ORIGINAL ARTICLE

Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India

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Abstract Groundwater is an essential and vital component of any life support system. It is not only the basic need for human existence but also a vital input for all development activities. The present hydro-geochemical study was confined to the coastal belt of Alappuzha district, which lies in the coastal lowland division of Kerala. Groundwater quality and its suitability for irrigation and domestic purpose were examined by various physico-chemical parameters such as pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. These parameters were used to assess the suitability of groundwater for domestic purpose by comparing with the WHO and Indian standards. TDS, sodium adsorption ratio (SAR), and permeability index were used for irrigation suitability assessment. The sample analysis reveals that the groundwater is not entirely fit for drinking with respect to pH, EC, Ca^{2+}, Mg^{2+}, Na^+, and Cl^-. In some of the collected samples, the concentrations of these parameters exceed the permissible limits of WHO and ISI standards. Based on TDS and SAR almost all samples are suitable for irrigation purpose except a few locations, which show values beyond the permissible limits. $Ca–Mg–HCO_3$ is the dominant water type in the study area. The sequence of the abundance of the major cations and anions is $Ca > Na > Mg > K = HCO_3 > Cl > SO_4$. Based on the total hardness and TDS, 96 % of groundwater samples are found suitable for drinking purpose.

Introduction

Water is a chief natural resource essential for the existence of life and is a basic human entity. Water resources are harnessed for various purposes like drinking, agricultural, industrial, household, recreational, and environmental activities, etc. Groundwater is one of the major sources of drinking water all over the world (Bear 1979). Of the 37 Mkm^3 of freshwater estimated to be present on the earth, about 22 % exists as groundwater, which constitutes about 97 % of all liquid freshwater potentially available for human use (Foster 1998). There has been tremendous increase in the demand for fresh water due to over exploitation and growth in population. Since groundwater is a renewable natural resource and a valuable component of the ecosystem, it is vulnerable to natural and human impacts. It is estimated that approximately one-third of the world's population use groundwater for drinking (Nickson et al. 2005) and about one million people are directly dependent upon the groundwater resources in Asia alone (Foster 1995). In most parts of India, groundwater forms the major source of water

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supply for drinking and agricultural purposes. Quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes. Groundwater quality data give important clues to the geologic history or rocks and indications of groundwater recharge, discharge and storage (Walton 1970). Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Subramani et al. 2005; Schiavo et al. 2006; Magesh and Chandrasekar 2011; Krishna Kumar et al. 2011). According to Babiker et al. (2007), the chemistry of groundwater is not only related to the lithology of the area and the residence time the water is in contact with rock material, but also reflects inputs from the atmosphere, from soil and weathering as well as from pollutant sources such as mining, land clearance, saline intrusion, industrial and domestic wastes. Excessive irrigation activities also resulted in groundwater pollution in India (Pawar and Shaikh 1995; Sujatha and Reddy 2003). During the past 100 years, India's per capita water availability has decreased fourfold whereas for Kerala, it has decreased fivefold (Basak 1992). The over exploitation of groundwater in the coastal zones has detrimentally affected its quality and quantity and may result in negative water balance, triggering seawater intrusion.

Groundwater used for domestic and irrigation purposes can vary greatly in quality depending upon type and quantity of dissolved salts. It contains a wide variety of dissolved inorganic chemical constituents in various concentrations, resulting from chemical and biochemical interactions between water and the geological materials. Dissolved salts should be present in irrigation water in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals.

Alappuzha coastal stretch has been selected for the present study, which is the only district in Kerala where domestic and irrigation requirement is harnessed from groundwater source on a large scale. This is one among the major coastal zones of the state, where the demand for groundwater resources has accelerated in recent period (CGWB 2007). Manjusree et al. 2009 studied the groundwater quality of the coastal aquifers of Chennam-Pallippuram panchayath (Alappuzha district) and assessed that the groundwater in the panchayath if fit for drinking and irrigational purpose. But, the spatial extent of groundwater suitability was not reported in any study. Hence, the present study was carried out to evaluate the spatial extent of groundwater quality and its suitability for drinking and agricultural uses in the coastal stretch of Alappuzha district.

Study area

The study area lies in Alappuzha district, which is one of the well-developed coastal districts in southern part of Kerala covering an area of 1,414 km². The present study area lies between 76°32′–76°42′E longitudes and 09°26′–09°48′N latitudes and stretches about 30 km along the coast (Fig. 1). The study area is mainly drained by Pamba river and its tributaries viz. Achankovil and Manimala rivers. The minimum to maximum temperature in the study area ranges from 23 to 33 °C, respectively. The study area experiences two seasons: southwest monsoon season (June–Sept); and northeast monsoon season (Oct–Dec). The average annual rainfall in the study area ranges between 2,180 to 3,484 mm and experiences a humid tropical climate.

