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ASSESSING THE HYDROCHEMICAL CHARACTERISTICS OF GROUNDWATER IN KASARAGOD'S KARIANGOTE RIVER BASIN, KERALA, INDIA

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Abstract

This study investigates the influence of natural phenomena and anthropogenic activities on the quality of drinking water in the Kariangote River basin, of Kasaragod, Kerala, India. A total of 62 groundwater samples were collected during the pre-monsoon season and analysed for various physico-chemical properties, including pH, electrical conductivity, total dissolved solids, salinity, calcium, magnesium, sodium, potassium, chloride, sulfate, total hardness, and alkalinity. The analysis revealed significant spatial variations in these properties within the study area. The findings indicate that the quality of groundwater is adversely affected in coastal, estuarine, and tidal zones due to seawater intrusion. The seawater intrusion was observed to extend approximately 20 km inland along the major river stretch. The presence of seawater has led to an increase in salinity and altered the overall chemical composition of the groundwater in these areas. Additionally, the study highlights the impact of anthropogenic activities on groundwater quality, emphasizing the need for effective management strategies to ensure access to safe drinking water for the communities residing in the Kariangote River basin.

Key words: *groundwater quality, Kariangote River basin, coastal zone, physico-chemical* properties*, salinity*

1. Introduction:

Groundwater is one of the nation's most vital natural resources, serving as a primary source of drinking water for both urban and rural areas in India (Jaiswal et al., 2003). Beyond its significance in providing drinking water, it plays a crucial role in agriculture and industry. Therefore, both its quality and quantity are essential for society. The quality of groundwater is influenced by natural factors such as the quality of infiltrated rainwater, geological conditions, ion exchange processes in the subsurface, biological activities and residence time of water (Todd,1980; Amadi et al., 1987; Subramani et al., 2005; Jeevanandam et al., 2007). Additionally, anthropogenic factors, including chemicals from agricultural practices, sewage discharge, and industrial waste disposal, significantly impact groundwater quality (Cude, 2001; Milovanovic, 2007; Mukate et al. 2015). In coastal areas, groundwater quality is further affected by saltwater intrusion and tidal activity (Omprakash and Gadikar, 2018; Kumar et al., 2015; Kanagaraj et al., 2018; Sylus and Ramesh, 2018).

Kerala, situated on the southwest coast of India between the Arabian Sea and the Western Ghats, experiences its main rainfall during the South-West monsoon from June to

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September, with additional rain in the North-East monsoon from October to December and some more during the summer showers (Ramachandran Nair, 1986). Despite the substantial rainfall, Kerala faces a significant challenge related to the quality and quantity of groundwater. Given that groundwater is primarily used for domestic and agricultural purposes in rural areas, it must meet specific water quality standards (Pillai and Ouseph, 2000). The demand for groundwater for domestic and irrigation purposes increases during the summer months, leading to concerns about declining water quality and falling groundwater levels during this period. Therefore, this study aims to evaluate the quality of groundwater for drinking purposes in the Kariangote River basin, which is the second-largest river basin in the Kasaragod of Kerala, India. The study also examines the impact of natural and anthropogenic activities on groundwater quality.

2. *Materials and methods:*

The Kariangote River basin is situated in the southern part of Kasaragod district in Kerala, India. The study area spans from 75°07’60” to 75°20’72” E longitudes and from 12°14’05” to 12°22’98’’ N latitudes (Figure 1). The river originates from the Padinalkad Ghat Reserve Forest in Coorg district, Karnataka, at an elevation of 1520 meters above mean sea level (amsl). With a total length of 64 km, the river covers an area of 561km^2, out of which 429km^2 is in Kerala state and 132km^2 is in Karnataka state.

