Vol. V No. 1 February 2012

The IUP Journal of
Soil and Water Sciences

The Icfai University Press
www.iupindia.in

Spatial Assessment of Groundwater Quality in Kerala, India

Boominathan M[1], Karthick B[2], Sameer Ali[3] and Ramachandra T V[4]

Groundwater is located in soil pore spaces and in the fractures of lithologic formations under subsurface. Pollutants leached to the ground make their way down into groundwater and contaminate an aquifer. The study focuses on the physicochemical and biological quality of groundwater spatially in Kerala to assess its suitability for drinking and understand the type of hydrochemicals and spatial distribution of major ions. Groundwater samples from 98 locations covering all districts in Kerala state, India were collected and analyzed, as per standard protocol. The results revealed that fecal coliform bacteria and pH were exceeding in many places. Nitrates exceeded permissible limits in two samples which contained 45.3 mg/L and 50 mg/L at Kayamkulam (Alappuzha) and Old Munnar (Idukki). Fluorides exceeded the desirable limit (1 mg/L) at Mullackal (1.4 mg/L) and Kalikulam Junction (1.2 mg/L) in Alappuzha district and Kollengode (1.6 mg/L) in Palakkad district. Hydrochemical types, relationship among the physicochemical parameters, characterization of sampling sites according to the physicochemical and biological characters and the spatial distribution of major ions are also discussed.

Keywords: Groundwater, Water quality, BIS standards, Piper diagram, Geostiff diagram, Spatial analysis

Introduction

Fresh water quality has gained substantial attention in recent years throughout the world (Chang, 2004). Groundwater (0.06% of Earth's available water) is a key source of drinking water among freshwater resources. This relatively small volume is critically important as it represents 98% of the freshwater readily available to humans (Zaporozec and Miller, 2000). India, diverse in terms of population (70% rural and 30% urban) depends on groundwater for drinking and domestic purposes (Reddy *et al.*, 1996 and Jaiswal *et al.*, 2003). Groundwater meets the drinking water requirement of over 50% of Kerala's population (Kerala Water Authority, 1991; Pillai and Ouseph, 2000; and Roy, 2004).

[1] Project Assistant, Energy and Wetlands Research Group, Centre for Ecological Sciences, Bangalore – 560 012, India. E-mail: boomi@ces.iisc.ernet.in

[2] Research Associate, Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore – 560 012, India. E-mail: karthick@ces.iisc.ernet.in

[3] Project Assistant, Energy and Wetlands Research Group, Centre for Ecological Sciences, Bangalore – 560 012, India. E-mail: energy@ces.iisc.ernet.in

[4] Co-ordinator, Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore – 560 012, India; and is the corresponding author. E-mail: cestvr@ces.iisc.ernet.in

The physicochemical and biological characteristics of groundwater in a given area are determined by the natural-geological formations (Subramani *et al.*, 2005), weathering, dissolution, precipitation, ion exchange and biological processes (Jeevanandam *et al.*, 2007) as well as anthropogenic activities. Often groundwater is contaminated by non-point sources (agricultural, urban runoff) and point sources (sewage, industrial effluents disposal) in many developing countries including India (Jeevanandam, 2007; and Jain *et al.*, 2010). In the recent years, the unplanned urbanization has influenced the quality as well as quantity of the water, evident from declining groundwater table, higher levels of contamination (Ramachandra and Uttam Kumar, 2008). These factors have necessitated the understanding of groundwater quality in the recent years (Yanggen and Born, 1990).

In Kerala, prevalence of water-borne diseases like diseases of gastrointestinal system (Panikar and Soman, 1984), diarrhea, dysentery, typhoid, worm infestations and infectious hepatitis (Aravindan, 1989; and Kunhikannan and Aravindan, 2000) are attributed to groundwater contamination, especially fecal coliform contamination (Kerala Water Authority, 1991; Radhakrishnan *et al.*, 1996; Calvert and Andersson, 2000; Panicker *et al.*, 2000; Rahiman *et al.*, 2003; Laluraj *et al.*, 2005; Laluraj *et al.*, 2006; Babu *et al.*, 2007; Harikumar and Kokkal, 2009; Rejith *et al.*, 2009; and Varghese and Jaya, 2009). Low pH was reported from many places (Gopinath and Seralathan, 2006; Laluraj and Gopinath, 2006; Vijith and Satheesh, 2007; Harikumar and Kokkal, 2009; and Rejith *et al.*, 2009). Harikumar and Kokkal (2009) have also reported high amount of alkalinity, magnesium, hardness, chloride, calcium and TDS. The contamination of groundwater by chloride, TDS and fluoride were reported by Harikumar *et al.* (2000); Laluraj *et al.* (2005); George and Prakasam (2008); and Shaji *et al.* (2007 and 2009).

Most of these reports are fragmented and were restricted to a particular panchayat or river basin or district. A comprehensive study covering the entire region would aid the decision-making process to implement the effective strategies to minimize or mitigate contamination of drinking water sources. This study focuses on the physicochemical and biological quality of groundwater throughout Kerala to assess its suitability for drinking as per standards (Bureau of Indian Standards - BIS, 1991) and to see the types of hydrochemicals and spatial distribution of major ions.