The study area falls under the coastal lowland physiographic unit of Kerala. The charnockite, khondalite and granites form the basement and are overlain by laterite/alluvial sediments. The coastal alluvium comprising of sand and clay and the major abstraction of groundwater is from tertiary sedimentary formation (CGWB 2007). The borehole lithology at Pallippuram (Lat. 09°44′48″N and Long. 76°21′53″E) indicates that the unconsolidated Quaternary sediments comprising sands constitute the upper layer underlain by clay, clayey sand, laterites, clay with limestone, clay with few sand, sandy clay, etc. (Fig. 2).
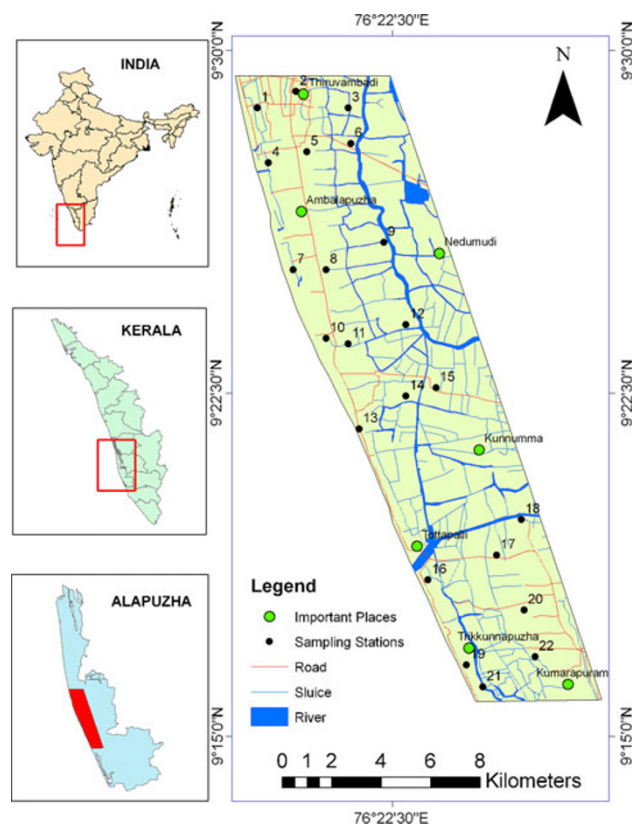

Fig. 1 Location map of the study area

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However, towards the coastal side (western part), the Quaternary sedimentary sequence, consisting of alternate layers of sand and clay, has a total depth of 445 m at Arthungal (Lat. 09°39′32″N and Long. 76°17′59″E) (Manjusree et al. 2009).

Methodology

The base map of the study area were scanned and digitized from the Survey of India (SOI) Toposheets No. 58C/7 and 58C/11 (1:50,000). ArcGIS®10 is used to map and analyze the data for the evaluation of groundwater quality. The area was equally divided into 21 grids for facilitating representative groundwater sample collection from the area and for assessing its suitability for domestic and irrigation purposes.

Groundwater samples were collected from 22 shallow open dug wells during January (2009) representing the post monsoon season. The location of sampling points is shown in Fig. 1. High-density polyethylene (HDPE) bottles were used for sample collection. The samples were filled up to the brim and were immediately sealed to avoid exposure to air and were labeled systematically. The labeled samples were analyzed in the laboratory for various physico-chemical parameters. During sample collection, (handling and preservation) standard procedures recommended by the American Public Health Association (APHA 1995) were followed to ensure data quality and consistency.

The pH and electrical conductivity (EC) were measured in situ by using Hanna (HI9828 USA) multi-parameter probe and the major ions (Ca, Mg, Na, K, HCO_3, SO_4, Cl)

Fig. 2 Cross section of the under laying lithology

were analyzed using the standard methods suggested by the American Public Health Association (APHA 1995). Among the analyzed ions, sodium (Na) and potassium (K) were determined by using flame photometer. Total hardness (TH) as $CaCO_3$, calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-) and chloride (Cl) were analyzed by volumetric methods and sulfates (SO_4^{2-}) were estimated by using the colorimetric method. The hydro-chemical facies (Piper diagram) and the Wilcox plot in the study area were plotted using AquaChem 4.0 software.

The suitability of groundwater for agricultural and domestic purposes were evaluated by comparing the values of different water quality parameters with those of the World Health Organisation (WHO 2004) and Indian standard specification (ISI 1993) guidelines values for drinking water.

GIS-analysis

The spatial analysis of various physico-chemical parameters was carried out using the ArcGIS®10 software. In order to interpolate the data spatially and to estimate values between measurements, an inverse distance weighed (IDW) algorithm was used. The IDW technique calculates a value for each grid node by examining surrounding data points that lie within a user-defined search radius (Burrough and McDonnell 1998). All of the data points are used in the interpolation process and the node value is calculated by averaging the weighted sum of all the points.

Results and discussion

The quality standards for drinking water have been specified by the World Health Organization (WHO) in 2004. The behavior of major ions (Ca, Mg, Na, K, HCO_3, SO_4, Cl) and important physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH) and the suitability of groundwater in the study area are discussed below.

