

Evaluation of physico-chemical quality of groundwater in the surroundings of Valiathura sewage farm in Thiruvananthapuram District, Kerala, South India

Jainy Varghese⊠ and D.S. Jaya

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Abstract

The present study was conducted to determine the changes in the physico-chemical characteristics of the groundwater in the surroundings of the sewage farm in Valiathura, Thiruvananthpuram district, Kerala. For this, 42 groundwater samples (29 dug wells and 13 bore wells) were collected bimonthly from the study area during the period January to December 2010 covering pre-monsoon, monsoon and post-monsoon seasons and the major physico-chemical parameters were analysed. The values recorded for parameters such as total alkalinity (330 mg/l), potassium (63.40 mg/l), magnesium (52.39 mg/l) and phosphates (4.71 mg/l in dug wells at some stations exceeded the desirable limits for drinking water quality prescribed by WHO and BIS standards. The Sodium Adsorption Ratio (0.20 - 6.33), Percent sodium (8.54 - 71.83) and Permeability Index values (48.07 - 119.35) showed that all the groundwater samples in the study area were suitable for irrigation purposes. The study revealed that about 31% of the dug wells adjacent to the sewage farm and Parvathy Puthen Ar canal were moderately contaminated and consumption of water from these wells may lead to various health problems in residents. As nutrients like phosphates, sodium, potassium, magnesium were high in well water samples and prolonged consumption of nutrients enriched well water may cause health problems such as high blood pressure, bowel cancer (due to phosphates), cardiovascular diseases (due to sodium and magnesium), renal diseases (due to sodium and potassium).Therefore effective management measures should be taken to protect the groundwater sources in Valiathura area.

Key words: correlation analysis, groundwater quality, irrigational quality, physico-chemical parameter, sewage farm

Introduction

Groundwater is an important renewable resource in the earth. It is the major source of water supply for domestic, irrigational and industrial purposes. About one third of the world's population use groundwater for drinking (UNEP, 1999). The quality of groundwater depends on the several factors like topography, rainfall, soil texture, soil permeability, depth to groundwater level and aquifer characteristics. Today the accelerated pace of urbanisation, industrialisation and population explosion increased the demand for water sources and exerted more and more pressure on the groundwater bodies (Sharma and Kaur, 1996; Kumar, 2002). Natural and anthropogenic activities created major stress on the groundwater sources in the world. High population density along the coastal areas resulting over abstraction of groundwater through dug wells and resulting saline

Author's Address

Department of Environmental Sciences, University of Kerala, Kariavattom Campus, Thiruvananthapuram, Kerala Email: jainy.env@gmail.com water intrusion problem. Human groundwater contamination can be related to sewage disposal system, disposal of solid and liquid wastes, fertiliser application, animal wastes, improperly constructed septic tank system, latrine pits, land application of sludge and partially treated waste water etc. Among these the use of sewage (waste water) for irrigation is one of the important sources of groundwater pollution. The impact of sewage irrigation on groundwater quality was studied by various authors (Quin, 1978; Raju et al. 1991; Sial et al. 2005; Mahmood and Magbool, 2006; Gwenzi and Munondo, 2008; Meena et al. 2010 and Sheet, 2012) in different parts of the world. Omana (2002) carried out a preliminary study on physicochemical and bacteriological characteristics of water from four selected wells subjected to sewage pollution in Thiruvananthapuram city and reported that the well water was contaminated. Chithra (2010) studied the impacts of sewage irrigation on grass cultivation in the sewage farm. Previous studies conducted by Varghese and Java (2009) on

the bacteriological quality of groundwater sources around the sewage farm showed that the most of the groundwater sources are with bacteriological contamination. The quality of groundwater sources in the surroundings of the sewage farm at Valiathura is under threat due to the seepage of waste water from septic tanks and latrine pits, polluted Parvathy Puthen Ar canal and saline water intrusion (Omana, 2002). The people living in this directly area dependent on the available groundwater for their dailv domestic and agriculture needs. The review of literature showed that there were no detailed studies regarding the drinking and irrigational quality of water from the groundwater sources in the surroundings of sewage farm. Therefore the major objective of this study was to characterize the physico-chemical quality of dug wells and bore wells in the residential areas near the sewage farm in Valiathura. Thiruvananthapuram district.

Material and methods Study area

The study was conducted in groundwater sources (dug wells and bore wells) in the surroundings of the sewage farm at Valiathura in the coastal stretch of Thiruvananthapuram District, Kerala. The Survey of India (SOI) Toposheet 58D/15/NE and 58D/15/SE of 1:25,000 scale have been used for the preparation of location map of the study area. The study area lies between longitude 76° 54' 51" E to 76° 57' 33" E and latitude 8° 26' 26" N to 8° 29' 29" N. The location map of the study area is shown in Fig.1. Valiathura sewage farm comprises an area of 108 acres and is maintained by the Dairy Development Department, Kerala state where grass cultivation is done. The main grass species cultivated here are Para Grass (Brachiaria mutica) and Hybrid Napier (Pennisetum purpureum). It has a capacity to handle 80 million litres of sewage per day (Chithra, 2010).