Materials and Methods

Study Area

Kerala, a coastal state in the southwest of peninsular India is situated between 8° 15′N-12° 50′N latitude and 74° 50′E-7° 30′E longitude. It receives rainfall from southwest monsoon (June-September) and northeast monsoon (October-November). According to the 2001 census, Kerala's population is 31,841,374 persons, with population density being 819 people per square kilometer (http://censusindia.gov.in). Kerala has a

Table 1: Physicochemical and Biological Parameters and the Methods			
Parameters	**Units**	**Methods**	**Section No. APHA, 1995**
pH	-	Electrode Method	4500-H^+ B
WT	°C		2550 B
Salinity	ppm		2520 B
TDS	ppm		2540 B
EC	µS		2510 B
DO	mg/L	Iodometric method	4500-O B
Alkalinity	mg/L	HCl Titrimetric Method	2320 B
Cl^-	mg/L	Argentometric Method	4500-Cl^- B
Hardness	mg/L	EDTA Titrimetric Method	2340 C
Ca^{2+}	mg/L	EDTA Titrimetric Method	3500-Ca B
Mg^{2+}	mg/L	Calculation Method	3500-Mg B
Na^+	mg/L	Flame Emission Photometric Method	3500-Na B
K^+	mg/L	Flame Emission Photometric Method	3500-K B
F^-	mg/L	SPADNS method	4500-F^- D
NO_3^-	mg/L	Nitrate Electrode method	4500-NO_3^- D
SO_4^{2-}	mg/L	Turbidimetric method	4500-SO_4^{2-} E
PO_4^{3-}	mg/L	Stannous Chloride Method	4500-P D
Fecal coliform	MPN/100 mL	Multiple Tube Fermentation Technique	9221 B

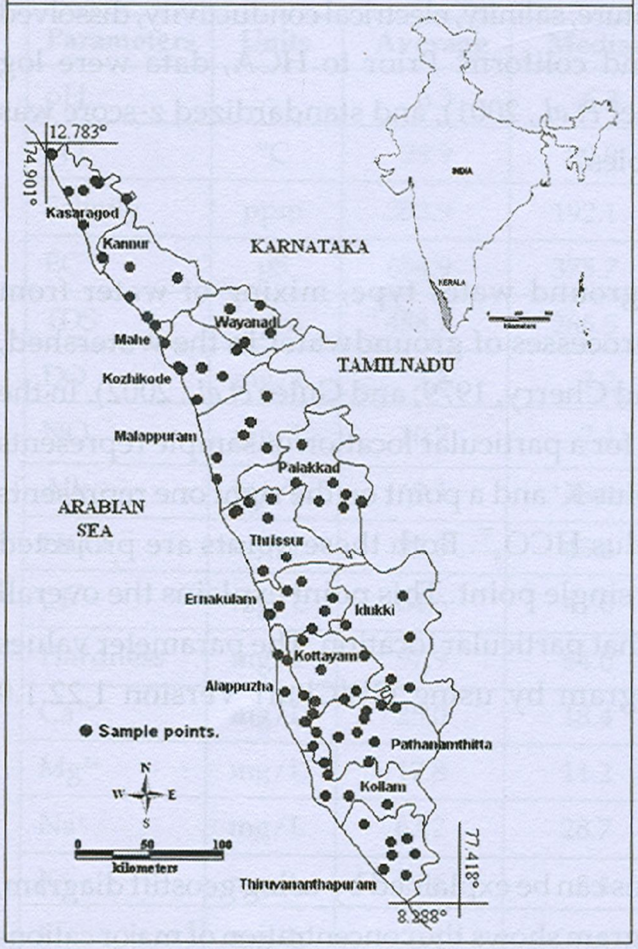
Note: WT - Water Temperature; TDS - Total Dissolved Solids; EC - Electrical Conductivity; and DO - Dissolved Oxygen.

geographical area of 38,863 sq km (http://www.kerala.gov.in) with a diverse topography; from the lowlands adjoining the sea on the west, the landscape ascends steadily towards the east to the midlands and further on to the highlands sloping from the Western Ghats.

Sample Collection

Stratified random sampling was adopted to collect groundwater samples from 98 wells covering all districts (Figure 1) during the summer period (April-May 2007). Summer season was chosen for water quality analysis as the water situation in most parts of Kerala is acute during that period. A minimum of four samples and maximum of 11 samples were collected from each district of Kerala. Samples were collected in disinfected 2.5 liter plastic containers. After collection, the samples were labeled with sample number, date of collection, latitude and longitude (retrieved from Garmin GPS).

Figure 1: Locations for Groundwater Sampling



Physical, Chemical and Biological Analysis

In situ measurements of pH, water temperature, salinity, total dissolved solids and electrical conductivity were recorded with EXTECH COMBO electrode (EC500) and nitrates by using Orion Ion Selective Electrode. Alkalinity, chloride, hardness, calcium, magnesium, sodium, potassium, fluoride, sulphate, phosphates and coliform bacteria were analyzed at Environment Chemistry Laboratory, Center for Ecological Sciences, as per the standard procedure given in APHA (1995). Bicarbonate and carbonate were calculated by using the formula given by Russell (2006). Coliform bacteria were estimated by using standard Multiple Tube Fermentation Technique (MTFT), nine multiple tube dilution technique using double and single strength Bromo-Cresol Purple, MacConkey medium and Membrane filter techniques by using M-EC test agar, and MPN Index was calculated from MPN table (APHA, 1995). Indian standard specifications for drinking water IS: 10500, 1992 (Reaffirmed 1993) were adopted in this study.

Data Analysis

Correlation

Correlations among variables were determined using Pearson product movement coefficient through RLPlot version 1.4. The value of correlation coefficient greater than or equal to -0.50 or +0.50 is statistically significant at 95% confidence level (Einax *et al.*, 1997).

Cluster Analysis

Hierarchical Cluster Analysis (HCA) was carried out using R version 2.7.1 (R Development Core Team, 2008). This has been done in Q mode (classification of samples according to their parameters) to cluster the samples into groups, using Euclidean distance with Ward's method. HCA helped to group the samples with similar characteristics (Guler *et al.*, 2002). Twenty variables were used in this analysis, viz., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}, TDS, pH, water temperature, salinity, electrical conductivity, dissolved oxygen, alkalinity, hardness, fluoride and coliform. Prior to HCA, data were log transformed in PAST version 1.98 (Hammer *et al.*, 2001), and standardized z-score was computed to give equal weight to all variables.