Drinking suitability

The analytical results have been evaluated to ascertain the suitability of groundwater in the study area for drinking and agricultural uses. The analytical results for all the parameters for the groundwater samples in the study area are presented in the Table 1.

pH

pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The pH of water provides vital information in many types of

Table 1 Physico-chemical characteristics of groundwater in the study area

Sample no.	pH	EC (μmhos/cm)	TDS (mg/l)	TH (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO₃ (mg/l)	SO₄ (mg/l)	Cl (mg/l)
1	5.69	340	284	544	42.4	106.4	17.2	8.1	148	0.07	52
2	6.08	410	304	154	66.4	6.3	25.3	7.2	220	0.08	34
3	6.31	1,020	642	332	1147.4	11.2	79.5	10.8	490	0.09	92
4	5.23	125	130	404	22.4	84.6	6.1	2.2	110	0.00	12
5	5.75	400	318	382	152.8	61.2	31.6	8.4	170	0.11	42
6	6.35	800	592	244	92	3.4	99	10.9	370	0.00	92
7	5.79	64	94	88	30.4	2.9	1.8	0.4	60	0.02	500
8	5.87	69	100	94	18.4	11.7	2.6	0.8	80	0.08	12
9	6.45	600	354	492	72.8	75.3	45.3	0.8	290	0.16	72
10	6.9	260	198	142	45.8	6.8	12.3	3.8	170	0.00	32
11	6.86	270	235.5	156	40.8	13.1	5.8	5.1	200	0.09	18
12	6.51	690	460	186	43.2	19.0	73.5	1.5	310	0.19	80
13	6.52	890	595.4	266	53.6	32.1	1.8	10.1	330	0.01	132
14	6.3	570	477	162	51.2	8.3	50	11.2	310	0.04	56
15	6.53	470	322	208	72	6.8	27.1	2.1	290	0.04	28
16	6.16	350	294.2	136	52	1.5	27.9	3.8	190	0.04	34
17	6.52	420	434	184	73.6	4.4	26.1	8.3	240	0.06	52
18	6.57	500	341.2	236	56	23.3	41.1	3.8	290	0.19	40
19	6.62	430	269.4	194	58.4	11.7	14.3	5.9	210	0.02	22
20	5.46	170	184	70	17.6	6.3	17.8	2.8	120	0.18	22
21	5.86	2,200	1,898.6	424	83.2	52.5	272.5	9.8	110	0.76	540
22	6.5	260	201.4	238	54.4	24.8	10.2	2.4	170	0.19	18
Min	5.23	64	94	70	17.6	1.5	1.8	0.4	60	0.00	12
Max	6.9	2,200	1,898.6	544	1,147.4	106.4	272.5	11.2	490	0.76	540
Mean	6.2	514.0	396.8	242.5	106.7	26.1	40.4	5.5	221.7	0.1	90.1
SD	0.4	453.6	369.7	132.6	234.3	30.2	58.2	3.7	105.2	0.2	142.6

SD standard deviation

geochemical equilibrium or solubility calculations (Hem 1985). The limit of pH value for drinking water is specified as 6.5–8.5 (WHO 2004; ISI 1993). The pH value of most of the groundwater samples in the study area varies from 5.2 to 6.8 (Fig. 3a), which clearly shows that the groundwater in the study area is slightly acidic in nature. This may be attributed to the anthropogenic activities like sewage disposal and use of fertilizers in the highly populated coastal segment of the study area followed by natural phenomenon like intrusion of brackish water into the sandy aquifers, which initiates the weathering process of underlain geology.

Electrical conductivity (EC)

Electrical conductivity is a measure of water capacity to convey electric current. The most desirable limit of EC in drinking water is prescribed as 1,500 μmhos/cm (WHO 2004). The EC of the groundwater is varying from 64.02 and 2199.57 μmhos/cm with an average value of 514 μmhos/cm (Fig. 3b). Higher EC in the study area

indicates the enrichment of salts in the groundwater. The value of electrical conductivity may be an approximate index of the total content of dissolved substance in water. It depends upon temperature, concentration and types of ions present (Hem 1985). The EC can be classified as type I, if the enrichments of salts are low (EC < 1,500 μmhos/cm); type II, if the enrichment of salts are medium (EC 1,500 and 3,000 μmhos/cm); and type III, if the enrichments of salts are high (EC > 3,000 μmhos/cm). According to the above classification of EC, 96 % of the total groundwater samples come under the type I (low enrichment of salts) and 4 % under type II (medium enrichment of salts). The effect of saline intrusion may be the reason for medium enrichment of EC in the study area. The effect of pH may also increase the dissolution process, which eventually increases the EC value.

Total dissolved solids (TDS)