Fig. 1 Location map of study area



Sample collection and Physico-chemical analysis Groundwater samples (n=42) were collected bimonthly from the residential area around the sewage farm during the period January to December 2010 covering three seasons viz, premonsoon, monsoon and post-monsoon. Depth to Water level in the study area was measured by using graduated tape before collecting the water samples from the study area. The water samples were collected on polyethylene bottles prewashed with dilute hydrochloric acid and rinsed with the water sample before filling them to the required capacity. The collected dug well samples (DW1-DW29) and bore well samples (BW1-BW13) were analysed to determine various physico-chemical parameters using the standard procedures described in APHA (1995), Trivedi and Goel (1986) and Saxena (1998). Temperature, pH and electrical conductivity of water samples were measured immediately after sampling using thermometer, pH meter (Systronics, India) and conductivity meter (Systronics model, 601 E) respectively. Correlation analysis was done using Statistical Package for Social Sciences (SPSS, version 17). Chloro Alkaline Indices (CAI) can be calculated using the equation as suggested by Schoeller (1977) as,

CAI 1 =
$$\frac{Cl^{-} - (Na^{+} + K^{+})}{Cl^{-}}$$

CAI 2 = $\frac{Cl^{-} - (Na^{+} + K^{+})}{SO_{c}^{2-} + HCO_{c}^{-} + CO_{c}^{2-} + NO_{c}^{-}}$

Textural analysis of Soil

Texture of the soil samples were determined by using International Pipette analysis (Jackson, 1967). For this, soil samples were collected from the 31 sampling stations from the study area.

Irrigational Quality of Groundwater

To analyse the irrigational quality of groundwater the parameters such as Sodium Adsorption Ratio, Percent Sodium, Residual Sodium Carbonate, Magnesium Ratio, Permeability Index, Kelley's Ratio (Raghunath, 1987; Todd, 2001; Eaton, 1950; Pandian and Sankar, 2007; Kelley, 1946 and Doneen, 1964) were calculated. All the concentrations are expressed in meq/l.

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

Percent Sodium (%Na)

 $\% Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$

Residual Sodium Carbonate (RSC)

$$RSC = (HCO_3^- - CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Magnesium Ratio (MR)

$$\mathbf{MR} = \frac{\mathbf{Mg}^{2+} \times \mathbf{100}}{\mathbf{Ca}^{2+} + \mathbf{Mg}^{2+}}$$

Permeability Index (PI)

$$\mathbf{PI} = \frac{\mathbf{Na}^+ + \sqrt{\mathbf{HCO}_3^-}}{\mathbf{Ca}^{2+} + \mathbf{Mg}^{2+} + \mathbf{Na}^+}$$

Kelley's Ratio (KR)

$$\mathbf{KR} = \frac{\mathbf{Na^+}}{\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}}}$$

Results and Discussion Groundwater level

During pre-monsoon, monsoon and post-monsoon seasons, the depth to water level in the study area ranges from 1.24 to 4.80 m bgl (below ground level) (avg=2.63), 0.91 to 4.60 m bgl (avg=2.45) and 0.67 to 4.42 m bgl (avg=2.24) respectively. The study showed that depth to water level was seasonally varied during the study period.

Physico-chemical characteristics of groundwater The analytical results of physico-chemical parameters of dug well and bore well water in the study area are given in Table 1. The temperature of shallow groundwater is controlled to a considerable extent by the atmospheric temperature (Karanth, 1987). The average temperature of groundwater samples in the study area were found as 29.61°C, 28.90°C and 28.42°C during pre-monsoon, monsoon and post-monsoon seasons respectively. The hydrogen ion concentration (pH) of samples in pre-monsoon varied from 5.42 to 7.16 (Avg=6.37) and in monsoon, it varied from 5.75 to 8.26 (Avg=7.02). The pH of groundwater samples during post-monsoon season ranged between 5.58 and 7.34, with an average value of 6.71.