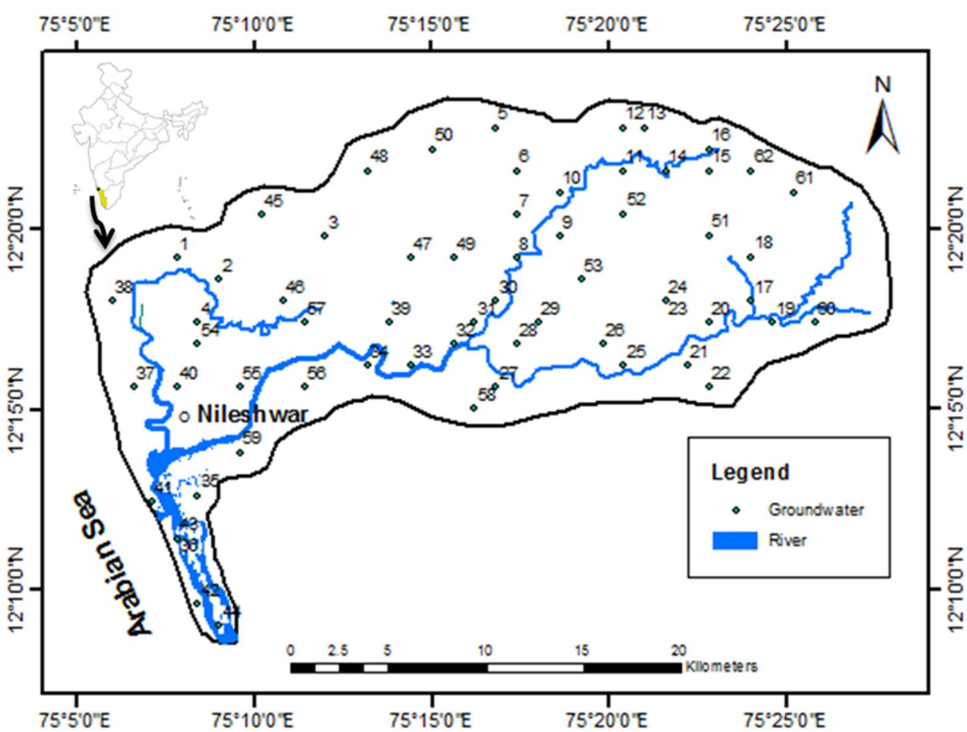

Fig. 1. Map showing the area of study and locations of ground water sampling stations.

Physiographically, the Kariangote River basin comprises three distinct units: the coastal plain, the midland, and the eastern highland regions (Soman, 1977; Rajan and Anil Kumar, 2005). The coastal plain has an elevation of less than 10 meters above mean sea level, and in Kasaragod district, the widest part of the coastal plain is observed along the estuarine area of the Kariangote River. This area is primarily characterized by recent alluvial deposits, which are sandy in nature. The midland region features rugged topography with small hillocks, valleys, and plateaus covered by hard lateritic deposits. The altitude in this region ranges between 10 and 200 meters above mean sea level. The eastern highland includes the foothills of the Western Ghats, with altitudes ranging from 200 meters to 600 meters above mean sea level. The area is composed of weathered and fractured crystalline rocks, such as gneisses and charnockites. Several doleritic dykes and garnetiferous quartzites have also been observed in this region (Soman, 1977; Nair and Sugatha, 1983). The region typically experiences an average annual rainfall of 3600 mm, with the majority of the precipitation occurring during the South-West monsoon season (Ramachandran Nair, 1986).

In the current study, a total of 62 groundwater samples were collected from different sites between April and May 2022. These locations were chosen based on geological and geomorphological factors. The groundwater samples were obtained from dug wells and stored in new 1-liter polyethylene bottles. Before sampling, these bottles were thoroughly cleaned with pure water and rinsed with the same water that was being sampled. The precise coordinates of the sampling sites were determined using a Garmin GPS - eTrex-10. The collected samples underwent analysis to assess several physico-chemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, calcium (Ca^{2+}), magnesium (Mg^{2+}), Sodium (Na^+) and potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2-}), total hardness (HT), and alkalinity. The physical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity were measured in situ using a HANNA - HI 98195 multi-parameter water quality portable meter. Chemical parameters including total hardness (HT), alkalinity, calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-) were determined through the complexometric titration method recommended by APHA (2005). Na^+ and K^+ levels were determined using a Systronics-130 flame photometer, while SO_4^{2-} concentrations were measured using a Systronics spectrophotometer-169.

All the obtained physico-chemical data were then mapped spatially using the ArcGIS platform (ArcMap 10.3). Furthermore, statistical analysis of the data was conducted using SigmaPlot-11 software.

3. Results and discussion:

In the subsequent section, the findings related to the water quality attributes of 62 dug well samples are presented. The statistical parameters of the groundwater samples are summarized in Table 1. All results were compared against the standard permissible limits outlined by the Bureau of Indian Standards (BIS, 2012) and the World Health Organization (WHO, 2006), as shown in Table 2.

Table 1: Statistical parameters of various physico-chemical attributes of the groundwater samples.

Parameters	Minimum	Maximum	Average
pH	5.53	7.86	6.5
EC (μS/cm)	26	798	111.7
TDS (mg/L)	13	399	56.4
Salinity (psu)	0.01	0.39	0.1
Ca^{2+} (mg/L)	5	160	27.3
Mg^{2+} (mg/L)	1.2	22	5.5
Na^{2+} (mg/L)	32	75.1	48.6
K^{+} (mg/L)	1.1	3.3	1.5
Cl^{-} (mg/L)	20.3	287.6	40.9
SO_4^{2-} (mg/L)	0.8	5	1.7
TH (mg/L)	15	250	51.0
Alkalinity (mg/L)	10	190	38.0

Table 2: Drinking water standards of WHO (2006) and BIS (2012) showing the maximum permissible limit.