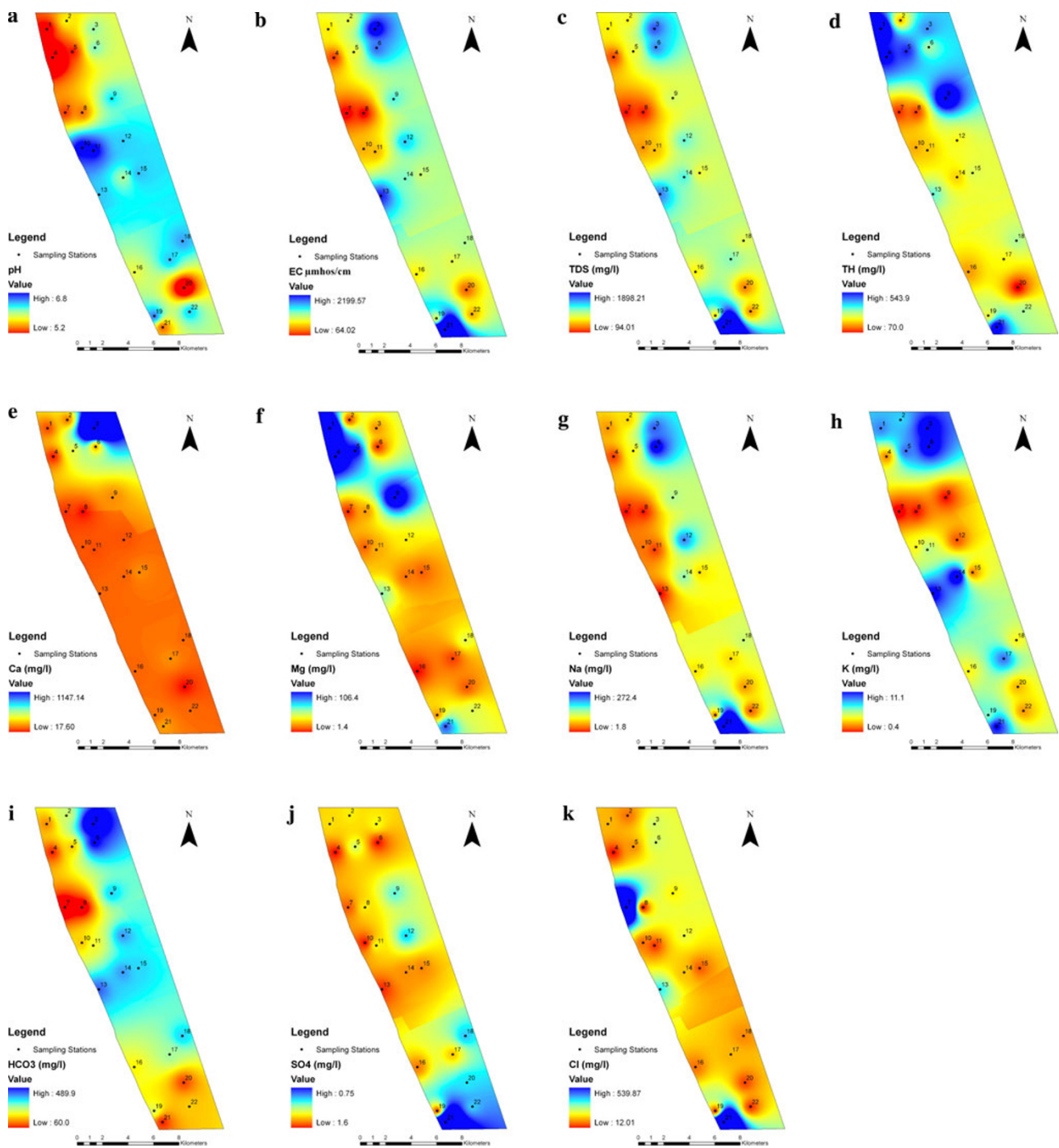According to WHO specification TDS up to 500 mg/l is the highest desirable and up to 1,500 mg/l is maximum

Fig. 3 **a** pH map of the study area, **b** EC map of the study area, **c** TDS map of the study area, **d** TH map of the study area, **e** Ca map of the study area, **f** Mg map of the study area, **g** Na map of the study area, **h** K map of the study area, **i** HCO$_3$ map of the study area, **j** SO$_4$ map of the study area, **k** Cl map of the study area

permissible. In the study area the TDS value varies between a minimum of 94.01 mg/l and a maximum of 1,898.21 mg/l (Fig. 3c), indicating that most of the groundwater samples lies within the maximum permissible limit. According to the Davis and De Wiest (1966)

(Table 2) classification of groundwater based on TDS, 82 % of the total groundwater samples are desirable for drinking (TDS < 500 mg/l), 14 % permissible for drinking (500–1,000 mg/l) and 4 % is suitable for irrigation purposes. High concentration of TDS in the groundwater

Table 2 Classification of groundwater based on TDS (Davis and De Wiest 1966)

TDS (mg/l)	Water type	% of samples
<500	Desirable for drinking	82
500–1,000	Permissible for drinking	14
<3,000	Useful for irrigation	4
>3,000	Unfit for drinking and irrigation	–

sample is due to leaching of salts from soil and also domestic sewage may percolate into the groundwater, which may lead to increase in TDS values.

Total hardness (TH)

The total hardness is varying from 70 to 543.9 mg/l (Fig. 3d). Groundwater of the entire study area lies within the maximum permissible limit prescribed by ISI. Sawyer and McCarty (1967) classified groundwater, based on TH, as ground water with TH <75, 75–150, 150–300 and >300 mg/l, designated as soft, moderately hard, hard and very hard, respectively (Table 3). According to the above categorization, only 4.54 % of the total groundwater samples are soft; 18.18 % belongs to moderately hard; 50 % belongs to hard and the remaining 27.27 % comprises very hard water. The analytical result indicates the water in the study area is hard to very hard. The hardness of the water is due to the presence of alkaline earths such as calcium and magnesium. The drinking water quality is evaluated by comparing with the specifications of TH and TDS set by the World Health Organization and Indian standards (Table 4).