The pH of the groundwater samples showed acidic to alkaline nature during the study periods. The pH of groundwater commonly ranges from 6 to 8.5 (Ramakrishnan, 1998). In the present study about 45% of dug wells and all bore wells samples recorded acidic pH (<6.5) during pre-monsoon season and this was below the desirable limit of drinking water quality standards (BIS, 1991). Conductivity is a measure of the ability of water sample to carry an electric current (Rajvaidya and Markandy, 2005). Electrical conductivity of groundwater samples ranged between 144.50µS/cm and 1015µS/cm with an average of 499.66µS/cm during pre-monsoon season. Lowest value (144.50µS/cm) was reported at DW25 and higher value (1015µS/cm) was recorded at DW29. In monsoon season, electrical conductivity of water samples ranged from 165.15µS/cm to 1578µS/cm. The minimum and maximum value was observed at BW2 and DW29 respectively.But on post-monsoon season, the highest electrical conductivity value (1228.50 µS/cm) was recorded at DW29, and the lowest value (171.8 µS/cm) was recorded at DW23. The water quality is usually judged on the basis of electrical conductivity value (Venkateswarlu, 1996) as excellent (less than 250 µS/cm); good (250-750 μ S/cm); permissible (750-2000 μ S/cm); needs treatment (2000-3000 µS/cm); and unsuitable for most purposes (>3000 μ S/cm). Based on this, the present study revealed that the majority of groundwater samples have high dissolved ions and they come under excellent to permissible category.Turbidity means the clarity of water. The turbidity values in ground water samples varied from 0.1 - 6.35 NTU during pre-monsoon, 0.1- 5.7 NTU during monsoon and 0.55- 4.65 NTU postmonsoon season. According to WHO standards, the desirable limit of turbidity in drinking water is 5 NTU. The turbidity values of DW5 and BW7 exceeded the desirable standard limit during premonsoon and monsoon seasons respectively. This may be due to the dissolution of silt and clay from the soil in the study area. The total dissolved solids (TDS) means the total concentration of dissolved minerals (salts) in water. The average concentration of total solids in groundwater samples were observed as 543.45 mg/l (pre-monsoon),460.49 mg/l (monsoon), 329.10 mg/l (post-monsoon) and total suspended solids (TSS) were recorded as 233.86 mg/l, 174.61 mg/l and 85.25 mg/l during in bathing and laundry and form scales in utensils.

pre-monsoon, monsoon and post-monsoon respectively. The concentration of TDS varies from 91 to 657 mg/l in pre-monsoon samples, 88.50 to 815 mg/l in monsoon samples and 75 to 609 mg/l in post-monsoon samples. According to WHO standards, the desirable limit of TDS for drinking water is 500 mg/l. The study showed that TDS content of all the water samples except station at DW19 (monsoon) and DW29 (monsoon and postmonsoon) were within the desirable limit.Total alkalinity of water is due to the presence of carbonates, bicarbonates and hydroxide ions. The minimum and maximum concentration of total alkalinity in groundwater samples were 40 mg/l (DW5) and 240 mg/l (DW25) in pre-monsoon season. During monsoon season total alkalinity of groundwater samples ranges from 40 mg/l to 250 mg/l (DW29) whereas in post-monsoon season it ranged between 70 mg/l (BW11) and 330 mg/l (DW26). According to BIS (1991) guidelines for acceptable limit of total alkalinity in drinking water is 200 mg/l. The study reported that total alkalinity of majority of the water samples were above the acceptable limit prescribed by BIS for drinking water (1991) during the study period. The mean value of bicarbonate ion in the water samples was found as 167.31 mg/l, 143.79 mg/l and 201.88 mg/l during pre-monsoon, monsoon and post-monsoon respectively. Bicarbonate is the major anion in groundwater is coming from CO₂ released by organic decomposition in the soil. The bicarbonate concentration is significantly higher in groundwater when compared to that of surface water.Hardness is due to the presence of the salts of calcium and magnesium compounds in the form of bicarbonates, sulphates and chlorides (Ramakrishnan, 1998). The hardness values recorded for water samples collected from the study area varied from 73 mg/l to 345 mg/l during pre monsoon, from 70 mg/l to 335 mg/l during monsoon and from 90 mg/l to 370 mg/l during post monsoon seasons. Water is commonly classified based on the degree of hardness by Sawyer et al. (2003) as soft (0-75 mg/l); moderately hard (75-150 mg/l); hard (150-300 mg/l) and very hard (above 300 mg/l). In the present study, most of the water samples belong to moderately hard to very hard category except DW25 (pre-monsoon) and BW2 (monsoon). Hard water prevents foam formation when soap was used