Parameters	WHO, 2006	BIS, 2012
pH	6.5-8.5	6.5-8.5
TDS (mg/L)	500	500
Ca^{2+} (mg/L)	100	75
Mg^{2+} (mg/L)	30	30

Na^{2+} (mg/L)	200	-
K^{+} (mg/L)	10	-
Cl^{-} (mg/L)	200	250
SO_4^{2-} (mg/L)	250	250
TH (mg/L)	500	200
Alkalinity (mg/L)	120	200

The groundwater samples exhibit a pH range from 5.53 to 7.86, with an average value of 6.5. The majority of the samples fall within the pH range of 6, as illustrated in Figure 2a. The spatial distribution of pH indicates that the water samples tend to be more acidic in the northeast (NE) and northwest (NW) directions, while they are more basic in the west (W) direction. This acidity is likely attributed to the presence of lateritic rock types, which typically have an acidic pH (CESS, 1984), and the higher organic matter content in those regions (Matthess and Pekdeger, 1981). Similar acidity has been documented in various locations in Kerala by Gopinath and Seralathan (2006) and Harikumar and Kokkal (2009). Conversely, the basic nature of the water samples could be due to the presence of dissociated anions or the high salinity of the shallow aquifer. Most of the water samples fall within the permissible pH limits outlined by the WHO (2006) and the BIS (2012), making them suitable for drinking purposes.

The electrical conductivity (EC) of the groundwater samples varies between 26 and 798 µS/cm, as depicted in Figure 2b, with an average value of 111.7 µS/cm. Lower EC values are observed in the eastern directions, indicating good groundwater quality and conversely, in the western direction along the coastal and estuarine stretch EC values are considerably higher. This elevation in EC could be attributed to the influx of salt from the adjacent Arabian Sea (Todd, 1980).

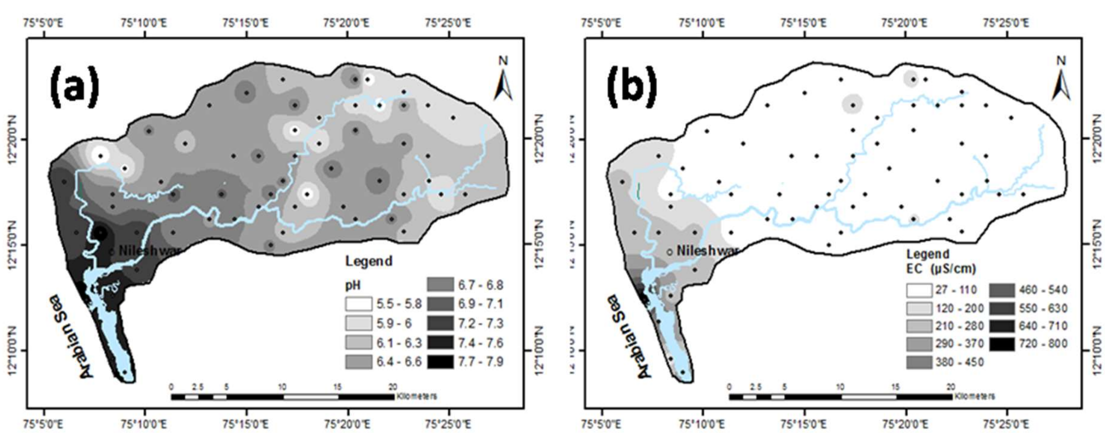

Fig. 2 Spatial distribution map showing pH (a) and electrical conductivity **-** EC (b) of groundwater samples.

The total dissolved solids (TDS) values in the groundwater samples range from 13 to 399 mg/L, with an average of 56.4 mg/L, as shown in Figure 3a. According to Carroll (1962), all these groundwater samples fall within the category of fresh water. A relatively high concentration of TDS is noticed near the coastal plain, and this increase might be linked to saltwater intrusion. It's worth noting that TDS values at all locations remain within the desirable limits recommended for drinking purposes (<500 mg/L) by both the WHO (2006) and the BIS (2012). This suggests that the groundwater in these areas is suitable for consumption.

The salinity of the groundwater samples varies from 0.01 to 0.39 practical salinity unit (psu), with an average of 0.1 psu, as illustrated in Figure 3b. The groundwater exhibits higher salinity in the westward direction, particularly near the coastal, estuarine, and tidal zones. The rise in salinity in these areas can indeed be attributed to seawater intrusion. This intrusion adversely affects the quality of groundwater, making it less suitable for various purposes, including drinking and agriculture.

