicate in groundwater largely derives from natural sources such as the weathering of silicate minerals in rocks. It plays a critical function in water chemistry, regulating pH levels and reacting with other dissolved minerals. While silicate itself is not dangerous, its presence can impact water hardness and lead to scale in pipes and industrial systems. Recent research shows that silicate minerals may also play a role in arsenic pollution in groundwater, since certain circumstances can lead to the release of arsenic from silicate mineral structures. Additionally, research has studied the geological effect of silicate concentrations in volcanic aquifers, highlighting their function in groundwater evolution (Alam, Wu, and Cheng 2014; Jude et al., 2024). The concentration of silicate in the study area ranges from 4.80 to 138.60 mg/l during pre-monsoon, with an average value of 55.10 mg/l. In the southwest monsoon, the concentration varies from 2.6 to 166.4 mg/l with an average value of 62.67 mg/l. The spatial distribution map of silicate (Fig. 14) shows that a higher concentration of silicate is detected in more parts of the location during SWM than in PRM.

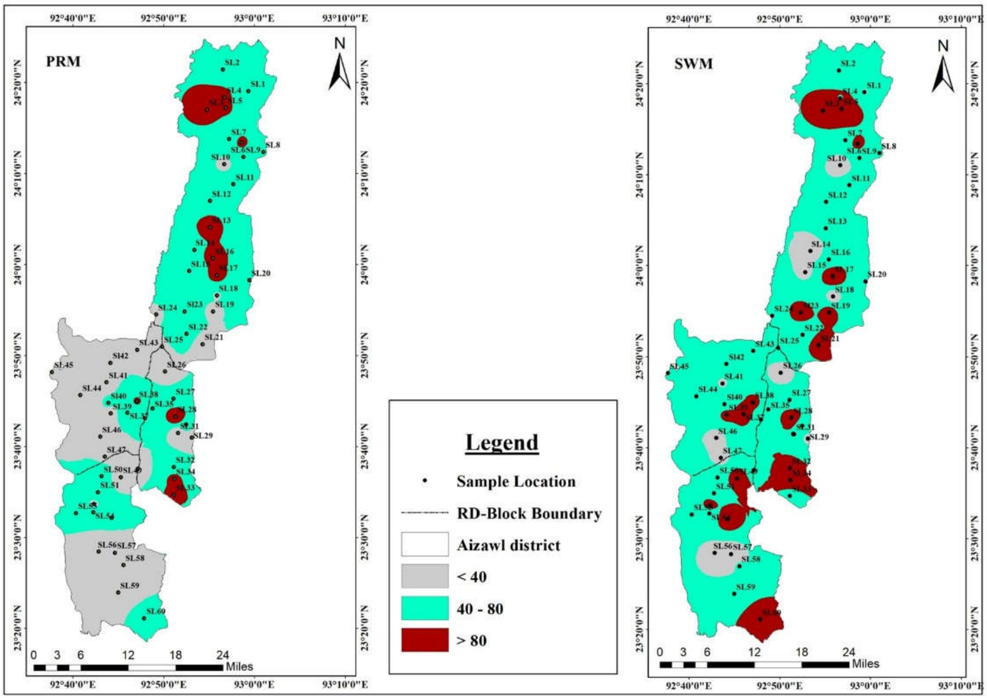

Fig 14. Spatial variation of Silica in the study area during PRM and SWM.

Conclusion

The physicochemical characteristics analysis of water in the study area results show that the majority of the parameters do not exceed the standard recommended by WHO (2011) and BIS (2012), except for pH, which shows some location falls out of the permissible limit during both seasons (Pre-monsoon and Southwest monsoon). HCO_3 is the dominant anion during both seasons, and Ca is the dominant cation in both seasons. The spatial variation map of all the parameters shows that the majority of high concentrations are detected in the central part of the study area, where Aizawl city is located. Therefore, the results indicate that the water quality is primarily affected by urbanisation and population growth. Proper waste management and proper discharge of human effluents could prevent the water from quality degradation. Nevertheless, the analysis of quality results in the study area shows that most of the water is suitable for domestic usage, agriculture, industries and different purposes.

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