Calcium and magnesium (Ca and Mg)

Calcium and magnesium are the most abundant elements in the natural surface and groundwater and exist mainly as bicarbonates and to a lesser degree in the form of sulfate and chloride. Ca^{2+} concentrations are varying from 17.60 to 1,147.14 mg/l (Table 4; Fig. 3e). Relatively, the higher concentration of Ca^{2+} observed is 1,147.14 mg/l from the groundwater sample 3. The rest of the groundwater samples show Ca^{2+} from 18.4 to 153 mg/l. The desirable limit of calcium concentration for drinking water is specified as 75 mg/l (ISI 1993) which shows that few groundwater samples fall beyond the permissible limit. Only 5 % of the groundwater samples taken from study area have crossed the maximum permissible limit of 200 mg/l for calcium but 9 % are above the desirable limit. The higher Ca^{2+} content can cause abdominal ailments and is undesirable for domestic uses as it causes encrustation and scaling. Magnesium content is varying from 1.4 to 106.4 mg/l (Table 1;

Fig. 3f). The maximum permissible limit of Mg^{2+} concentration of drinking water is specified as 100 mg/l (ISI 1993) and 150 mg/l (WHO 2004). Sample number 1 exceeds the ISI limit as it shows a value of 106.4 mg/l.

Sodium and potassium (Na and K)

Sodium ranks sixth among the elements in order of abundance and is present in most of natural waters. Sodium is generally found in lower concentration than Ca^{2+} and Mg^{2+} in freshwater. The concentration of Na^+ is varied from 1.8 to 272.4 mg/l. The maximum permissible limit of sodium is 200 mg/l and it reveals that few samples are exceeding the permissible limit of WHO and ISI (Table 4; Fig. 3g). The intake of high level of Na^+ causes increased blood pressure, arteriosclerosis, oedema and hyperosmolarity. Groundwater with high Na content is not suitable for agricultural use as it tends to deteriorate the soil.

Potassium is a naturally occurring element; however, its concentration remains quite lower compared with Ca, Mg and Na. Its concentration in drinking waters seldom reaches 20 mg/l. The concentration of K^+ is observed between 0.4 and 11.1 mg/l from the groundwater (Fig. 3h). The maximum permissible limit of potassium in the drinking water is 12 mg/l and it was found that all the samples are below the permissible limit of WHO (Table 4). In comparison with Na^+, the low concentration of K^+ is due to the high resistance of potash feldspars to chemical weathering in the study area.

Bicarbonate (HCO_3)

The value of HCO_3 is observed from 60 to 489.9 mg/l (Fig. 3i), which is the dominant ion, except in the groundwater, occurring near the coast (Table 1). The higher concentration of HCO_3 in the water points to the dominance of mineral dissolution (Stumm and Morgan 1996).

Sulfate (SO_4)

Sulfate is one of the major anion occurring in natural waters. The upper limit for sulfate concentration for drinking water is 150 mg/l (ISI 1993). The sulfate concentration in the study area ranges between 0.75 and 1.6 mg/l (Fig. 3j) with an average value of 0.76 mg/l indicating that all samples fall within the desirable limit.

Chloride (Cl)

The origin of chloride in groundwater may be from diverse sources such as weathering, leaching of sedimentary rocks and soils, intrusion of saltwater, windblown salt in

Table 3 Sawyer and McCarty's classification of groundwater based on hardness

Total hardness as CaCO$_3$ (mg/l)	Water type	Range (no. of samples)	Percent
<75	Soft	70 (1 sample)	4.55
75–150	Moderately hard	88–142 (4 samples)	18.18
150–300	Hard	154–266 (11 samples)	50.00
>300	Very hard	332–544 (6 samples)	27.27

precipitation, domestic and industrial waste discharges, municipal effluents, etc. (Karanth 1987). In the study area, the concentration of chloride is between 12.01 and 539.87 mg/l (Fig. 3k). Relatively, the higher concentration of Cl is observed from the groundwater sample 21. The Desirable limit of chloride for drinking water is specified as 250 mg/l (ISI 1993; Table 4). The excess of chloride in the water is usually taken as an index of pollution and considered as tracer fro groundwater contamination (Loizidou and Kapetanios 1993). In natural waters, the concentration of Cl bears strong correlation with the Na content and specific conductance. Chloride determinations may serve to indicate the intrusion of waters of different composition or to trace and measure rates and volumes of water mass movements.