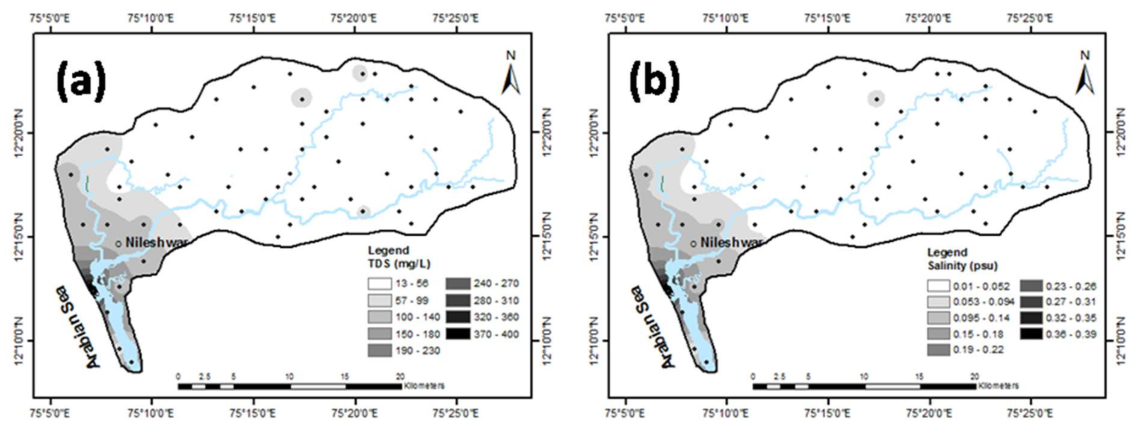

Fig. 3 Spatial distribution map of total dissolved solids - TDS (a) and salinity (b) of groundwater samples.

The calcium (Ca^{2+}) content in the groundwater samples ranges from 5 to 160 mg/L, with an average of 27.3 mg/L, as depicted in Figure 4a. Notably, certain samples near the coast exhibit elevated calcium levels. This increase could be attributed to seawater intrusion, where saline water from the sea infiltrates into freshwater aquifers, leading to higher calcium concentrations. Alternatively, the high calcium values might also result from the introduction of domestic waste into the fresh water aquifer, as suggested by Kumar et al. (2006) and Singh and Balasingh (2011). Both of these factors can contribute to the alteration of calcium levels in groundwater samples.

The magnesium (Mg^{2+}) content in the groundwater samples ranges from 1.2 to 22 mg/L, with an average of 5.5 mg/L, as shown in Figure 4b. Importantly, all these groundwater samples fall within the desirable limits set by the WHO (2006) and the BIS (2012). This means that the magnesium levels in these samples meet the recommended standards for safe drinking water.

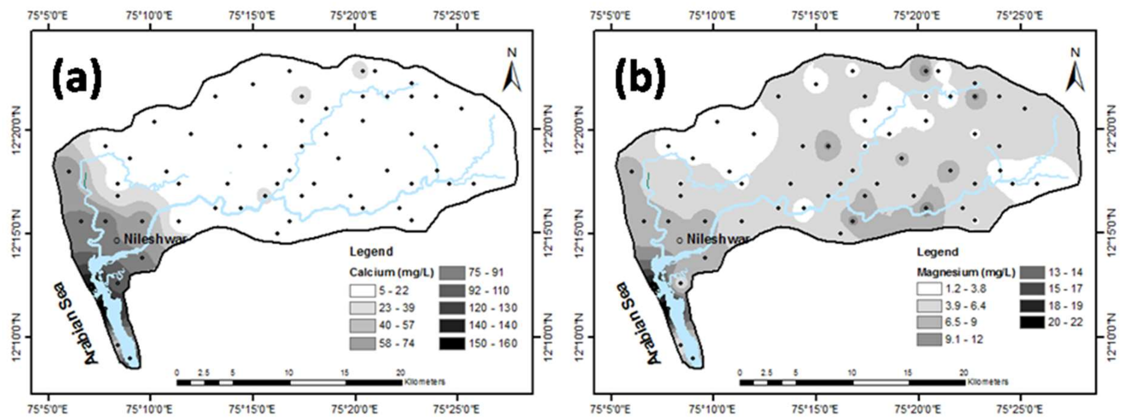

Fig. 4 Spatial distribution map of calcium (a) and magnesium (b) content of groundwater samples.

The primary source of sodium (Na^+) and potassium (K^+) in groundwater is seawater intrusion. Additionally, these elements can be introduced through rock-forming minerals and agricultural practices. In the studied area, the sodium content ranges between 32 mg/L to 75.1 mg/L, with an average of 48.6 mg/L (Fig. 5a). For potassium, the concentration varies between 1.1 mg/L to 3.3 mg/L, with an average of 1.5 mg/L (Fig. 5b). These concentrations indicate the presence of both sodium and potassium in the groundwater, likely influenced by the intrusion of seawater and geological factors in the region.

