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Assessment and Characterization of Groundwater Quality of Malabar Coast in Kerala, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to assess and characterize the groundwater quality of coastal aquifer of the Vatakara-Koyilandy stretch in the Kozhikode district of Kerala. Mann-Kendall Test was used for analysing the trend in groundwater levels. The Piper diagram was applied to determine the chemical facies of the groundwater and identify the evolution of hydrochemical parameters of groundwater sources. The source of the dissolved ions in the groundwater was described by the Gibbs diagram. The suitability of groundwater for irrigation was determined using the United States Salinity Laboratory diagram. Geostatistical tools were used to describe the spatial variability of groundwater levels and salinity and the ordinary kriging method was used to plot the spatial variability maps. It was found that Na^+ was the predominant cation with maximum concentration varying from 455.6 mg/l to 1844 mg/l during pre-monsoon and post-monsoon; respectively. Concentration of Cl^- in pre-monsoon and post-monsoon varied from 184 mg/l to 2417 mg/l and 99 mg/l to 714 mg/l; respectively. Other anions in the groundwater were SO_4^{2-} and HCO_3^- with an

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average concentration of 239.79 mg/l and 129.59 mg/l in pre-monsoon and 110.73 mg/l and 75 mg/l in post-monsoon; respectively. The trend in groundwater in confined and semi-confined aquifers showed negative trends whereas eight wells resulted in a significantly negative trend. However, a significant decreasing trend was observed in wells near the coasts. The most dominant cations were (Na^+, and K^+) and the dominant anions were SO_4^{2-} and Cl^-. The dominant cations and anions were from the mixing of seawater with the groundwater. The Na^+ ions were also found to be from the same source. In most of the area, the groundwater was highly to very high highly saline with medium sodium and not suitable for irrigation. In the unconfined aquifer, 25.2% and, in the semi-confined aquifer 24.0% area was found to be unfit for irrigation.

Keywords: Aquifer characterization; geostatistics; groundwater; hydrochemical analysis; seawater intrusion; trend analysis.

1. INTRODUCTION

Large-scale groundwater extraction to meet the increasing water demand due to rapid urbanisation and expansion of agriculture is causing land subsidence and saltwater intrusion in along the coast in several regions [1,2,3]. Deterioration in groundwater quality due to seawater intrusion in the coastal aquifer is a widespread environmental hazard [4,5,6]. Groundwater becomes unfit for human consumption and irrigation due to seawater-freshwater interactions [7,8]. Excessive pumping in coastal aquifers causes a decline ofgroundwater level and reversal of hydraulic gradient which results in the movement of seawater into the freshwater aquifer.

The migration of saline water into the fresh groundwater zone is known as seawater intrusion which is a serious concern in coastal regions. Seawater intrusion is the most common among the various salinisation sources, followed by inland salinity of groundwater, oil and gas-field brine, halite dissolution, and domestic, agricultural, and industrial effluents [5]. When coastal aquifers are pumped at a faster rate, the groundwater level drops, allowing seawater to infiltrate the freshwater due to a reverse hydraulic gradient. Large-scale seawater intrusion has occurred in coastal places worldwide due to sea-level rise, extreme weather events, changing precipitation patterns, and groundwater depletion [9]. If seawater intrusion is not controlled along the coast, then it will spread to the inland aquifer, causing water quality to deteriorate due to saltwater up-coning as well. Even less mixing of seawater with freshwater renders it unfits for human consumption, while slightly greater amounts make it unfit for irrigation [10].

The deterioration in groundwater quality can be determined by analysing the concentration of the chemical components which is highly influenced by geological and human actions [11,12]. There are several studies on hydro-geochemical analysis for determining the Hydrochemical facies of the groundwater and identifying the evolution of hydrochemical parameters of groundwater sources [13-16]. The functional sources of chemical constituents in the groundwater were studied by [17,18,15] by preparing the Gibbs diagram. Information on the suitability of the contaminated groundwater due to its salinity hazard was explored using the United State Salinity Laboratory (USSL) diagram in many studies [15,19]. Identifying the trends in long-term groundwater level and salinity data using the non-parametric Mann-Kendall test can give insight into the sustainability of the groundwater sources for irrigation water management [20,21,22]. Geostatistical methods are widely used for developing spatial prediction maps of groundwater level, contamination and its constituents [23,24,17].

Kerala has about 600 km long coastline. Decadal pre-monsoon and post-monsoon water level trend (1996-2005) suggests groundwater levels are declining at the rate of 0.1 m/yr or more in 13% and 30% of monitoring wells, respectively [25,26]. The shallow aquifers that draw water from the coastal alluvium are mostly fresh, while a few isolated areas near lakes, tidal rivers, and backwater channels may be saline throughout the summer. Water in shallow wells near backwaters, lagoons, lakes, and tidal rivers is saline. During the summer, Kerala's rivers frequently experience saline water intrusion in their lower reaches. As the freshwater in these water bodies reduces, sweater intrudes upstream, in turn, the pumped wells adjacent to the river discharge saline water. The Kuttiady is one such river in the Kozhikode district of Kerala which is affected by this problem [27].

In this study, the coastal region of the Malabar coast in Kozhikode district of Kerala, known as the rice bowl, was selected. Groundwater decline and salinity are the major problems in this area. Hence, there was a need to conduct a study on groundwater quality assessment and characterisation of the aquifer for irrigation and domestic applications. Geostatistical methods and hydro chemical analysiswere carried out to assess and characterise the groundwater quality.