Hydro-geochemical facies

Most natural water can be represented as solution of three cationic constituents, viz., Ca^{2+}, Mg^{2+} and alkaline metals and of three anionic constituents viz., SO$_4{}^{2-}$, Cl$^-$ and those contributing to alkalinity, i.e., CO$_3{}^{2-}$ and HCO$_3{}^-$. Therefore, linear plots are most suitable for the representation of groundwater composition. The modified trilinear diagram was presented by Piper (1944). The diagram consists of three distinct fields—two triangular fields and one diamond-shaped field. Different groundwater can be identified by their position in the diamond field. Cations expressed as percentages of total cations in meq/l plot as a single point on the left triangle while anions plot in the right triangle. Similarities and differences among groundwater samples can be revealed from the trilinear because water of similar qualities will tend to plot together as groups. Distinct groundwater qualities can be quickly distinguished by their plotting in certain areas of the diamond field. The analytical values obtained from the groundwater samples are plotted on Piper trilinear diagram to understand the hydrochemical regime of the study area. The Piper trilinear diagram for the groundwater samples is presented in the Fig. 4, which clearly explains the variations of cation and anion concentration in the study area. The diamond-shaped field of piper diagram is further divided into four classes, namely Ca^{2+}–Mg^{2+}–Cl$^-$–SO$_4{}^{2-}$, Na$^+$–K$^+$–Cl$^-$–SO$_4{}^{2-}$, Na$^+$–K$^+$–Cl$^-$–HCO$_3$ and Ca^{2+}–Mg^{2+}–HCO$_3{}^-$. In the study area majority of samples belong to the Ca^{2+}–Mg^{2+}–HCO$_3{}^-$ type and in the post monsoon period there is a dominance of Ca^{2+}–Mg^{2+} type water.
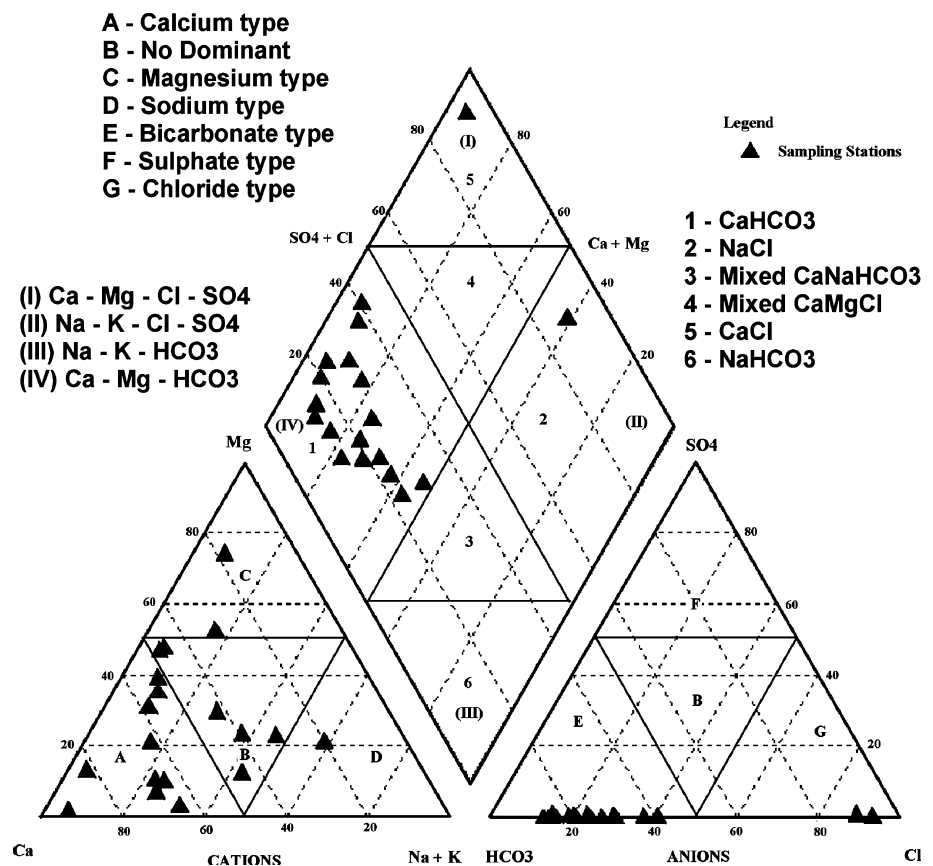
Irrigation suitability

Salinity indices such as sodium percentage (Na%), sodium absorption ratio (SAR) and permeability index (PI) are important parameters for determining the suitability of groundwater for agricultural uses.

Sodium percent (Na%)

The sodium in irrigation waters is usually denoted as percent of sodium. According to Wilcox (1955), in all natural

Table 4 Groundwater samples of the study area exceeding the permissible limits prescribed by WHO (2004) and ISI (1993) for drinking purpose

Sl no.	Water quality parameters	WHO International Standards 2004		Indian Standard (ISI 10500, 1993)		Range in the study area
		Most desirable limit	Max. allowable limit	Highest desirable	Max. permissible	
1	pH	6.5	8.5	6.5–8.5	6.5–9.5	5.2–6.8
2	EC (μmhos/cm)	1400	–	–	–	64–2,200
3	TDS	500	1,500	500	2,000	94–1,898.6
4	TH (as CaCO$_3$)	100	500	300	600	70–544
5	Ca^{2+}	75	200	75	200	17.6–1,147.4
6	Mg^{2+}	50	150	30	100	1.5–106.4
7	Na$^+$	–	200	–	200	1.8–272.5
8	K$^+$	–	12	–	–	0.4–11.2
9	CO$_3{}^{2-}$	–	–	–	–	–
10	HCO$_3{}^-$	–	–	–	–	60–490
12	SO$_4{}^{2-}$	200	400	200	400	0–0.76
11	Cl$^-$	200	600	250	1,000	12–540

Units = mg/l

Fig. 4 Piper plot describing hydrogeochemical facies of the study area

A - Calcium type
B - No Dominant
C - Magnesium type
D - Sodium type
E - Bicarbonate type
F - Sulphate type
G - Chloride type