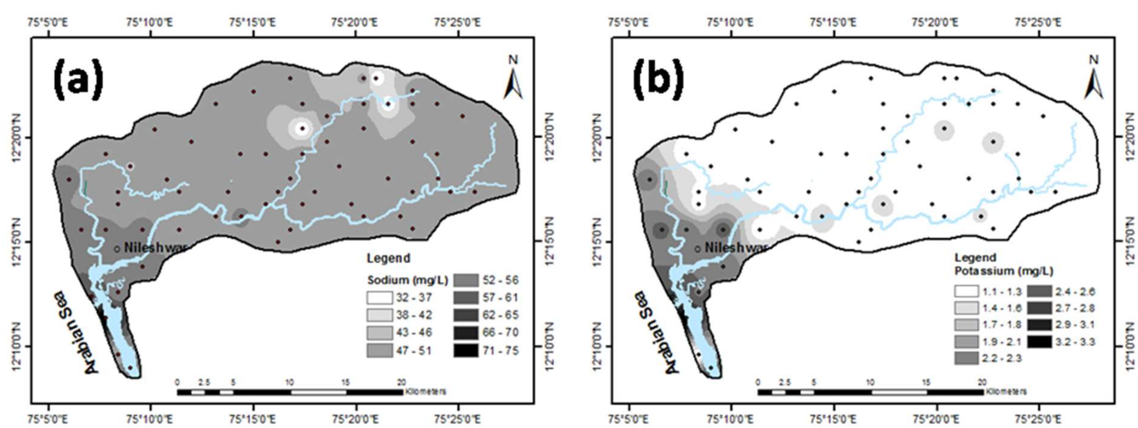

Fig. 5 Spatial distribution map of sodium (a) and potassium (b) of groundwater samples.

The chloride (Cl^-) content in the groundwater samples ranges from 20.3 to 287.6 mg/L, as shown in Figure 6a. Importantly, majority of these samples fall within the permissible limit of 250 mg/L recommended by both the WHO (2006) and the BIS (2012). There is a gradual increase in chloride content observed towards the coastal belt, where seawater is its main source (Matthess, 1982; Hem, 1985, 1993; Laluraj et al., 2005; Shaji et al., 2009). In the mid and highland areas, chloride levels are relatively low due to lower contributions from geological formations such as charnockites and gneisses, as well as a low rate of percolation of agricultural and domestic wastes into the groundwater system (Mariappan et al., 2000; Kresic, 2006; Biddau et al., 2017).

This variation in chloride levels can be attributed to the seawater intrusion and geological factors.

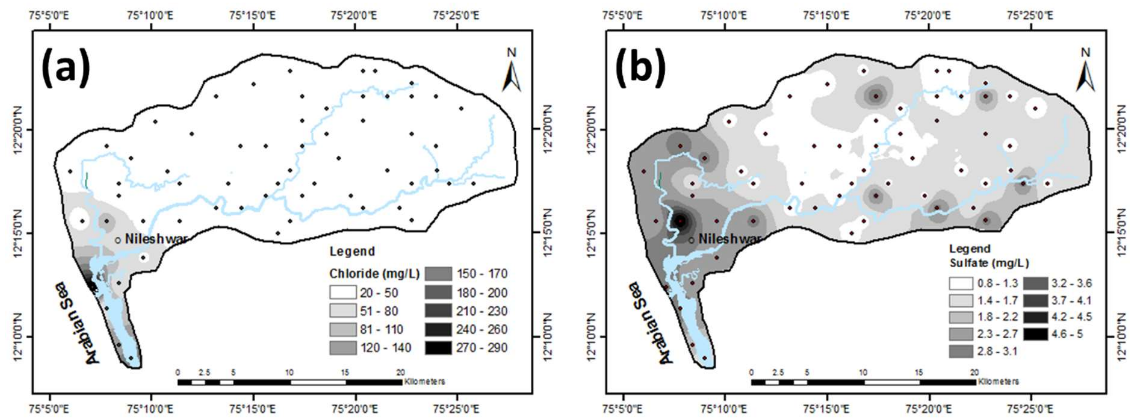

Fig. 6 Spatial distribution map of chloride (a) and sulfate (b) of groundwater samples.

Sulfate (SO_4^{2-}) is introduced into groundwater through various sulphur-bearing minerals and atmospheric deposition. In the studied area, the sulfate concentration ranges from 0.8 mg/L to 5 mg/L, as shown in Figure 6b.

The total hardness (TH) of the groundwater samples ranges from 15 to 250 mg/L, with an average value of 51 mg/L. As depicted in Figure 7a, most of the samples fall within the soft water category (0 – 75 mg/L), with moderately hard water observed in the estuarine region and hard water primarily encountered towards the coast. Out of the 62 samples, 50 are categorized as soft water, 10 as moderately hard, and two as hard water (Sawyer and McCarty (1967); U.S. Environmental Protection Agency-EPA, 1986).