Groundwater samples were collected at regular intervals. The other data required for the study was collected from the related state and central departments. The trend analysis of the groundwater level and salinity, the hydrochemical facies, the mechanism governing groundwater chemistry and the calculation of the irrigation index were carried out to assess the water quality and characterise the aquifer. Geochemical processes and their governing mechanisms were examined using Gibbs diagrams. Hydrochemical Facies Evolution Diagram was used to determine the condition of the saltwater intrusion and its process. Mann Kendall’s test and Sen’s slope method were employed to investigate the trend in the groundwater level and quality. Spatial prediction maps of groundwater level and salinity were also developed using the Kriging method available in Arc GIS.

2. MATERIALS AND METHODS

2.1 Study Area Description

The Vatakara-Koyilandy coastline stretch is part of Kerala's Kozhikode coast, which is also known as the Malabar coast. The shore is 25 kilometres long and is located 20 kilometres north of Kozhikode, Kerala. It is located between 75º 73'-75º62' East longitudes and 11º 42'-11º 56' North latitudes, with a total area of 270 km^2 (Fig. 1). The west of the research area is bounded by the Arabian Sea. The study area has a humid subtropical climate with an average temperature of 27° C. The average annual rainfall in the area is 2700 mm. Of this 65 % is received during the North-East monsoon and 25% is received during the South-west monsoon. The rest of the rainfall occurs in other months.

The soil types in the region are coastal alluvial soil in coastal plain and in low-lying areas. Riverine alluvial soil are found along riverbanks. At some places red loam soil and brown hydromorphic soil are also found [28,29,30]. The alluvium deposits are underlain by laterite and sedimentary rocks, mostly charnockites with mafic granulite enclaves. The coastal zone is covered by excessively drained to moderately drained sandy deposits, and the alluvium deposits are covered by excessively drained to moderately drained sandy deposits [31,28,32]. Groundwater in weathered crystallines is present under unconfined conditions and semi-confined in deep crystalline formations. Groundwater table depth ranges from 0.73 m to 16.11 m below ground level [31]. The well-logs of representative wells suggest aquifer consists of three layers namely; the top unconfined layer, an aquitard and a semi-confined aquifer at the bottom (Fig. 2). The soil conditions are ideal for growing coconuts, spices, and plantation crops, and are average for other crops. Coconut, spices, paddy and plantation crops are the most important crops cultivated in the study area [33].

The Kuttiyadi River which flows through this region originates from the Banasura peak in the Naripatta hills in Wayanad and flows for 74 km until joining the Arabian Sea near Kottackal. The river drains a total area of 583 km^2.The river flows through evergreen forests in the upper catchment and densely populated midlands and plains with rubber, coconut, and rice fields. Kuttiyadi irrigation project (Peruvannamuzhi dam) in the upstream catchment provides the drinking water needs of Kozhikode Corporation and surrounding villages. Hence maintaining the Kuttiyadi River's water quality at suitable levels is essential. Seawater intrusion is a major problem that affects the quality of water in the Kuttiady river and adjoining aquifers. During low flows the tidal water cause seawater intrusion into the river up to 24 km upstream [34]. With a decrease in groundwater recharge and an increase in water demand throughout the summer, the severity of seawater intrusion has increased over the years. The salinization of groundwater systems is adversely affecting the water supply for agriculture and domestic sectors.

2.2 Data Collection

Water samples from the pumped wells and river were collected from different locations at regular intervals. The sampling in the river was done starting from the river mouth to 22 km along the river. The interval between the sampling points was 1.0 km up to 3.0 km in length and 2-5 km afterwards. Groundwater wells located 100 m and 200 m away from the river were selected from water sampling. The water quality was analysed in the water quality laboratory of CWRDM, Kozhikode. Water quality parameters analysed were, Sodium (Na^{+}), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^{+}), Chloride (Cl^{-}), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^{-}), total dissolves salts (TDS), electrical conductivity (EC) and pH.