		PRE-MO	NSOON			MONS	OON		POST-MONSOON				
Parameters	Average	SD	Min.	Max.	Average	SD	Min.	Max.	Average	SD	Min.	Max.	
T (°C)	29.61	0.58	28.35	31.15	28.90	0.69	27.50	30.50	28.42	0.84	26.75	30.50	
pН	6.36	0.37	5.42	7.16	7.03	0.48	5.75	8.26	6.71	0.34	5.58	7.34	
EC (µS/cm)	499.66	187.70	144.50	1015.50	549.37	270.26	165.15	1578.00	477.44	204.00	171.85	1228.50	
TS (mg/L)	543.45	221.40	246.00	1090.00	460.49	181.55	112.00	1163.00	329.10	143.12	112.50	861.00	
TDS (mg/l)	309.60	116.27	91.00	657.00	285.88	138.41	88.50	815.00	243.85	102.65	75.00	609.00	
TSS (mg/l)	233.86	132.82	22.50	636.00	174.61	90.99	16.50	348.00	85.25	51.26	23.50	252.00	
TA as CaCO ₃ (mg/l)	135.95	49.04	40.00	240.00	119.05	55.43	40.00	250.00	165.48	64.97	70.00	330.00	
HCO_3^- (mg/l)	167.31	57.93	48.80	292.80	143.79	65.31	48.80	305.00	201.88	79.26	85.40	402.60	
TH as CaCO ₃ (mg/l)	177.07	58.31	73.00	345.00	140.71	52.57	70.00	335.00	211.19	63.71	90.00	370.00	
Ca ²⁺ (mg/l)	43.71	14.09	17.64	76.96	43.13	17.35	12.03	106.22	45.47	17.48	20.04	108.22	
Mg ²⁺ (mg/l)	18.80	7.90	8.53	52.39	8.12	3.99	2.44	19.50	23.70	8.62	6.09	51.17	
Na ⁺ (mg/l)	54.43	30.01	8.50	131.95	64.12	42.73	9.70	182.50	51.46	32.39	5.35	138.70	
K ⁺ (mg/l)	13.77	9.18	1.75	39.35	16.29	12.89	1.95	63.40	14.18	9.62	2.10	40.00	
NH ₃ (mg/l)	0.07	0.09	0.02	0.61	0.10	0.17	0.01	0.73	0.09	0.11	0.01	0.50	
$NO_2^-(mg/l)$	0.86	0.57	0.04	2.40	0.70	0.48	0.10	1.97	0.98	0.62	0.06	2.54	
NO ₃ (mg/l)	1.96	1.12	0.27	4.14	3.56	0.82	1.79	5.10	3.95	0.81	2.33	6.12	
$SO_4^{2-}(mg/l)$	26.93	17.04	3.07	72.44	33.35	21.59	6.50	134.57	28.78	21.68	3.44	86.82	
$PO_4^{3-}(mg/l)$	0.71	0.87	0.00	4.71	0.59	0.46	0.00	1.71	0.81	0.68	0.01	2.24	
Cl ⁻ (mg/l)	59.84	26.77	17.04	137.03	66.49	37.98	17.75	202.35	58.63	26.52	21.30	145.55	
Salinity(mg/l)	109.81	49.12	31.27	251.45	121.91	69.55	32.57	371.31	107.59	48.66	39.09	267.08	
Turbidity(NTU)	0.64	1.10	0.10	6.35	0.63	0.98	0.10	5.70	1.14	0.78	0.55	4.65	

Table 1 Analytical data of groundwater samples during pre-monsoon, monsoon and post-monsoon seasons

T Temperature, EC Electrical Conductivity, TS Total Solids, TDS Total Dissolved Solids, TSS Total Suspended Solids, TA Total Alkalinity, TH Total Hardness, NTU Nephelometric Turbidity Unit, SD Standard Deviation

The scaling is caused by the deposition of $CaCO_3$ and Mg(OH)₂ (Abbasi, 1998). The present study showed that when people consuming this hardwater it may chance to occur cardiovascular diseases. The concentration of calcium in groundwater samples ranged between 17.64 mg/l (DW25) and 76.96 mg/l (DW26) during pre-monsoon season. During monsoon season, calcium content ranged from 20.04 to 106.22 mg/l whereas in post-monsoon season it ranged from 20.04 to 108.22 mg/l. The concentration of magnesium ranged from 8.53 to 52.39 mg/l and 6.09 to 51.17 mg/l in pre-monsoon and post-monsoon seasons respectively. During the monsoon season the magnesium content in water samples were very low (2.44 - 19.50 mg/l). The average concentration of sodium in groundwater samples were recorded as 54.43 mg/l (premonsoon), 64.12 mg/l (monsoon) and 51.46 mg/l (post-monsoon). Most of the samples in the study area showed sodium content within the standard permissible limit. But water samples in some stations at DW7, DW15, DW18, DW19, DW 20, DW21, DW22, DW28, DW29 and BW11 showed high content of sodium during the study period. This may be due to the ingress of saline water from the study area to the groundwater sources. The only common mechanism for removal of sodium ion from natural waters is through ion exchange. The removal of sodium ion from sea water which is infiltered into fresh water aquifers has been to ion exchange (Ramakrishnan, attributed 1998). The mean concentration of potassium in water samples were observed as 13.77 mg/l, 16.29 mg/l and 14.18 mg/l in pre-monsoon, monsoon and