In "ideal" water, total hardness should not exceed 80 mg/L according to Bean (1962). The high total hardness observed in some samples can be attributed not only to the introduction of salt from seawater but also to anthropogenic activities such as sewage discharge and the addition of domestic or industrial pollutants (Jain and Sharma, 2002; Suma and Rajeshwari, 2013). These activities can significantly impact the mineral content of groundwater, leading to higher total hardness levels in certain areas.

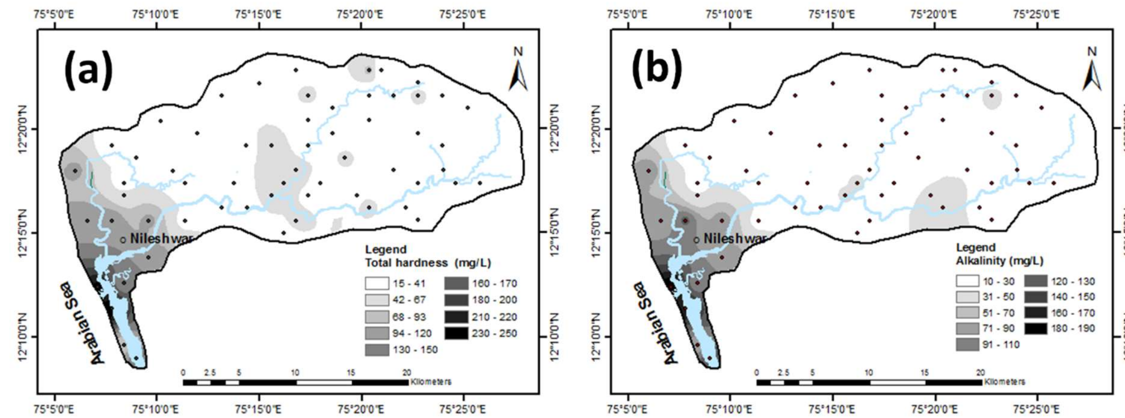

Fig. 7 Spatial distribution map of total hardness (a) and alkalinity (b) content of groundwater samples.

The alkalinity levels in the groundwater samples vary between 10 and 190 mg/L, with an average of 38.0 mg/L, as shown in Figure 7b. Importantly, all 62 water samples analysed fall within the acceptable limit of 200 mg/L as specified by the BIS (2012) ensuring their suitability for various purposes, including drinking.

Piper diagram

The Piper trilinear diagram (1944) is a valuable tool for representing and comparing water quality parameters. This diagram divides water samples into different hydro-chemical facies based on their cation and anion composition. In this method, water samples can be classified into various facies (Back and Hanshaw, 1965), such as:

Facies I: Ca^{2+}- Mg^{2+}- HCO_3^-

Facies II: Na^+- K^+- Ca^{2+}- HCO_3^-

Facies III: Na^+- K^+- Cl^-- SO_4^{2-}

Facies IV: Ca^{2+}- Mg^{2+}- Cl^-- SO_4^{2-}

Based on the analysis using this diagram in the present study, it's noted that most of the samples fall into the sodium chloride and sodium bicarbonate facies. This observation indicates the influence of seawater intrusion on the hydro-chemical characteristics of the groundwater. The Piper trilinear diagram helps to understand the sources and characteristics of different water samples, allowing for a detailed analysis of the water's composition and its potential implications.