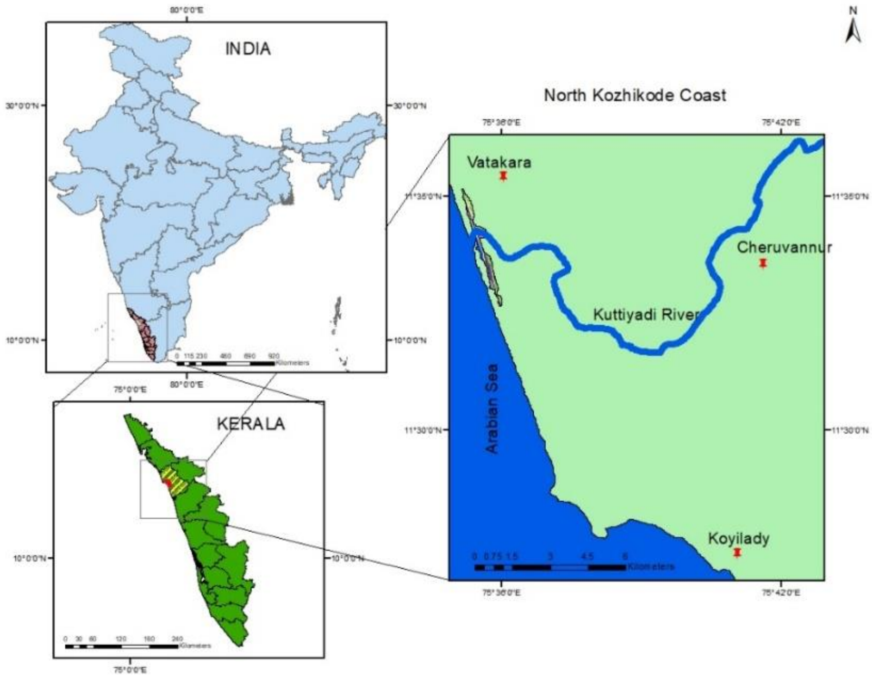

Fig. 1. Study area location map

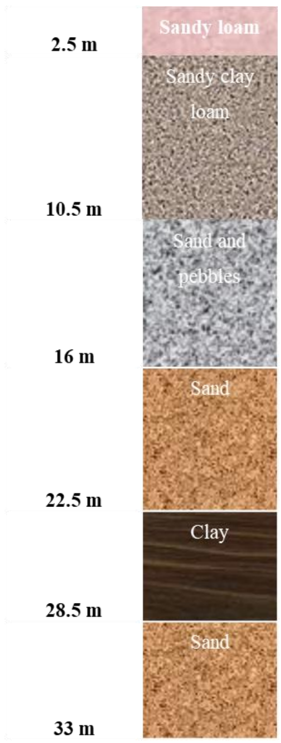

Fig. 2. Well log of the exploratory well in the study area

Data on groundwater level and salinity were also collected from the State Groundwater Department, State Public Health Department and the Central Groundwater Board. Data from 10 observation wells in the unconfined aquifer and 9 piezometers in the semi-confined aquifer observed between 2005 and 2020 were used to study the spatial variation of groundwater salinity and water levelof pre-and post-monsoon periods were used in the analysis.

2.3 Data Analysis

The statistical analysis was performed on water quality parameters for determining the minimum, maximum, mean and standard deviation. Mann-Kendall Test was used to detect the trend in annual rainfall series.

2.3.1 Mann-Kendall test

The trend in the annual rainfall series was detected by applying the non-parametric Mann-Kendall test [35,36].The magnitude of the slope was estimated using the Sen (Sen, 1968) slope estimator. The test was conducted with the null hypothesis (H_0) that there is no trend in the series and the alternative hypothesis that there was a trend in the series.

The Mann–Kendal-statistic S is given as:

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} (Sign(x_j - x_i)) \qquad (1)$$

Where,

$$Sign(x_j - x_i) = \begin{cases} 1 \; if x_j - x_i > 0 \\ 0 \; if x_j - x_i = 0 \\ -1 \; if x_j - x_i < 0 \end{cases}$$

The variance of S denoted by (σ_s^2) was computed from Eq. 2

$$\sigma_s^2 = \frac{n(n-1)(2n+5) - \sum_{j=1}^{q} t_j(t_j - 1)(2t_j + 5)}{18} \qquad (2)$$

where n is the number of data points, q is the number of tied groups in the data set and t_j is the number of data points in j^{th} tied group.

Then S and σ_s^2 were used to compute the test statistics Z_s as:

$$Z_s = \begin{cases} \frac{S-1}{б} if S > 0 \\ 0 \qquad if S = 0 \\ \frac{S+1}{б} if S < 0 \end{cases} \qquad (3)$$

An increasing trend is indicated by a positive value of S and a decreasing trend is indicated by a negative value. The null hypothesis H_0 that there is no trend in the data is either accepted or rejected if the computed Z_S statistics is less than or more than the critical value of Z-statistics obtained from the normal distribution table at 5% significance level.

The nonparametric Sen's method was used to estimate the slope. This involves computing slopes for all the pairs of time points and then using the median of these slopes as an estimate of the overall slope. The equation to estimate slope is given by Eq. 4.

$$Q_i = \frac{x_j - x_k}{j - k} \qquad (4)$$

Where, j > *k*. If there are *n* values x_ji series, we get as many as $N = ((n+1)/2)$ slope estimate Q_i. Sen's estimator of slope is simply given by the median of these *N* values of Q_i's.

$Q = Q_{[(N+1)/2)]}$ if N is odd
$Q = (Q_{[N/2]} + Q_{[(N+2)/2]})/2$ if N is even.

$Q_{med}$was computed by a two-sided test at 100 (1-α) % confidence interval.An increasing trend in time series is indicated by Positive value and decreasing trend by negative value.

2.4 Hydrochemical Analysis

Data on the concentration of major ions such as HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, etc K^+ were used for hydrochemical analysis using the Piper diagram. The trilinear Piper diagram proposed by [37], was applied to plot the concentration of major cations and anions to determine the chemical facies of the groundwater to identify the evolution of hydrochemical parameters of groundwater sources.

Trilinear Piper diagram was constructed with the help of Geochemical analyst software version 2015.1.14.

2.5 Mechanism Governing the Groundwater Chemistry

Gibb's diagrams are tool for understanding the various mechanisms and processes involved in groundwater chemistry [38].The source of the dissolved ions in the groundwater can be understood by the Gibbs diagram which is a plot of $(Na^+)/(Na^+ + Ca^{2+})$ vs TDS and $Cl^-/(Cl^- + HCO_3^-)$ vs TDS. Gibbs diagram was prepared with the help of GRAPHER software.

2.6 Irrigation Water Quality

The United States Salinity Laboratory diagram (USSL diagram) for suitability of water for agricultural uses was used to determine the suitability of groundwater for irrigation. Sodium percentage determines the ratio of sodium to the total cations viz., sodium, potassium, calcium and magnesium. The diagram was prepared using GRAPHER software.

SAR was prepared using the following formulae;

$$SAR = \frac{Na^+}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}}$$

Where, the ionic concentrations are expressed in meq/l.

2.7 Spatial Variation of Groundwater Level and Salinity

Geostatistical tools were used to describe the spatial variability of groundwater levels and salinity. Ordinary kriging was used to plot the spatial variability map of groundwater salinity and levels.

2.7.1 Ordinary kriging

Kriging involves both mathematical and statistical methods [39]. In this interpolation is based on the semi-variogram which is defined as half the average squared difference between the attribute values at all points separated by a lag distance h (Eq. 5).

$$\gamma(h,\alpha) = \frac{1}{2N(h,\alpha)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2 \quad (5)$$

Where,

$\gamma(h,\alpha)$: Semivariance as a function of both the magnitude of the lag distance or separation vector (h) and its direction (α)
$N(h,\alpha)$: number of observation pairs separated by h and direction α used in each summation
$Z(x_i)$: random variable at location x_i.