post-monsoon seasons respectively. Most potable groundwater contains less potassium and commonly ranges between 1 and 5 ppm (Ramakrishnan, 1998). Majority of the groundwater samples adjacent the sewage farm. Parvathy Puthen Ar canal and coastal area showed potassium values above the standard permissible limit of drinking water (BIS 1991).Nitrogen occurs in groundwater as dissolved organic nitrogen, ammonia, nitrite and nitrate. The major sources of nitrogen in groundwater are due to anthropogenic activities such as domestic sewage, waste water irrigation, fertilizers, organic waste disposal, and seepage from septic tanks. Shallow wells are more susceptible to nitrate contamination than bedrock wells (Jack and Sharma, 1983 and Ramsden, 1996). Under aerobic conditions, the natural concentration of nitrate in groundwater is few milligrams per litre and it depends on soil type and geological situation. As a result of human activities its concentration increases (WHO, gradually 2011). The concentration of ammonia in groundwater samples varied from 0.02 to 0 .61mg/l (pre-monsoon), 0.01 to 0.73 mg/l (monsoon) and 0.01 to 0.50 mg/l (postmonsoon). Natural levels in groundwaters are usually below 0.2 mg of ammonia per litre (WHO, 2003). The minimum and maximum concentration of nitrites in water samples were recorded as 0.04 -2.40 mg/l, 0.10 -1.97 mg/l, 0.06 -2.54 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. Nitrite levels in drinking-water are usually below 0.1 mg/l (WHO, 2011). The high concentration of nitrites in groundwater samples is due to the reduction mechanism of nitrate by microbial action in the study area. In normal groundwater, nitrate concentration is below 2 mg/l and its concentration gradually increases due to anthropogenic activities (Schivanna, 2008). During pre-monsoon season, nitrate content in groundwater samples varied from 0.27 mg/l to 4.14 mg/l whereas in monsoon season, it varied from 1.79 mg/l to 5.10 mg/l. The highest and lowest value was recorded as 6.12 mg/l and 2.33 mg/l during the post-monsoon season. The present study revealed that majority of the water samples collected from the study area showed the nitrate concentration above 2 mg/l for three seasons, but were within the permissible limit (45 mg/l) prescribed by WHO. This may be due to the leaching of waste water

from sewage farm, septic tanks, Parvathy Puthen Ar canal and latrine pits to the groundwater sources.

The sources of phosphates are sewage, fertilisers and household detergents. Compared to nitrates the phosphates are less soluble and moves slowly through the soil (Ramsden, 1996). The mobility of phosphates depends on the soil texture. The average concentration of phosphates in water samples estimated during pre-monsoon, monsoon and postmonsoon seasons were 0.71 mg/l, 0.59 mg/l and 0.81 mg/l respectively. Majority of the groundwater samples showed phosphate values above the permissible limit (0.3 mg/l) prescribed by BIS (1991). The results of present study is in agreement with the study conducted by Ho and Notodarmojo (1995), who reported that phosphorus movement through sandy soil is higher than that of loamy soils. The present study showed that the sulphate content in all the water samples collected during the different seasons were within the standard desirable limit WHO (1994). The average concentration of chlorides in water samples were recorded as 59.84 mg/l, 66.49 mg/l, 58.63 mg/l during pre-monsoon, monsoon and post-monsoon seasons respectively. In the present study, the chloride concentrations detected in the groundwater samples were within the desirable limits of WHO standards (1994) of drinking water quality. The water samples from DW7, DW15, DW18, DW19, DW20, DW21, DW22, DW28, DW29 and BW11 showed comparatively high content of chlorides in the three seasons studied. Salinity is an indication of the concentration of dissolved salts in water. During pre-monsoon, monsoon and post-monsoon seasons, the average value of salinity recorded in groundwater samples in the study area were 109.81 mg/l, 121.91 mg/l and 107.59 mg/l respectively.

The abundance of major anions in groundwater samples are in the order: $HCO_3 > Cl > SO_4 > NO_3 > PO_4$ during the different seasons of the study period. Among the major cations, calcium was dominant in pre-monsoon and post-monsoon seasons whereas in monsoon season sodium was the dominant in the ground water samples of the study area.

Relation between Soil texture and Groundwater quality

The quality of groundwater depends on the surrounding soil texture. Texture refers to the proportions of sand, silt and clay sized particles in



soil. It is important in determining properties such environment (Schoeller, 1977). The positive value as soil fertility, water and air movement and water storage in soils (Brevik, 2013). Texture affects movement of water through soil and also the movement of dissolved pollutants such as pesticides. The coarser the soil, the faster is the movement of percolating water and the less opportunity for adsorption or evaporation (Igbal et al. 2012). The present study showed that all the samples analysed from the study area is sandy texture (Fig. 2) and this may cause the rapid percolation of wastewater from sewage farm, latrine pits, Parvathy Puthen Ar canal to the shallow aquifers in the study area. It may result in the enrichment of ground water with phosphates, nitrates and other dissolved solids. Water percolation rates in sandy soils are much faster than in clayey soils (CESS, 2012). The study by Jalali (2007) showed that areas with sandy soils and shallow groundwater may have a chance of groundwater pollution.



Fig. 2 Soil Textural Triangle diagram

Gibbs Diagram

It is used to understand the relation between water composition and aquifer (Gibbs, 1970). In this diagram, precipitation dominance, evaporation dominance and rock-water interaction dominance field are shown. The results showed that most of the groundwater samples fall under the rock-water dominance during pre-monsoon, monsoon and post-monsoon seasons (Fig.3).