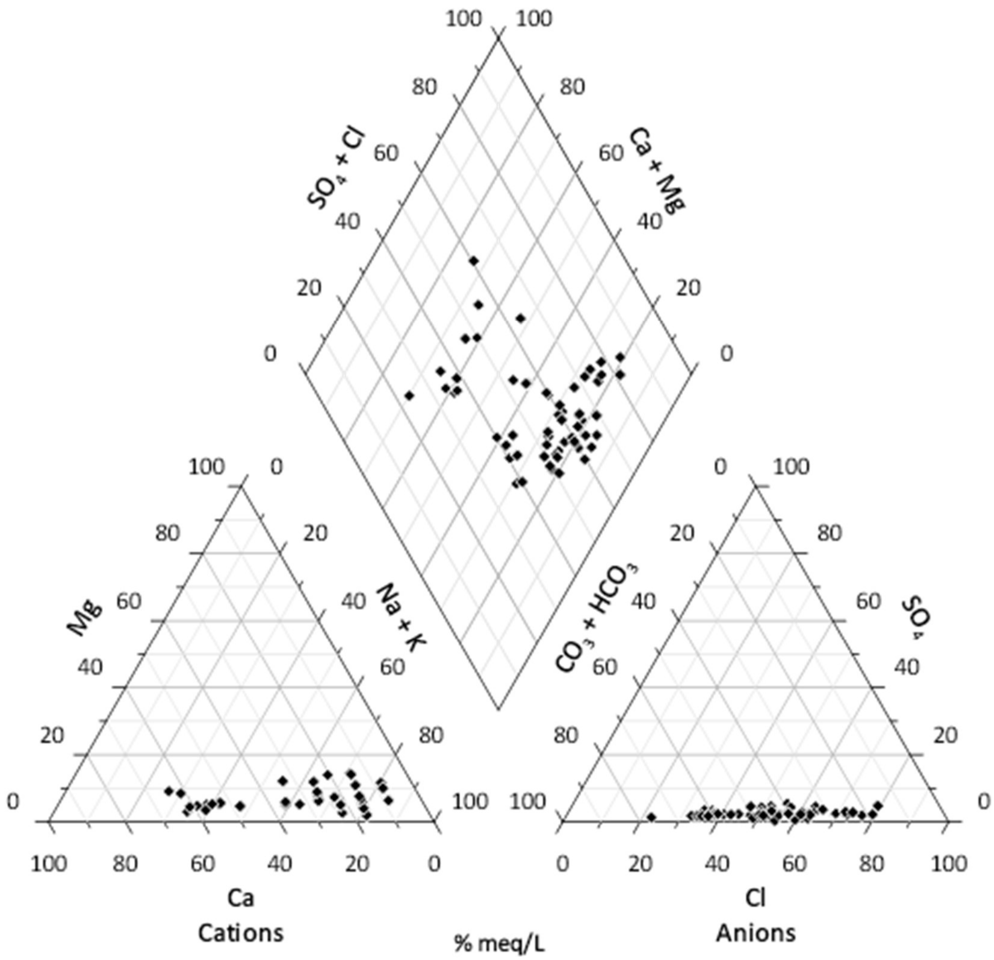

Fig. 8 The Piper trilinear diagram representing various hydro-chemical facies of groundwater samples.

Correlation of physico-chemical parameters:

In this study, a Karl Pearson's correlation analysis was conducted to explore the relationships between different physico-chemical parameters. The correlation matrix, detailing the relationships among 12 variables, was established, and correlation coefficients (*r*-values) were calculated (Table 3). The *r*-value, which ranges between +1 and -1, indicates the strength and nature of the relationship between variables. An *r*-value of +1 or close to +1 signifies a strong positive linear relationship between the variables and an *r*-value of -1 or close to -1 indicates a strong negative linear relationship between the variables. An *r*-value near zero suggests a weak or nonlinear relationship between the variables.

A strong positive correlation among EC, TDS, salinity, Ca^{2+}, K^{+}, Cl^{-}, alkalinity and total hardness is observed. The strong positive correlations imply interdependencies among these variables, highlighting their interconnected nature in the groundwater system. It is further supported by bivariate plots, which visually represent the relationships between these parameters (Fig. 9).

Table 3: Pearson's correlation matrix for various physico-chemical parameters of the groundwater samples.

	pH	**EC**	**TDS**	**Salinity**	**Ca^{2+}**	**Mg^{2+}**	**Na^{2+}**	**K^+**	**Cl^-**	**SO_4^{2-}**	**TH**	**Alkalinity**
pH	1.00	0.71	0.72	0.70	0.70	0.61	0.61	0.74	0.49	0.35	0.74	0.79
EC		1.00	1.00	0.99	0.84	0.67	0.62	0.81	0.79	0.53	0.86	0.90
TDS			1.00	0.99	0.85	0.67	0.62	0.81	0.78	0.53	0.87	0.90
Salinity				1.00	0.84	0.66	0.63	0.81	0.80	0.53	0.85	0.91
Ca^{2+}					1.00	0.46	0.66	0.84	0.68	0.50	0.87	0.87
Mg^{2+}						1.00	0.55	0.61	0.30	0.29	0.77	0.76
Na^{2+}							1.00	0.73	0.31	0.39	0.67	0.67
K^+								1.00	0.45	0.40	0.81	0.87
Cl^-									1.00	0.36	0.59	0.67
SO_4^{2-}										1.00	0.51	0.50
TH											1.00	0.93
Alkalinity												1.00

EC -µS/cm, **Salinity** - psu and remaining parameters in mg/L.