Piper Diagram

To understand geochemical evolution, ground water type, mixing of water from different sources and physicochemical processes of groundwater in the watershed, Piper (1944) diagram was used (Freeze and Cherry, 1979; and Guler *et al.*, 2002). In the diagram, a point on the left triangular part for a particular location or sample represents the major cations like Ca^{2+}, Mg^{2+} and Na^{+} plus K^{+} and a point on the right one represents the major anions like SO_4^{2-}, Cl^{-}, CO_3^{2-} plus HCO_3^{-}. Both these points are projected together in the diamond shaped part as a single point. This point explains the overall chemical character of the groundwater of that particular location. The parameter values were plotted as mg/L in the Piper diagram by using GWChart Version 1.22.1.0 (Winston, 2000).

Spatial Distribution

The spatial distribution pattern of major ions can be explained by using geostiff diagram, that is georeferenced stiff diagram. Stiff diagram shows the concentration of major cations (left side) and anions (right side) of a particular place in a single diagram. Geostiff diagram allows to plot one or more stiff diagrams spatially in a single diagram. The major cations and anions used to prepare geostiff diagram were Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} along with TDS in mg/L. The geostiff diagram was prepared in the shape file format by using geostiff version 1.0. Then the shape file was imported in QGIS version 1.4.0-Enceladus and the final image format was prepared using MapInfo version 6.0.

Results and Discussion

Drinking Water Quality

The summary of descriptive analytical results of the 98(n) well samples for various physicochemical and biological parameters is presented in Table 2. Among 98 samples, physicochemical and biological parameters of only nine samples, Attathodu, Pampa Valley, Athikayam, Vadaserikara, Pandalam (Pathinamthita district), Kandiyoor (Alappuzha), Kattachal (Kollam), Pazhayidam (Kottayam) and Nedumangadu (Thiruvananthapuram), were within the desirable limit as per BIS.

Table 2: Summary of Physical, Chemical and Biological Properties of Groundwater						
Parameters	Units	Average	Median	Minimum	Maximum	SD
pH	–	6.3	6.3	4.3	8.2	0.7
WT	°C	29.9	29.9	23.2	36.2	2.1
Salinity	ppm	352.9	192.1	14.8	4310.0	651.3
EC	µS	694.9	375.7	2.5	8640.0	1307.0
TDS	ppm	488.7	266.5	22.2	6060.0	913.6
DO	mg/L	3.3	3.2	0.0	7.5	1.5
NO_3^-	mg/L	10.7	7.4	0.1	50.0	10.5
Alk	mg/L	69.1	38.0	4.0	408.0	78.4
HCO_3^-	mg/L	83.0	45.6	4.8	489.6	94.1
Cl^-	mg/L	64.6	41.0	17.0	921.0	99.5
Hardness	mg/L	97.9	64.0	12.0	700.0	111.1
Ca^{2+}	mg/L	25.0	18.4	1.6	157.1	25.7
Mg^{2+}	mg/L	17.8	11.2	0.2	141.5	22.8
Na^+	mg/L	63.2	28.7	2.6	1203.2	165.2
K^+	mg/L	13.6	5.4	0.6	160.7	24.1
F^-	mg/L	0.4	0.4	0.2	1.6	0.2
SO_4^{2-}	mg/L	18.8	9.2	0.0	200.7	30.4
PO_4^{3-}	mg/L	0.1	0.1	0.0	1.3	0.2
Fecal coliform	MPN/ 100 mL	72.79	17	0	1600	204.48

Note: WT - Water Temperature, TDS - Total Dissolved Solids, EC - Electrical Conductivity, DO - Dissolved Oxygen; and SD - Standard Deviation.

The places having many parameters out of desirable limit are Fort Cochin (Ernakulam district), Placimada and Kollengode (Palakkad) and Koodungalur (Thrissur). The parameters exceeding the desirable limit in each district are given in Table 3. Among the parameters analyzed, MPN and pH were out of the desirable limit in many samples via 66 and 61 samples respectively. Overall, 89 samples were affected by one or more parameters, thereby causing the 90.82% of groundwater in the study area unsuitable for drinking.

The physicochemical parameters analyzed to characterize the water based on BIS standards are:

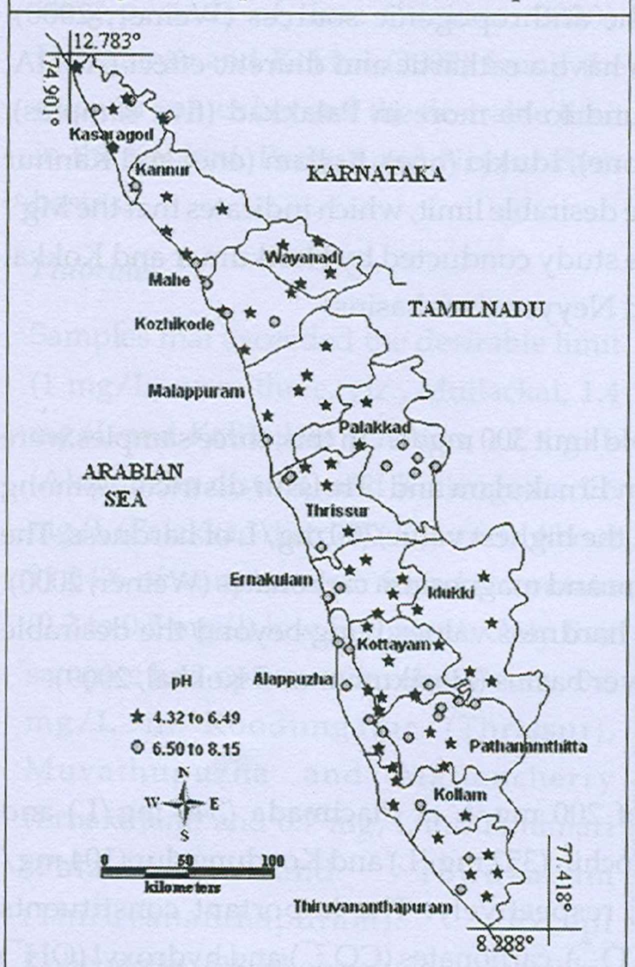
Table 3: Number of Parameters Exceeding the Desirable Limit Per District			
District	No. of Samples Analyzed	No. of Samples Exceeding the DL with One or More Parameters	Parameters Exceeding the DL
Alappuzha	7	6	pH, NO_3^-, F^-, TDS, Sal, MPN
Ernakulam	8	8	pH, Alk, Har, Ca^{2+}, Mg^{2+}, TDS, Sal, MPN
Idukki	5	5	pH, NO_3^-, Mg^{2+}, MPN
Kannur	5	5	pH, Mg^{2+}, MPN
Kasargod	11	11	pH, MPN
Kollam	6	5	pH, Mg^{2+}, TDS, MPN
Kottayam	7	6	pH, MPN
Kozhikode	7	7	pH, MPN
Malappuram	6	6	pH, Ca^{2+}, TDS, MPN
Palakkad	8	8	pH, Alk, Cl^-, Har, Mg^{2+}, F^-, TDS, Sal, MPN
Pathanamthitta	7	2	pH
Thiruvananthapuram	7	6	pH, TDS, MPN
Thrissur	9	9	pH, Alk, Cl^-, Har, Ca^{2+}, Mg^{2+}, SO_4^{2-}, TDS, Sal, MPN
Wayanad	5	5	pH, MPN

Note: Sal - Salinity; TDS - Total Dissolved Solids; Alk - Alkalinity; Har - Hardness; and DL - Desirable Limit.

pH

Most of the groundwater samples n = 86 were acidic in nature, and the remaining 12 samples were alkaline. Among 86 samples, 61 were found to have pH 4.32-6.46, less than the desirable limit 6.5-8.5. It is shown spatially in Figure 2. The low pH of groundwater may be the result of sulphide oxidation (Weiner, 2000), acidic nature of the soil or due to aquifer origin (Harikumar and Kokkal 2009). This can be curbed by adding clam or oyster shells to drinking water in the wide-mouthed barrels (Bordalo and Savva-Bordalo, 2007). Low pH was observed in Idukki (Rejith *et al.*, 2009), Kottayam (Vijith and Satheesh, 2007), Muvattupuzha (Gopinath and Seralathan, 2006; and Laluraj and Gopinath, 2006) districts and Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009).

Figure 2: Spatial Variation of pH



Salinity

Most of the samples (89 out of 98) were lying within the fresh water salinity range (< 500 ppm). Salinity was found to be higher in Aluva (2900 ppm) and Kothamangalam (3000 ppm) of Ernakulam district and in Guruvayoor (3180 ppm) municipal well and Koodungalur (4310 ppm) in Thrissur district. This may be due to the addition of more chlorides in municipal well for disinfection purpose or sea water intrusion. Comparatively, another sample from Guruvayoor near a pilgrimage site had very less salinity (590 ppm) than that of Guruvayoor municipal well. Other samples having more salinity were from Palakkad (Kollengode and Placimada), Thrissur (Chavakkad and Koodungalur) and Alappuzha (Veeyapuram) districts, which had salinity between 600 and 900 ppm.

TDS

The TDS range was 22.2 to 6060 ppm. The highest value 6060 ppm was found in Koodungalur (Thrissur district). The TDS was more than the desirable limit of 500 ppm in Thrissur (eight samples), Ernakulam (four), Palakkad (three), Malappuram (one), Alappuzha (one), Kollam (one) and Thiruvananthapuram (one) districts. Evaporation, groundwater movement through solute mineral containing rocks, untreated sewage, waste deposits and agrochemicals are the main contributors to high TDS value. The difference in the taste of non-potable and potable water is often due to the presence of high TDS level in water addition to certain metals, particularly iron, copper, manganese and zinc (Weiner, 2000). The high TDS values were observed by Shaji *et al.* (2009) in Chavara, Quilon district and Harikumar and Kokkal (2009) from Kabbini, Periyar and Neyyar river basins.

Magnesium

Magnesium was more than the desirable limit of 30 mg/L in many places at Palakkad and the highest value was found at Koodungalur (Thrissur) 141.46 mg/L. Magnesium mainly comes from the ferromagnesium minerals in igneous rocks and magnesium carbonates in sedimentary rocks than the anthropogenic sources (Weiner, 2000). Concentrations greater than 125 mg/L can have a cathartic and diuretic effect (APHA, 1995). Magnesium contamination was found to be more in Palakkad (five samples), followed by Thrissur (three), Ernakulam (one), Idukki (one), Kollam (one) and Kannur (one). A majority of samples were within the desirable limit, which indicates that the Mg^{2+} is contributed by the natural processes. The study conducted by Harikumar and Kokkal (2009) also found high value in Periyar and Neyyar river basins.

Hardness

Five out of 98 samples exceeded the desirable limit 300 mg/L . In this, three samples were from Palakkad and rest of the samples from Ernakulam and Thrissur districts. Among these districts, Thrissur (Kodungallur) had the highest value 700 mg/L of hardness. The principal sources of hard water were calcium and magnesium carbonates (Weiner, 2000). Harikumar and Kokkal (2009) also found hardness values lying beyond the desirable limit in the Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009).