Chloro-alkaline Indices (CAI)

Chloro-alkaline Indices are used to study the ion exchange between the groundwater and its aquifer of CAI1 and CAI2 indicates that the sodium and potassium from water are exchanged with magnesium and calcium in rock favouring base exchange reactions (chloro-alkaline equilibrium). The negative value of CAI1 and CAI2 explains the magnesium and calcium from water are exchanged with sodium and potassium in rock favouring cation-anion exchange reactions (chloro-alkaline disequilibrium). Based on this, all the samples except DW3 and DW25 showed negative chloroalkaline indices during pre-monsoon season. In monsoon season, majority of samples comes in negative CAI except DW23 and DW25. During post-monsoon season about 28.5% and 71.5% water samples belong to positive and negative CAI respectively. The results revealed that there are cation-anion exchange reactions in the groundwater samples of the study area.

Hydrochemical Facies

Piper (1944) Trilinear diagram is used to understand the water type of the study area. This diagram consists of two lower triangular fields and a central diamond shaped field. The percentage reacting values of the cations and anions are plotted as a single point at the lower left and right angles respectively. These are projected upwards parallel to the sides of the triangles to give point which indicates the water quality types (Raghunath, 1987). The diagram reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups (Todd, 2001). The Piper plot can be classified into six categories viz, I (Ca-HCO₃) type); II (Na-Cl type); III (Mixed Ca-Na-HCO₃) type); IV (Mixed Ca-Mg-Cl type); V (Ca-Cl type) and VI (Na-HCO₃ type). The Fig.4 showed that during pre-monsoon and post-monsoon season majority of the groundwater samples were Ca-HCO₃ type whereas in monsoon season Na-Cl type were dominant. The Na-Cl type water indicates that the groundwater samples in the study area is mixed with sea water due to the tidal effect. The remaining samples fall in mixed water type during the study periods.

Interrelationship between **Physico-chemical Parameters**

Pearson correlation coefficient is used to study the nature and strength of relationship between two variables.



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Fig. 3 Controlling mechanisms for groundwater quality during (A) Pre-monsoon (B) Monsoon and (C) Post-monsoon seasons







Based on groundwater chemistry, three sets of strong relationships exist between major cations and anions (Douglas and Leo, 1977) are (1) The highly competitive relationship between ions having same charge but a different valence number e.g. Ca^{2+} and Na^{+} (2) The affinity between ions having different charges but the same valence number e.g. Na^{+} and Cl^{-} (3) The non-competitive relationship between ions having the same charge and same valence number e.g. Ca^{2+} and Mg^{2+} (Kumar and Divya, 2012; Manjusree *et al.* 2009).

The highly competitive relationship: Ca^{2+} with Na^+ (0.563**) and Ca^{2+} with K^+ (0.561**) have significant correlation. SO_4^{2-} with Cl^- (0.461**) has low positive correlation (Table 2). The affinity ions relationship: Na^+ with Cl^- (0.868**) has strong positive correlation. Ca^{2+} with SO_4^{2-} (0.549**) has low positive correlation. The non-competitive relationship: Na^+ with K^+ (0.822**) has significant correlation. Ca^{2+} with Mg^{2+} (0.238**) and $HCO_3^$ with Cl^- (0.061) has very low positive correlation.

The present study found that electrical Conductivity of groundwater samples showed strong positive correlation with TS (0.796**), TDS (0.971**), Ca²⁺ (0.740**), Na⁺ (0.921**), K⁺ (0.817**), Cl⁻ (0.837**) (Table 2) From the analysis, it can be concluded that high concentration of EC in groundwater is due to the influence of dissolved ions from the waste water. A significant positive correlation (0.868**) was found between sodium ion and chloride ion in the groundwater samples. This may be due to the ingress of salt water from the Parvathy Puthen Ar canal or from the sea to the groundwater sources in the study area.

Groundwater quality for Irrigation

The suitability of groundwater for irrigation purpose mainly depends on the type and quantity of dissolved solids. High concentration of salts directly or indirectly affects both plants and soils. Salts may harm plant growth physically by limiting the uptake of water through modification of osmotic pressure or chemically by metabolic reactions such as those caused by toxic constituents. Effects of salts on soils, causing changes in soil structure, permeability and aeration, indirectly affect plant growth (Todd, 2001).The results of the groundwater classification for irrigation purpose based on different irrigational quality parameters are presented in Table 3.