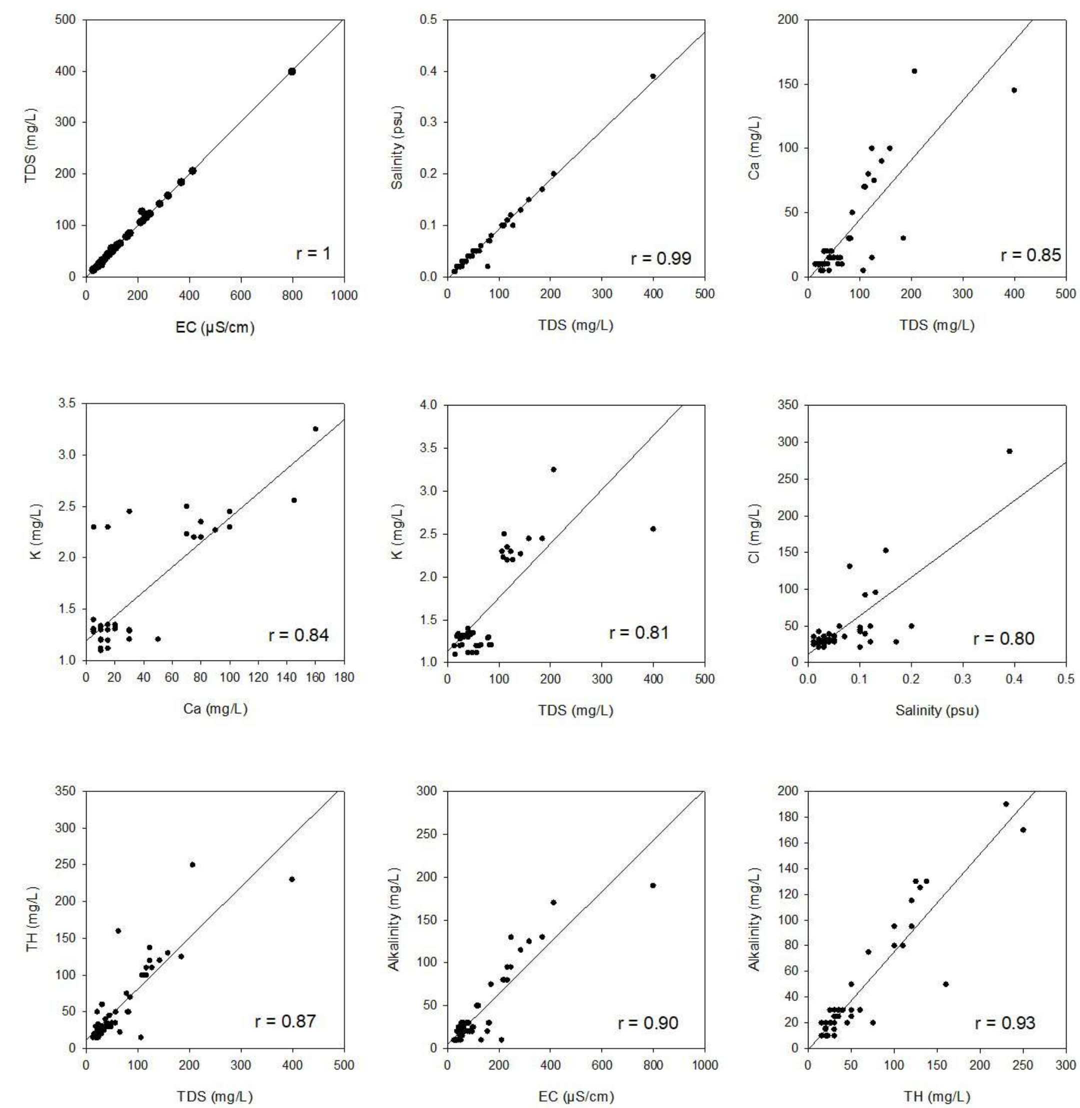

Fig. 9 Bivariate plots showing inter-relationship among various physico-chemical attributes.

4. Conclusions:

The study focused on evaluating the drinking water quality in the Kariangote River basin of Kasaragod, Kerala, India, considering both natural and anthropogenic factors. During the pre-monsoon season, 62 groundwater samples were analysed for various physico-chemical parameters. The findings revealed a deterioration in groundwater quality in coastal, estuarine, and tidal zones, which was characterized by increased basicity, salinity, hardness, sodium and chloride content.

The study highlighted challenges such as groundwater shortages in mid-land and hilly regions during summer months, and excessive groundwater extraction causing seawater intrusion in coastal areas, leading to severe groundwater quality issues. Despite these challenges, most of the physico-chemical parameters met WHO and Indian standards for drinking water, except in a few locations.

The influence of tides was observed along the main river stretch up to 20 km from the coast, impacting wells adjacent to the river. Generally, groundwater quality was poorer in the western part of the study area compared to the eastern side. The study identified saltwater intrusion as a significant factor affecting groundwater quality, emphasizing the need for focused attention, especially in coastal zones. The study recommended the conjunctive use of groundwater resources, particularly in coastal areas. Additionally, it emphasized the necessity of proper sanitation and waste disposal facilities in densely populated regions to maintain groundwater quality.

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