Alkalinity

Alkalinity exceeded the desirable limit of 200 mg/L at Placimada (340 mg/L) and Kollengode (408 mg/L) in Palakkad, Fort Cochin (352 mg/L) and Koodungalur (304 mg/L) in Ernakulam and Thrissur districts, respectively. The important constituents contributing alkalinity are bicarbonate (HCO_3^-), carbonates (CO_3^{2-}) and hydroxyl (OH^-) anions (Weiner, 2000). The highest value of alkalinity was observed by Harikumar and Kokkal (2009) in the Neyyar river basin.

Chlorides

Chlorides exceeded the desirable limit of 250 mg/L at Placimada 314.35 mg/L , Kollengode 268.29 mg/L in Palakkad district and Koodungalur 921.01 mg/L in Thrissur district. All other samples (n = 9 5) were within the desirable limit. In natural waters, chloride comes from weathering of chloride minerals. People having heart and kidney problems have high risk when exposed to high amount of chlorides (Weiner, 2000). Laluraj *et al.* (2005), in the coastal zone of Central Kerala, and Harikumar and Kokkal (2009), in the Kabbini and Neyyar river basins, have found the chloride values beyond the desirable limit.

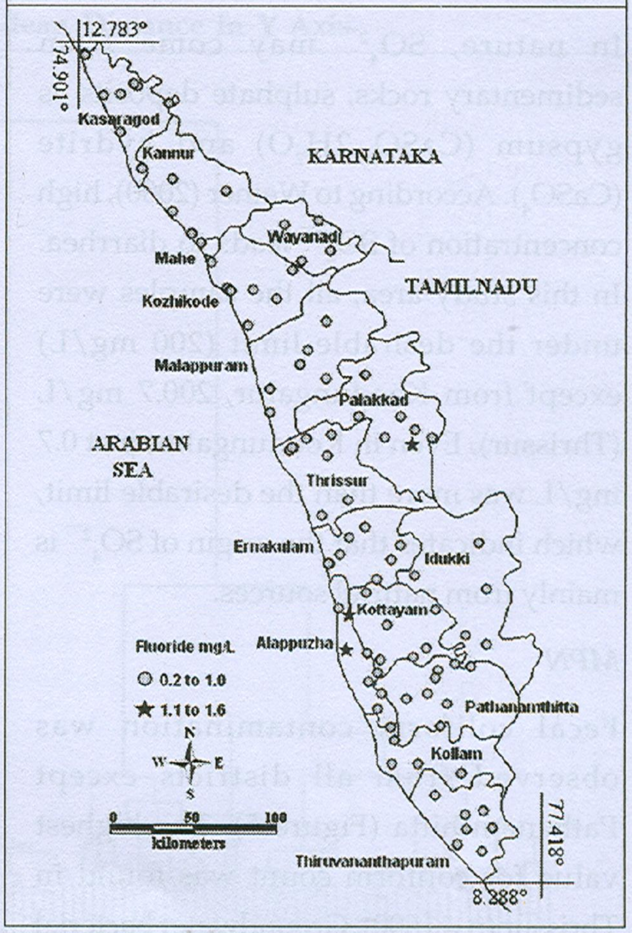
Calcium

Three places out of 98 places sampled, exceeded the desirable limit of 75 mg/L. They were Fort Cochin (157.11 mg/L), Ponnani (109.02 mg/L) and Koodungalur (120.24 mg/L) in Ernakulam, Malappuram and Thrissur districts, respectively. Calcium in groundwater is mainly due to the dissolution of minerals. High concentration of calcium may increase the risk of kidney stones when exposed for long periods of time (Weiner, 2000). Harikumar and Kokkal (2009) found the calcium values beyond the desirable limit in the Kabbini, Periyar and Neyyar river basins.

Fluorides

Samples that exceeded the desirable limit (1 mg/L) were three, viz., Mullackal, 1.4 mg/L and Kalikulam Junction, 1.2 mg/L (Alappuzha district) and Kollengode, 1.6 mg/L (Palakkad district) (Figure 3). About 91.84% of samples were found to contain (0.2 to 0.5 mg/l) low F^- content. Only five samples had optimum level of F^- viz., 0.6 mg/L in Koodungalur (Thrissur), Muvathupuzha and Mattancherry (Ernakulam) and 0.7 mg/L in Kannimari (Palakkad) and Thiruvallam (Thiruvananthapuram). Except Kollengode, all other values were within WHO (World Health Organization) (2008) guideline value (1.5). Fluoride comes from weathering of minerals like fluorite (CaF_2), cryolite (Na_3AlF_6), and fluorapatite ($Ca_5F(PO_4)_3$) (Weiner, 2000). Low F^- content (< 0.60 mg/L) causes dental caries, whereas high (>1.20 mg/L) fluoride levels cause fluorosis (ISI, 1983). Fluoride contamination was observed by George and Prakasam (2008) in the Edamulackkal Grama Panchayat, Kollam District, Harikumar *et al.* (2000) from the Thrissur, Palakkad, and Alappuzha Districts, and Shaji *et al.* (2007) in Palghat District.

Figure 3: Spatial Variation of Fluoride



Nitrates

Except two samples which contained 45.3 mg/L and 50 mg/L in Kayamkulam (Alappuzha) Old Munnar (Idukki), all samples were within the desirable limit of 45 mg/L (Figure 4). According to WHO (2008), all samples were within the guideline value (50 mg/L). This indicates that the anthropogenic influence is minimal in ground water. Fertilizers, animal waste and human sewage are the main sources for nitrates. High concentration (>1-2 mg/L) of nitrate in groundwater may be the result of manure seepage and fertilizers through agricultural activities (Weiner, 2000). High nitrate content causes gastric carcinomas and blue baby diseases/methemoglobinemia in the case of children (Comly 1945; and Gilly *et al.*, 1984).