The kriging equation is given by Eq. 6

$$Z^*(x_0) = \sum_{i=1}^{n} \lambda_i . Z(x_i) with \sum_{i=1}^{n} \lambda_i = 1 \quad (6)$$

Where,

$Z^*(x_0)$: random variable at the location x_0, $Z(x_i)$: measured value at a location x_i,
λ_i: weighting factor assigned to $Z(x_i)$
n: number of observations

3. RESULTS AND DISCUSSION

3.1 Statistical Summary of Water Quality Pre-Monsoon and Post Monsoon Seasons

The range of the electrical conductivity in the study area varied between 4.30 dS/m to 0.76 dS/m during pre-monsoon and 1.96 dS/m to 0.66 dS/m in post-monsoon. The TDS in pre-monsoon season varied from 2.79 kg/m^3 to 0.51 kg/m^3 and in post-monsoon and in post-monsoon it varied from 1.28 kg/m^3 and 0.36 kg/m^3 (Table 1). Data showed Na^+ was the predominant cation with a maximum concentration of 1844 mg/l and 455.6 mg/l during pre-monsoon and post-monsoon; respectively. Other cations with higher concentrations were K^+, Mg^{2+} and Ca^{2+} with an average concentration of 440.45 mg/l, 324.68 mg/l and 226.89 mg/l in pre-monsoon and 196.89 mg/l, 139.09 mg/l and 139.09 mg/l in post-monsoon respectively.

Chloride concentration in pre-monsoon varied from 184 mg/l to 2417 mg/l and in post monsoon it varied from 99 mg/l to 714 mg/l. Other anions were SO_4^{2-} and HCO_3^- with an average concentration of 239.79 mg/l and 129.59 mg/l in pre-monsoon and 110.73 mg/l and 75mg/l in post-monsoon; respectively. The EC, TDS and concentration of all the anions and cations were found to be decreasing from pre-monsoon to post-monsoon.

Table 1. Statistical data for the analysed groundwater samples

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	TDS	EC	pH
Premonsoon										
Minimum	58.61	29	119	54.32	74	45	184	0.51	0.76	6.8
Maximum	492.6	786.3	1844	1023	196.6	1146	2417	2.79	4.30	8.6
Mean	226.89	324.68	697.50	440.45	129.59	239.79	755.76	1.41	2.11	8.1
STDV	133.26	250.08	473.54	344.66	36.961	363.44	620.56	0.71	1.10	0.6
Postmonsoon										
Minimum	41	22	74.3	39.8	53.8	30.2	99	0.36	0.66	6.9
Maximum	251	314	455.6	428	128	425	714	1.28	1.96	8.1
Mean	107.45	139.09	312.89	196.89	75.88	110.73	327.96	0.75	1.12	7.6
STDV	59.42	91.42	138.19	142.12	19.38	136.42	211.92	0.26	0.44	0.5

Ca^{2+}: Calcium (mg/l), Mg^{2+}: Magnesium (mg/l), Na^{+}: Sodium (mg/l), K^{+}: Potassium (mg/l), HCO_3^{-}: Bicarbonate(mg/l), SO_4^{2-}: Sulphate (mg/l), Cl^{-}: Chloride (mg/l), TDS: Total Dissolved Solids (kg/m^3), EC: Electrical conductivity (dS/m)

3.2 The Trend in Groundwater Level and Quality

The results of trend analysis for pre-monsoon groundwater levels in both confined and semi-confined aquifers using the Mann-Kendall test and Sen's slope estimates are given in the Tables 2-5. All the monitoring wells in both confined and semi-confined aquifers showed negative trends whereas eight wells resulted in a significantly negative trend (Table 2 & Table 3). A significant decreasing trend was observed in wells near the coasts. There was a significant rise in the groundwater salinity in both unconfined and semi-confined aquifers (Table 4 and Table 5). The Mann-Kendall test reveals that the study area is affected by the decline in groundwater level and seawater intrusion during pre-monsoon. The groundwater decline is creating a reverse hydraulic gradient which results in the movement of seawater into the freshwater aquifer [40]. Due to this, the groundwater in parts of the study is becoming unsuitable for drinking as well as irrigation purposes.

Since the test was conducted with a 95 % confidence level, the p-value <0.05 was considered to be significant. All the monitoring wells in both confined and semi-confined aquifers in the region showed negative trends whereas eight wells resulted in a significantly negative trend. A significant decreasing trend was observed in wells near the coasts. The salinity was also found to have an increasing trend in both the aquifers. In the unconfined aquifer, wells namely KKDOW019, KPH16, KPH95, KPH96, KPH31 and QKKD060 were found to have a significant falling trend in groundwater levels in last 15 years. The Z statistic was found to be more than 1.96. Among them, KPH96 resulted in a strongly falling trend with the highest Sen's slope, 0.22 and a p-value of 0.007. Similarly, in the semi-confined aquifer, W23765, KPH15 KPH65, and L01176 resulted in a significant falling trend in groundwater level. This clearly shows that the groundwater level is declining in both aquifers.

Trend analysis on groundwater salinity shows that all the wells have a rising trend with few of them having a significantly rising trend. Wells namely KPH16 and KPH96 had significantly rising trend in salinity in the unconfined aquifer. Sen's slope varies from 0.005 to 0.01. Similarly, in the semiconfined aquifer, KPH15 and L00994 were found to have significant negative trends. The Z statistics were 1.98 and 2.17 and the p-value was 0.04 and 0.02 respectively.

There is a significant rise in the groundwater salinity in both unconfined and semi-confined aquifers. The Mann-Kendall test reveals that the coastal aquifer in Vadakara, Kozhikode North is getting affected by the decline in groundwater and seawater intrusion. The groundwater decline causes the seawater to intrude into the groundwater over the years [40]. Which makes the groundwater unsuitable for drinking as well as irrigation.