(I) Ca - Mg - Cl - SO4
(II) Na - K - Cl - SO4
(III) Na - K - HCO3
(IV) Ca - Mg - HCO3

1 - CaHCO3
2 - NaCl
3 - Mixed CaNaHCO3
4 - Mixed CaMgCl
5 - CaCl
6 - NaHCO3

waters Na% is a common parameter to assess its suitability for irrigational purposes. The sodium percent (Na%) values was obtained by using the following equation:

$$Na\% = Na^+ \times 100/\left[Ca^{2+} + Mg^{2+} + Na^+ + K^+\right]$$

where all ionic concentrations are expressed in meq/l. The Wilcox diagram relating sodium percent and total concentration shows that 95.4 % of the groundwater samples fall in the field of good to permissible and 4.6 % of the groundwater samples fall in the field of doubtful for irrigation and no samples fall in the unsuitable category (Fig. 5; Table 5).

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, because sodium concentration can reduce the soil permeability and soil structure (Todd 1980). SAR is a measure of alkali/sodium hazard to crops and it was estimated by the following formula:

$$SAR = Na/[(Ca + Mg)/2]^{0.5}$$

where sodium, calcium, and magnesium are in meq/l. The SAR value of water for irrigation purposes has a significant

relationship with the extent to which sodium is absorbed by the soils. Irrigation using water with high SAR values may require soil amendments to prevent long-term damage to the soil, because the sodium in the water can displace the calcium and magnesium in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and loss of soil structure. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production.

The calculated values of SAR in the study area vary between 0.28 and 33.08 (Table 6). The classification of groundwater samples based on SAR values are shown in Table 7. The SAR values of all the samples are found within the range of excellent to good category, except sample 21 (SAR value >26), which is found to be unsuitable for irrigation purpose. For rating irrigation waters the US salinity diagram was used, in which the SAR is plotted against EC. The USSL (1954) plot indicates that 9.1 % of the groundwater samples fall in C1S1 (low salinity–low sodium type) and 72.7 % of the samples fall in the C2S1 category. This reveals that the water type in the study area has medium salinity with low sodium content and it can be used for irrigation on all type of soil (Fig. 6). About 13.6 % of the groundwater samples fall in the C3S1, indicating high salinity-high sodium type. Only 4.6 % falls in the
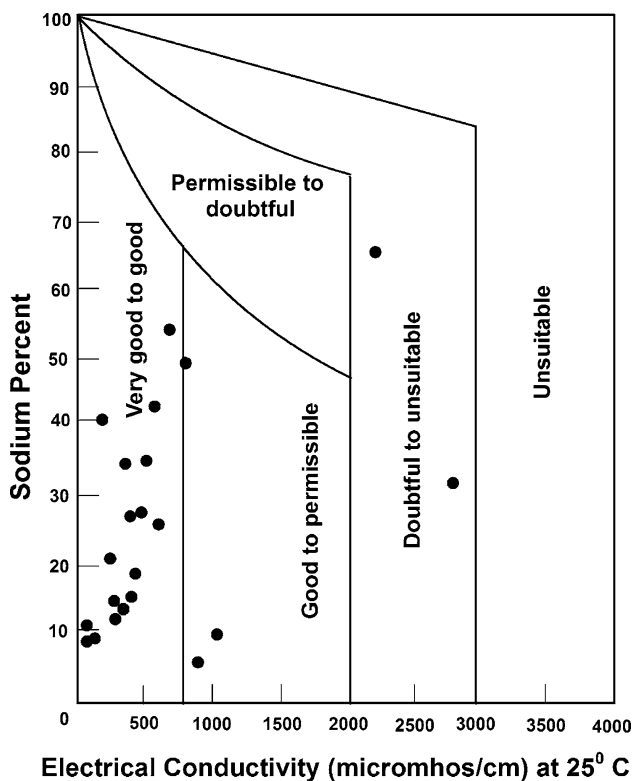
Fig. 5 Classification of irrigation water quality, with respect to total salt concentration and sodium percent

Table 5 Classification of groundwater based on Na% (Wilcox 1955)

Water quality	Sodium (%)	Percentage of samples
Excellent	<20	50
Good	20–40	31.8
Permissible	40–60	13.6
Doubtful	60–80	4.6
Unsuitable	>80	–

medium salinity to high sodium category (C3S2). This type of water can be used to irrigate salt tolerant and semi tolerant crops under favorable drainage condition.