Sodium Adsorption Ratio (SAR)

SAR is an important parameter for determining the suitability of groundwater irrigation. Based on SAR value, the quality of water can be categorised as Excellent (<10): Good (10-18): Doubtful (18-26) and Unsuitable (>26) (Raghunath, 1987). In this study, the SAR values obtained for all the groundwater samples analysed in the three seasons comes under excellent category. The US Salinity laboratory (USSL) diagram (Richards, 1954) was used for rating the irrigation waters, where SAR is plotted against electrical conductivity. The sixteen classes in the diagram indicate that the salinity hazard as low (C1), medium (C2), high (C3) and very high (C4) and similarly sodium hazard as low (S1), medium (S2), high (S3) and very high (S4). Groundwater classification based on USSL diagram shown in Fig 5. According to USSL is classification, about 78.5% samples belong to C2S1 category, and 9.6% and 11.9% samples falling C1S1 and C3S1 class respectively during the premonsoon season. In monsoon season, about 71.4% samples come under C2S1 category and the remaining samples are under C1S1 and C3S1 class whereas in post-monsoon season about 85.7% water samples falls in C2S1 category.

Percent Sodium (%Na)

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Soils containing large proportion of sodium with carbonate as the predominant anion are called alkali soils and those with chloride or sulphate as the predominant anion are known as saline soils (Todd, 2001). According to %Na value, water quality for irrigation purpose can be marked as <20 (Excellent); 20-40 (Good); 40-60 (Permissible); 60-80 (Doubtful) and >80 (Unsuitable) (Raghunath, 1987). Based on this, majority of the samples come under excellent to permissible category in three seasons. Wilcox (1948) classified the groundwater for irrigation purpose by plotting percent sodium against electrical conductivity. Based on Wilcox's diagram (Fig.6) majority of the groundwater samples in the study area belongs to Excellent-good to goodpermissible during the different seasons studied. But the water samples DW15, DW18, DW28, DW29 and BW11 come under permissible to doubtful category in monsoon and post monsoon seasons.



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Fig. 5 Rating of groundwater samples in relation to salinity and sodium hazard during (A) Premonsoon (B) Monsoon and (C) Post-monsoon seasons



Fig. 6 Wilcox diagram of groundwater samples during (A) Pre-monsoon (B) Monsoon and (C) Post-monsoon seasons.



Evaluation of Physico-chemical quality of Groundwater

	Т	pH	EC	SL	TDS	SSL	TA	HCO3 ⁻	TH	Ca ²⁺	${ m Mg}^{2+}$	\mathbf{Na}^{+}	\mathbf{K}^+	NH3	NO_2^-	NO ₃	SO_4^{2-}	PO4 ³⁻	CI ⁻	alinity	rbidity
								I												Š	Tu
Т	1	407**	155	.146	040	.303**	432**	435**	298**	315**	111	091	103	058	001	328**	137	104	021	021	168
pН		1	.083	236***	013	405**	.393**	.371**	.050	.271**	260**	.058	.052	028	193*	.216*	.104	.070	034	035	141
EC			1	.796**	.971**	.380**	.247**	.247**	.587**	.740***	.184*	.921**	.817**	.352**	.297**	.141	.606**	.069	.864**	.864**	208*
TS				1	.870**	$.850^{**}$	071	064	.356**	.483**	.151	.722**	.681**	.277**	.299**	061	.486**	.029	.679**	.679**	253**
TDS					1	.479**	.189*	.194*	.557**	.697**	$.208^{*}$.892**	.792**	.301**	.317**	.019	.572**	.081	.837**	.837**	262**
TSS						1	328**	321**	.039	.114	.046	.333**	.366**	.171	.194*	129	.253**	035	.315**	.315**	170
TA							1	.996**	.497**	.549**	.284**	$.202^{*}$.156	.138	.085	013	.125	.065	.067	.068	$.197^{*}$
HCO ₃								1	.504**	.547**	.291**	.194*	.143	.142	.095	025	.121	.069	.061	.062	$.197^{*}$
ТН									1	.770**	.675**	.433**	.439**	.203*	.302**	.085	.418**	.091	.424**	.425**	060
Ca ²⁺										1	.238**	.563**	.561**	.248**	$.205^{*}$.012	.549**	.009	.508**	.509**	099
Mg ²⁺											1	.148	$.188^{*}$.005	$.190^{*}$.080	.147	.067	.157	.157	.008
Na^+												1	.822**	.309**	.306**	.144	.554**	.116	.868**	.869**	246**
\mathbf{K}^+													1	.303**	.341**	.177*	.474**	.078	.694**	.693**	191*
NH ₃														1	.183*	.042	.158	089	.278**	.278**	031
NO ₂															1	$.208^{*}$.211*	.118	$.207^{*}$	$.207^{*}$	043
NO ₃																1	.161	$.180^{*}$.110	.110	030
SO ₄ ²⁻																	1	.027	.461**	.461**	181*
PO ₄ ³																		1	.013	.013	032
Cl.																			1	1.000**	208*
Salinity																				1	208*
Turbidit y																					1

 Table 2 Interrelationship between physico-chemical parameters of groundwater samples during

 Pre-monsoon, Monsoon and Post-monsoon seasons

**. Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

Residual Sodium Carbonate (RSC)

It is the bicarbonate content of water suggested by Eaton (1950). High concentration of bicarbonate ion in irrigation water leads to toxicity and affects the mineral nutrition of plants (Arabi *et al.* 2010). If RSC >2.5meq/l, the water is considered as unsuitable for irrigation and if the value of RSC between 1.25 and 2.5 meq/l, the water is marginally suitable, and the value of RSC <1.25meq/l, it is safe for irrigation purposes. In the present study, about 81%, 97.6% and 92.8% groundwater samples belong to safe to marginally suitable class during the pre-monsoon, monsoon and post-monsoon seasons respectively.