Table 2. The trend in groundwater level in the unconfined aquifer

Premonsoon				
Well ID	**Z**	**Sens slope**	**p-value**	**Trend**
KKDOW019	-2.3	-0.05	0.02	Fall
KKDOW174	-1.57	-0.008	0.11	Fall
KKDOW176	-1.89	-0.031	0.06	Fall
KPH16	-2.57	-0.036	0.01	Fall
KPH95	-2.07	-0.22	0.03	Fall
KPH96	-2.70	-0.023	0.007	Fall
KPH31	-2.41	-0.014	0.010	Fall
QKKD059	-1.93	-0.045	0.052	Fall
QKKD060	-2.21	-0.023	0.027	Fall

Table 3. The trend in groundwater level in the semi-confined aquifer

Premonsoon				
Well ID	**Z**	**Sens slope**	**p- value**	**Trend**
KPH15	-2.52	-0.046	0.01	Fall
KPH19	-1.31	-0.017	0.19	Fall
KPH65	-2.92	-0.029	0.003	Fall
L00994	-1.35	-0.02	0.17	Fall

Table 4. The trend in groundwater salinity in unconfined aquifer

Premonsoon				
Well ID	**Z**	**Sens slope**	**p-value**	**Trend**
KPH16	1.94	0.01	0.05	Rise
KPH95	0.9	0.006	0.36	Rise
KPH96	1.31	0.005	0.19	Rise
KPH31	2.03	0.011	0.04	Rise

Table 5. The trend in groundwater salinity in the semi-confined aquifer

Premonsoon				
Well	**Z**	**Sens slope**	**p- value**	**Trend**
KPH15	1.98	0.015	0.04	Rise
KPH19	1.22	0.003	0.22	Rise
KPH65	1.67	0.09	0.09	Rise
L00994	2.17	0.01	0.02	Rise

3.3 Hydrochemical Facies

The results of the Piper diagram for the pre-monsoon season in the year 2020 are presented in Fig. 3. On the cationic triangle, the samples fall within the (Na^+, Ca^+ and K^+). In 2020, the most dominant cations were (Na^+, and K^+) and the dominant anions were SO_4^{2-} and Cl^-. Hydrogeochemical facies were Na-Cl followed by Ca-Mg-Cl which indicates the influence of seawater intrusion or upconing into the coastal aquifer [5,41]. Furthermore, the dominant cations and anions were from seawater indicating the mixing of seawater with the groundwater [42].

3.4 Groundwater Chemistry

The Gibbs plot I of the ratios of anions Vs TDS (Fig. 4) showed a higher concentration of Cl^- proportion in most of the samples, indicating that Cl^- ions might have been generated by a variety of sources. The Gibbs plot I of the ratios of anions Vs TDS revealed the higher concentration of Na^+ proportion and its distribution in larger part indicated that the Na^+ ions are produced from a similar source or through the same geochemical process. In both the plots, all the samples showed evaporation crystallization dominance and no sample showed rock and precipitation dominance. This reveals the evaporation augment the concentration of Na^+ and Cl^- ions in the aquifer with increasing TDS [43]. The Na^+ and Cl^- ions present in the aquifer of the study area were generated from seawater and the salinity in the groundwater in some area may be due to the evaporation dominance of the ions [5,17,15]. From the spatial distribution on diagrams, and the statistical summary of the water sampling and analysis the aquifer is characterised by saline nature due to seawater intrusion.