Permeability index

Based on the permeability index (PI), a water suitability classification for irrigation water was developed by Doneen (1964). The PI was calculated by the following equation:

$$PI = \left[Na + (HCO_3)^{0.5} \right] \times 100 / [Na + Ca + Mg]$$

where all the ions are expressed in meq/l. The PI values in the study area vary from 1.93 to 28.14 during the post monsoon period (January 2009), with an average value of about 15.48 (Table 6). A classification based on PI was proposed by World Health Organization for assessing

Table 6 Computed values of Na%, SAR, PI and MH in the study area

Sl. no.	Na%	SAR	PI	MH
1	9.88	1.99	7.74	71.51
2	24.05	4.2	15.98	8.69
3	6.37	3.3	1.93	0.96
4	5.29	0.83	9.53	79.06
5	12.44	3.05	5.78	28.61
6	48.22	14.33	11.14	3.57
7	5.07	0.44	22.39	8.75
8	7.77	0.67	27.82	38.8
9	23.32	5.26	9.47	50.85
10	17.9	2.4	20.8	12.93
11	8.95	1.12	24.02	24.34
12	53.59	13.18	14.44	30.5
13	1.84	0.28	20.82	37.44
14	41.44	9.17	17.33	13.89
15	25.09	4.32	16.81	8.63
16	32.76	5.4	18.14	2.73
17	23.23	4.18	15.67	5.61
18	33.08	6.53	15.11	29.41
19	15.84	2.42	17.75	16.65
20	39.98	5.15	28.14	26.42
21	65.19	33.08	4.79	38.68
22	11.11	1.62	15.02	31.3

suitability of groundwater for irrigation purpose. According to the permeability index values, 90.9 % of the samples falls under the class 3 (PI < 25 %) and only 9.1 % belong to class 2 (PI ranged between 25 and 75 %) during the post monsoon period of 2009.

Magnesium hazard

In most waters calcium and magnesium maintains a state of equilibrium. A ratio namely index of magnesium hazard was developed by Paliwal (1972). According to this, high magnesium hazard value (>50 %) has an adverse affect on the crop yield as the soil becomes more alkaline.

$$\text{Magnesium ratio} = Mg^{2+} \times 100 / (Ca^{2+} + Mg^{2+})$$

Table 7 Classification of groundwater based on SAR values (Todd 1959; Richards 1954)

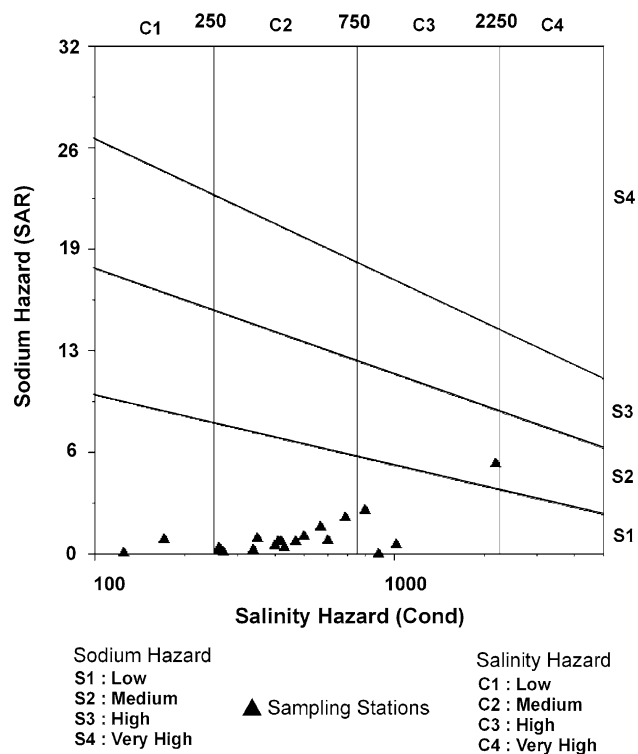| Water quality	SAR values	No. of samples
Excellent	<10	19
Good	10–18	2
Doubtful	18–26	–
Unsuitable	>26	1

Fig. 6 Classification of irrigation water quality, with respect to salinity hazard and sodium hazard

In the study area the magnesium hazard values falls in the range of 2.73 to 79.06 % (Table 6). In the study area, 86.36 % of the samples collected showed MH ratio <50 % (suitable for irrigation) while 13.64 % falls in the unsuitable category with magnesium hazard >50 %. The evaluation illustrates that 13.64 % samples can cause adverse effect on the agricultural yield.

Conclusion

Groundwater is an important source of drinking water for many people around the world. Contamination of groundwater generally results in poor drinking water quality, loss of water supply, high cleanup costs, high-cost alternative water supplies and potential health problem. In the present study, interpretation of hydrochemical analysis reveals that the groundwater in area is hard to very hard. The sequence of the abundance of the major cations and anions is $Ca > Na > Mg > K = HCO_3 > Cl > SO_4$. The dominant hydrochemical facies of groundwater in the study area is $Ca–Mg–HCO_3$. Distribution of the groundwater samples in piper diagram reveals that all of the groundwater samples fall under the calcium-magnesium-bicarbonate category. In the study area there is a dominance of $Ca^{2+}–Mg^{2+}$ type water. Based on the TH and TDS of almost all samples, the groundwater from Alappuzha coastal stretch is found to be

safe and suitable for drinking purposes. The majority of groundwater sources belong to C2S1, indicating medium salinity -low sodium water, which can be used for irrigation on all types of soil without danger of exchangeable sodium. Groundwater is immensely important to meet the human needs in the coastal areas of Alappuzha district. In spite of the pre-eminent position of groundwater for water supply in the coastal belt, it is surprising that no concrete efforts have been made to systematically assess the quantity and quality of this natural resource. Also the lack of knowledge stands in the way of formulation of any viable policy for the management of groundwater system of the coastal zone.

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