Sulphates

In nature, SO_4^{2-} may come from sedimentary rocks, sulphate deposits as gypsum ($CaSO_4.2H_2O$) and hydrite ($CaSO_4$). According to Weiner (2000), high concentration of SO_4^{2-} leads to diarrhea. In this study area, all the samples were under the desirable limit (200 mg/L) except from Koodungalur, 200.7 mg/L (Thrissur). Even in Koodungalur, just 0.7 mg/L was more than the desirable limit, which indicates that the origin of SO_4^{2-} is mainly from natural sources.

MPN

Fecal coliform contamination was observed from all districts except Pathanamthitta (Figure 5). The highest value for coliform count was found in Thrissur (n = 1600). Groundwater bacterial contamination may be due to improper disposal of organic garbage or leachates from the tanks or pits (Harikumar and Kokkal, 2009). The groundwater bacterial contamination will cause typhoid, diarrhea, cramps, nausea and headaches (http://www.epa.gov; Barrell *et al.*, 2000). A coliform study was conducted in coastal Kerala (Calvert and Andersson, 2000; and Laluraj *et al.*, 2005); Kottayam (Panicker *et al.*, 2000) and Thiruvananthapuram (Varghese and Jaya, 2009) districts; Chalakudy basin (Babu *et al.*, 2007), Kabbini, Periyar and Neyyar river basins (Harikumar and Kokkal, 2009) also recorded the presence of fecal coliform contamination.