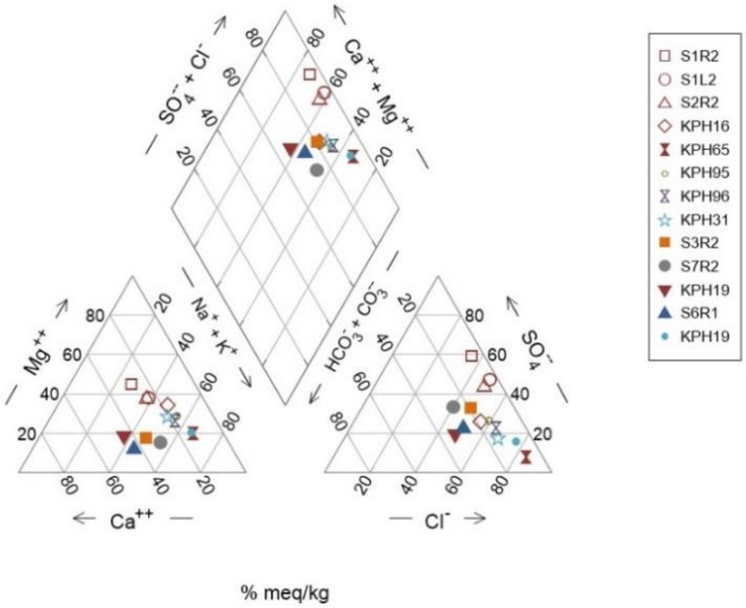

Fig. 3. Concentration of major cations and anions on Piper diagram

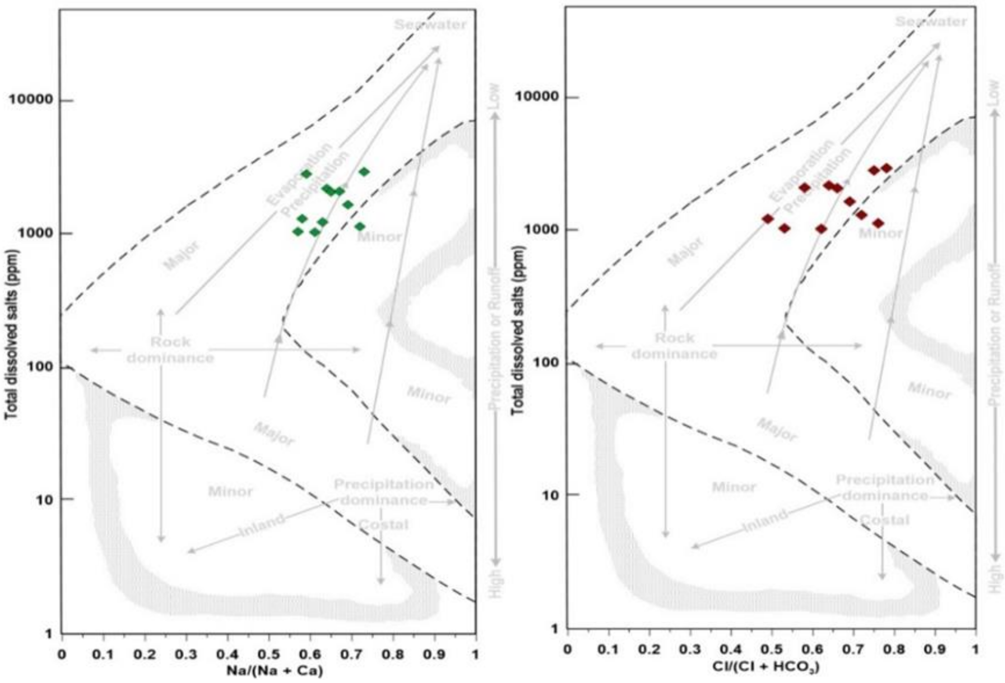

Fig. 4. Gibbs plot of ratios of anions and cations Vs TDS

3.5 Groundwater Quality for Irrigation

The USSL diagram include four classes of the salinity hazard based on the electrical conductivity of the water. The USSL diagram (Fig. 5) illustrates that most of the groundwater samples fall in the category of C3S2 (high salinity with medium sodium followed by C4S2 (very high salinity with medium sodium). The electrical conductivity ranges from 1.87 to 4.2 dS/cm and SAR values range from 12 to 18. The values of SAR specified 55% of thesamples contained low to medium sodium adsorption ratio. Gradual accumulation of Na^+ levels in soil might occur as a result of irrigating with water with high SAR values. It may have a negative impact on infiltration as wells as percolation rates thus resulting in inadequate aeration and soil crusting [42].

Groundwater with low salinity (EC< 0.5 dS/m) are suitable for agriculture provided there will not be any development of salinity [17]. In this study there is no groundwater samples in this category. Groundwater with medium salinity (EC 0.5-1 dS/m) and high salinity (EC 1-2.25 dS/m) can be used for irrigation with leaching, proper crop selection and other reclamation technique [17]. The result revealed that there was an occurrence of medium alkalinity and high to very high salinity hazards in the aquifer. About 35% of the samples were designated marginally suitable for agriculture and 65% of the samples were classified as unsuitable for agriculture due to the high salinity and little danger of exchangeable sodium [17,44].

3.6 Spatial Variability Map of Groundwater Level

The area under groundwater elevations less than 2 m, 2-4 m, and greater than 4 m were determined from the spatial variability maps of groundwater elevation in pre-monsoon and post-monsoon for the year 2020 for both unconfined and semi-confined aquifer. The results are presented in Fig. 6 and Table 6. In unconfined aquifer the area under water table elevation of less than 2 m was 27.1 % and in post monsoon 28.4 % m. Area under 2-4 m was 21.3% in pre-monsoon and 46.3% in post-monsoon. In pre-monsoon season, 51.6% area was under the depth water table depth greater than 4 m.There are areas with water table elevation below 0 m. This will create a reverse hydraulic gradient and thereby seawater intrusion to the coastal aquifer [32].

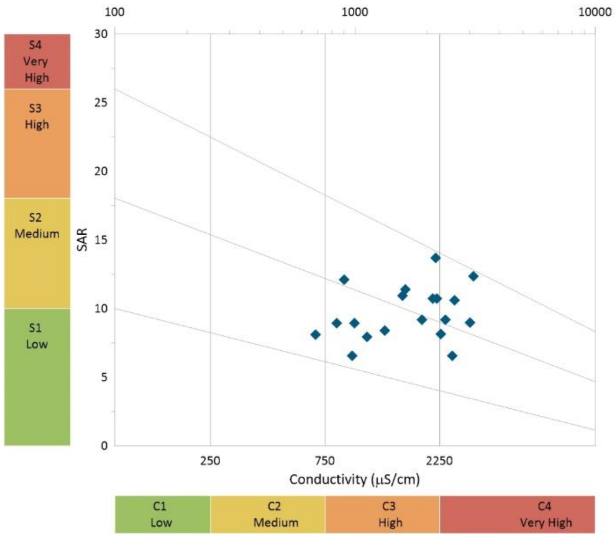

Fig. 5. USSL diagram

Table 6. Area under various water table elevation

Water table elevation	Area (%) Unconfined aquifer		Area (%) Semi-confined aquifer	
m	Pre-monsoon	Post monsoon	Pre-monsoon	Post monsoon
< 2	27.1	28.4	32.5	52.3
2.0 - 4.0	21.3	46.3	41.6	29.9
>4.0	51.6	25.3	25.9	17.8