Magnesium Ratio (MR)

It is defined as the excess amount of magnesium over calcium. Excess amount of magnesium affects

the quality of soils and there by leads to poor yield of crops (Pandian and Sankar, 2007). If MR >50, the water is considered as harmful and unsuitable for irrigation while MR<50 makes it suitable (Lloyd and Heathcoat, 1985). In this study, out of total 42 samples, about 81% and 69% samples belongs to suitable category during pre-monsoon and post-monsoon seasons respectively whereas in monsoon season all the groundwater samples (100%) are suitable for irrigation purposes.Kelly's Ratio (KR) The level of sodium measured against calcium and magnesium is known as Kelly' ratio, based on which irrigation water can be rated (Kelley, 1946 and Paliwal, 1967). The Kelly's ratio <1 indicates the good quality of water for irrigation, whereas >1 considered as unsuitable for irrigation purpose (Karanth, 1987). The results in the present study shows that during pre-monsoon season about



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			PRE-MO	ONSOON	MONS	SOON	POST-MONSOON			
Parameters	Range	Water Category	No. of samples	% of samples	No. of samples	% of samples	No. of samples	% of samples		
	<20	Excellent	1	2.4	Nil	Nil	5	11.9		
%Na	20-40	Good	24	57.1	9	21.4	21	50.0		
	40-60	Permissible	16	38.1	27	64.3	16	38.1		
	60-80	Doubtful	1	2.4	6	14.3	1	2.4		
	>80	Unsuitable	Nil	Nil	Nil	Nil	Nil	Nil		
Dag	<1.25	safe	21	50.0	26	61.9	25	59.5		
RSC	1.25	marginally	13	31.0	15	35.7	14	33.3		
	>2.5	Unsuitable	8	19.0	1	2.4	3	7.1		
MR	<50	Suitable	34	81.0	42	100.0	29	69.0		
	>50	Unsuitable	8	19.0	Nil	Nil	13	31.0		
DI	>75	Excellent	7	16.7	25	59.5	4	9.5		
F1	25-75	Good	35	83.3	17	40.5	38	90.5		
	<25	Unsuitable	Nil	Nil	Nil	Nil	Nil	Nil		
KR	<1	Suitable	39	92.9	25	59.5	40	95.2		
ilix	>1	Unsuitable	3	7.1	17	40.5	2	4.8		
	<10	Excellent	42	100	42	100.0	42	100.0		
SAR	10-18	Good	Nil	Nil	Nil	Nil	Nil	Nil		
	19-26	Doubtful	Nil	Nil	Nil	Nil	Nil	Nil		
	>26	Unsuitable	Nil	Nil	Nil	Nil	Nil	Nil		

 Table 3 Groundwater classification for irrigation purpose

% Na Percent Sodium, RSC Residual Sodium Carbonate, MR Magnesium Ratio, PI Permeability Index, KR Kelly's Ratio, SAR Sodium Adsorption Ratio

92.9% water samples reported KR <1, indicating good quality of water for irrigation and the remaining samples (7.1%) such as DW18, DW21 and BW11 showed KR >1. In monsoon season about 59.5% groundwater samples in the study area observed KR <1 and rest of it is unfit for irrigation. All the water samples except from two stations (DW12 and BW11) are suitable for irrigation during post-monsoon season.

Permeability Index (PI)

It is another important determinant for measuring the suitability of groundwater for irrigation purpose. The permeability index was developed by Doneen (1964). Based on the permeability indices, water can be classified into Class I, Class II and Class III types. Class I and Class II types are suitable for irrigation with 75% of maximum permeability and Class III types of water with 25% of maximum permeability. The present study showed that all the samples analysed in the study

area belong to Class I and Class II category in three seasons which is suitable for irrigation purpose. The soil permeability is affected by long term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents of the soil (Raju *et al.* 2009).

Conclusion

Therefore the study conclude that among the groundwater bodies evaluated for water quality, the dug wells adjacent to the sewage farm and Parvathy Puthen Ar canal showed more chemical contamination compared to that of bore wells in the study area. It is suggested to implement effective management measures like periodic cleaning of dug wells, disinfection of groundwater by using suitable disinfectants and dug well is constructed giving proper distance from septic tank must be implemented to protect the groundwater sources in the study area.



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