Figure 4: Spatial Distribution of Nitrate in Kerala

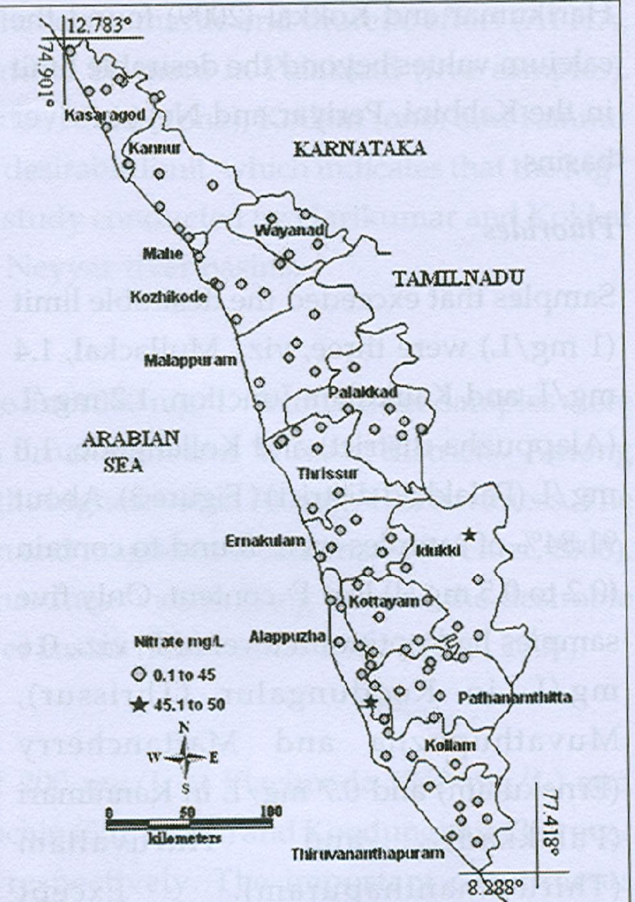


Figure 5: Spatial Variation of MPN

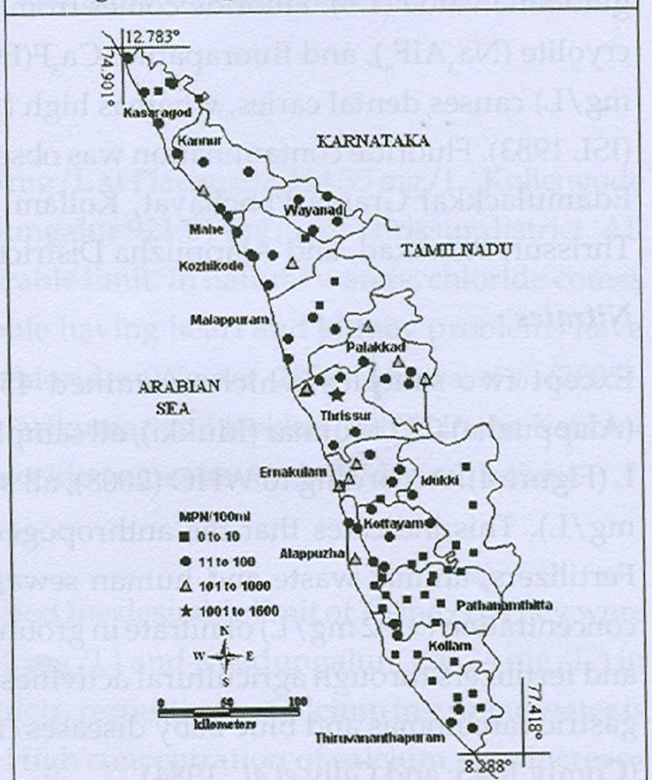
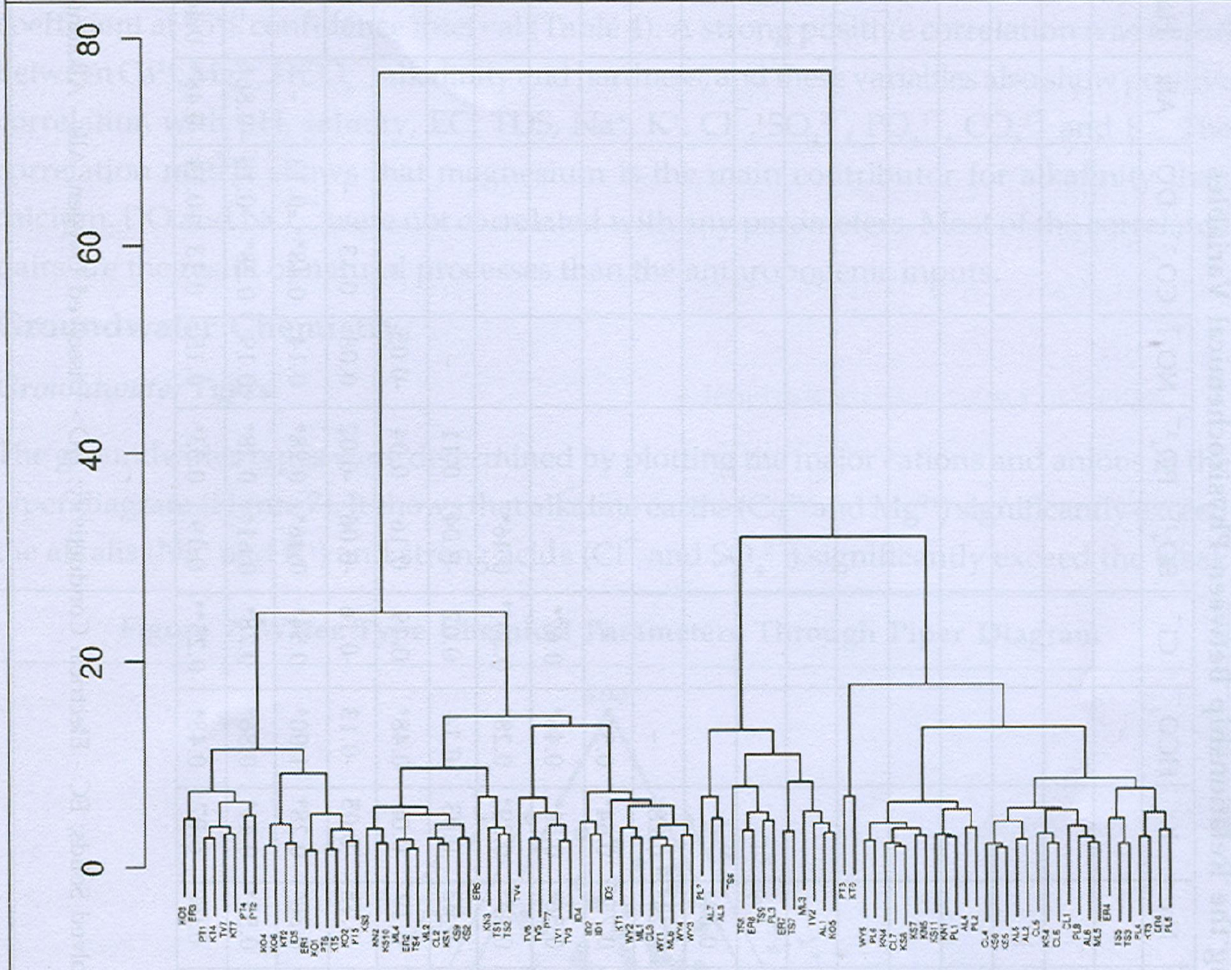


Figure 6: Hierarchical Cluster Analysis in Q Mode Using Ward's Method Showing Euclidean Distance in Y Axis



Note: AL-Alappuzha, CL-Kozhikode, ER-Ernakulam, ID-Idukki, KN-Kannur, KO-Kollam, KS-Kasaragod, KT-Kottayam, ML-Malappuram, PL-Palakkad, PT-Pathanamthitta, TS-Thrissur, TV-Thiruvananthapuram, WY-Wayanad; and Number 1 to 11 indicates that the place.

Cluster Analysis

Dendrogram of Hierarchical Cluster Analysis (HCA) have four clusters at Euclidean distance 20 (Figure 6). Cluster I samples were characterized by unpolluted sites and sites slightly exceeding the desirable limit of BIS (1993) by one or more parameters like pH, fecal coliform and TDS. Cluster II samples were mostly affected by pH, other parameters exceeding the desirable limit in this group were fecal coliform, TDS, Mg^{2+} and NO_3^-. The samples affected by many parameters along with sites exceeding the desirable limit in one or more parameters like TDS, Mg^{2+}, F^-, Ca^{2+} and fecal coliform were grouped in cluster III. Cluster IV had the samples mostly affected by fecal coliform; other parameters exceeding the desirable limit in this group were pH, TDS, Mg^{2+}, NO_3^- and hardness. All clusters were affected by fecal coliform (anthropogenic contamination), though the quantity of anthropogenic contamination varied between clusters.

Table 4: Correlation Matrix Showing the Relationship Between Physicochemical Variables