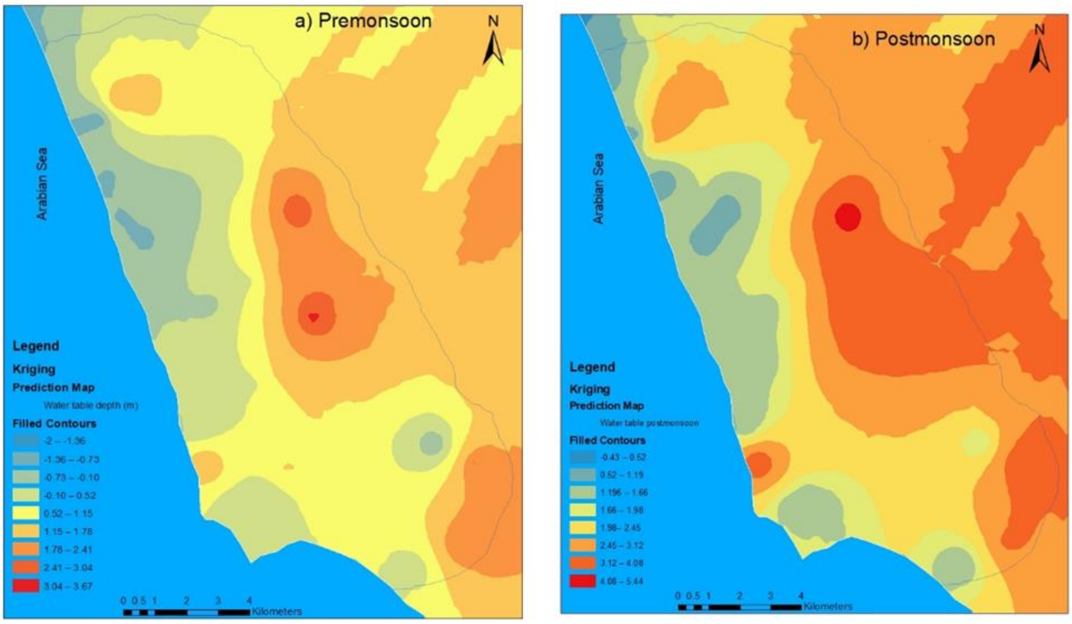

Fig. 6. Spatial variability map of groundwater level in unconfined aquifer

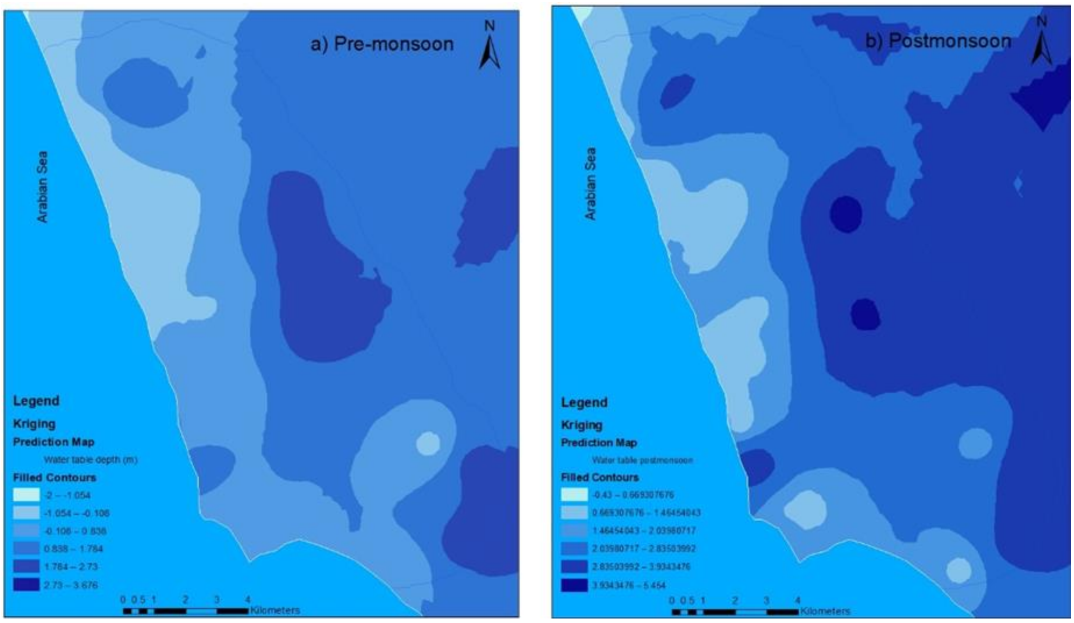

Fig. 7. Spatial variability map of groundwater level in semi-confined aquifer

In semi-confined aquifer (Fig. 7 and Table 6), the water table elevation under less than 2 m in pre-monsoon was in 32.5 m of the total area and post-monsoon it was in 52.3 %. Area under water table elevation of 2-4 m in pre-monsoon was 41.6 % which decreased to 29.9% in post-monsoon. Area under water table elevation of more than 4 m in pre andpost monsoon were 25.9% and 17.8 %; respectively. The improvement in groundwater level in the aquifer during post-monsoon may be due to the recharge in the unconfined aquifer and vertical leakage through the semiconfined aquifer during monsoon [45].

3.7 Spatial Variability Map of Groundwater Salinity

Irrigation water quality classification based on Central Pollution Control Board of India (CPCB, 2018) was used for the categorisation of suitability of groundwater for irrigation. The electrical conductivity in the aquifer varied from 0.2ds/m to 4.3 dS/m. In unconfined aquifer (Fig. 8 and Table 7), most of the area lies in the EC range of 0.75-2.25 dS/m (Pre-monsoon- 31.7%, post-monsoon-44.5%).The area in pre-monsoon season under EC of more than 4 dS/m was 25.2 %, which is unfit for irrigation. As of now the most of the area lies under moderately safe to unsafe category which in future may increase due to increasing groundwater pumping [46].

In semi-confined aquifer (Fig. 9 and Table 7), 20.1% area was under safe and moderately safe category which is almost same in post monsoon. The area under moderately unsafe category was 33 %. The area under moderately safe category increased from 21.7% in pre-monsoon to 45.5 % in post monsoon. About 24.0% area was categorised as unfit for irrigation in pre-monsoon and there is no area present in this category during post-monsoon. During monsoon, recharge occurs in the unconfined aquifer and vertical leakage through the semiconfined aquifer diminishes the reverse hydraulic gradient in the aquifer thus reduces the salinity [45].

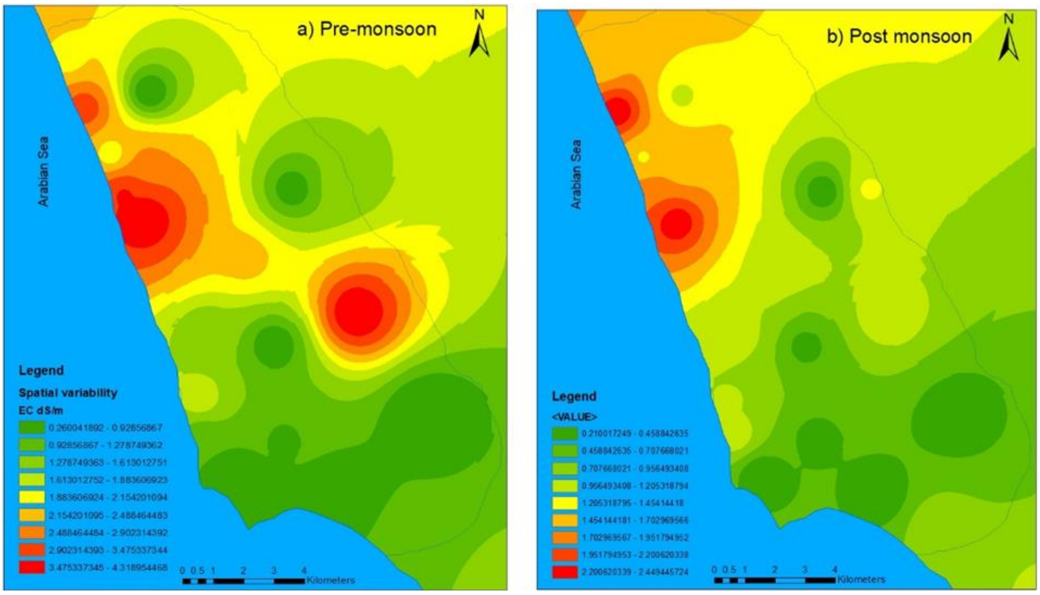

Fig. 8. Spatial variability map of salinity in unconfined aquifer

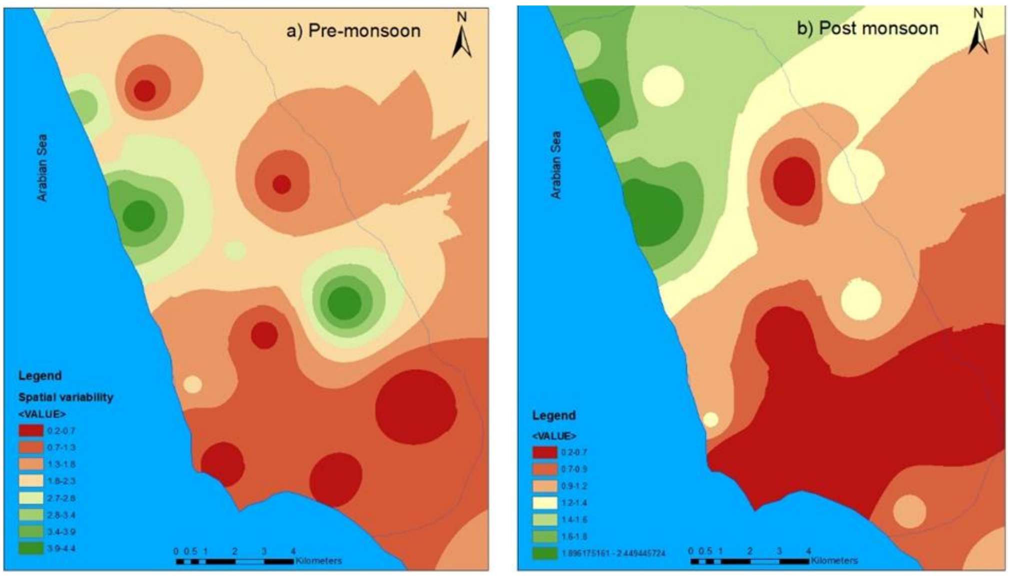

Fig. 9. Spatial variability map of salinity in semi-confined aquifer

Table 7. Percentage area under various EC classes

EC range dS/m	Area (%)		Area (%)	
	Pre-monsoon	Post- monsoon	Pre-monsoon	Post- monsoon
< 0.75	23.1	31.6	20.1	20.6
0.75-2.25	31.7	44.5	21.7	45.5
2.25-4	20	23.9	33.6	33.9
>4.0	25.2	0	24.6	0

4. CONCLUSION

The characterization of the coastal aquifer of Kozhikode district in Kerala was done based on physical and chemical parameters, hydrogeochemical analysis, trend analysis and spatial variations in groundwater levels and salinity. The aquifer consists of three layers; the top unconfined layer, and the bottom semi-confined layer which are separated by an aquitard. It was concluded that the dominant cations and anions were from seawater due to the mixing of seawater with the groundwater. The groundwater in the affected area has medium alkalinity and high to very high salinity, and is not suitable for irrigation. Most of the area in unconfined aquifer in pre and post monsoon lies in the EC range of 0.75-2.25 dS/m. The area in pre-monsoon season under EC of more than 4 dS/m was 25.2 %, and is unfit for irrigation. As of now the most of the area lies under moderately safe to unsafe category which in future may increase as the groundwater table is declining. In semi-confined aquifer about 20.1% area in pre and post monsoon was under safe and moderately safe category whereas the groundwater in about 24.0% area was unfit for irrigation in pre-monsoon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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