	pH	WT	Sal	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	PO_4^{3-}	NO_3^-	CO_3^{2-}	DO	Alk	Har	F^-
pH	–																		
WT	0.16	–																	
Sal	0.15	0.17	–																
EC	0.14	0.17	0.99*	–															
TDS	0.14	0.17	0.99*	0.99*	–														
Ca^{2+}	0.49*	0.13	0.32*	0.31*	0.31*	–													
Mg^{2+}	0.43*	0.10	0.46*	0.46*	0.46*	0.62*	–												
Na^{+}	0.24**	0.13	0.51*	0.51*	0.51*	0.57*	0.48*	–											
K^{+}	0.19	0.26**	0.43*	0.39*	0.39*	0.51*	0.38*	0.64*	–										
HCO_3^-	0.64*	0.12	0.33*	0.33*	0.33*	0.66*	0.85*	0.29*	0.28*	–									
Cl^-	0.22**	0.17	0.64*	0.64*	0.64*	0.51*	0.79*	0.75*	0.64*	0.54*	–								
SO_4^{2-}	0.34*	0.22**	0.59*	0.59*	0.59*	0.53*	0.58*	0.56*	0.51*	0.46*	0.67*	–							
PO_4^{3-}	0.26**	0.15	0.14	0.14	0.14	0.46*	0.21**	0.27*	0.29*	0.28*	0.20**	0.46*	–						
NO_3^-	0.10	0.07	-0.09	-0.10	-0.10	0.16	0.18	-0.03	0.03	0.14	0.02	-0.04	0.11	–					
CO_3^{2-}	0.50*	-0.10	0.13	0.13	0.13	0.23**	0.28*	0.19	0.08	0.48*	0.19	0.16	0.04	-0.05	–				
DO	0.10	0.03	-0.07	-0.08	-0.09	-0.19	-0.16	-0.15	-0.05	-0.13	-0.16	-0.06	-0.02	0.08	0.13	–			
Alk	0.64*	0.12	0.33*	0.33*	0.33*	0.66*	0.85*	0.30*	0.28*	1.00*	0.54*	0.46*	0.28*	0.14	0.48*	-0.13	–		
Har	0.48*	0.11	0.46*	0.46*	0.46*	0.75*	0.98*	0.53*	0.44*	0.86*	0.78*	0.61*	0.28*	0.19	0.28*	-0.18	0.86*	–	
F^-	0.25**	0.13	0.08	0.08	0.08	0.21**	0.43*	0.04	0.07	0.48*	0.25**	0.19	0.33*	0.15	0.13	-0.14	0.48*	0.40*	–

Note: *Significant value at $p < 0.01$;

**Significant value at $p < 0.05 > 0.01$;

WT - Water Temperature; Sal - Salinity; TDS - Total Dissolved Solids; EC - Electrical Conductivity; DO - Dissolved Oxygen; Alk - Alkalinity; and Har - Hardness.

Correlation of Physicochemical Parameters

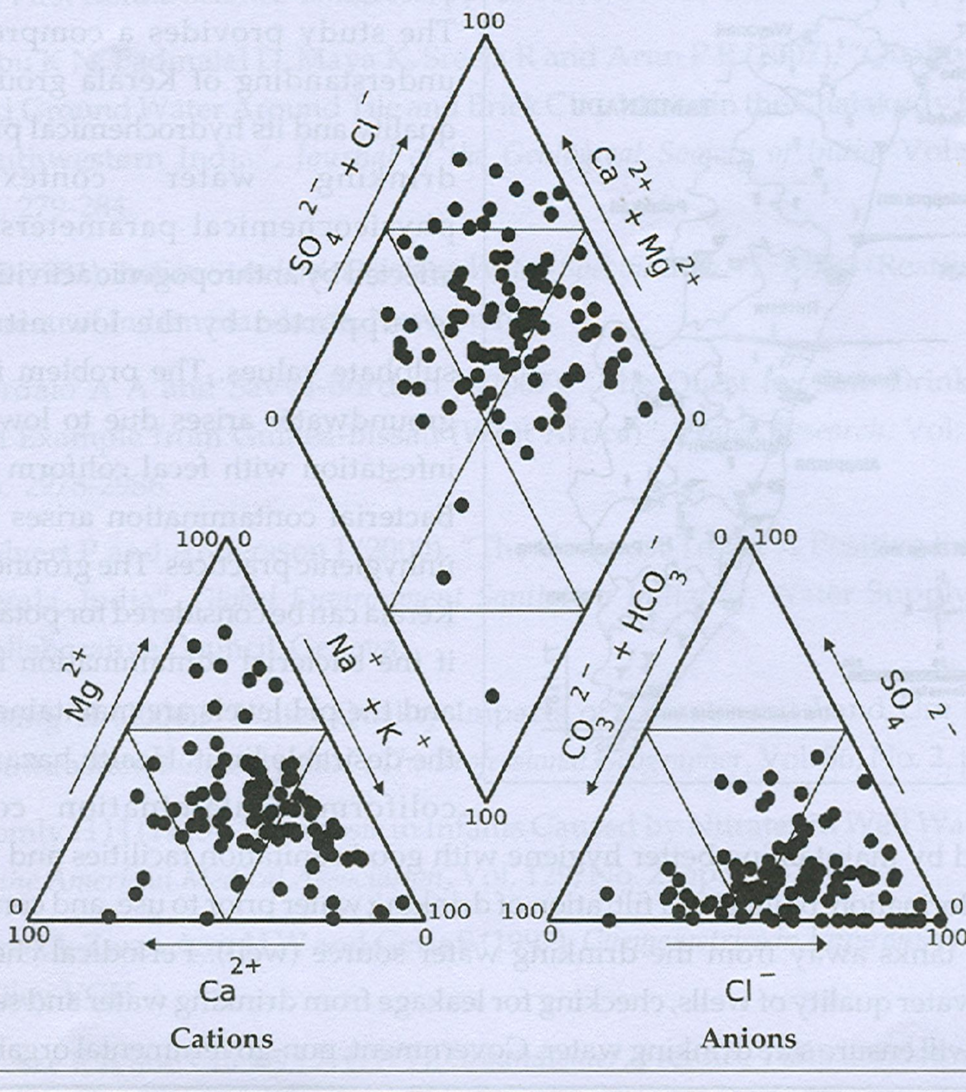
The relationship among water quality variables were analyzed by Pearson correlation coefficient at 95% confidence interval (Table 4). A strong positive correlation was found between Ca^{2+}, Mg^{2+}, HCO_3^-, alkalinity and hardness; and these variables also show positive correlation with pH, salinity, EC, TDS, Na^+, K^+, Cl^-, SO_4^{2-}, PO_4^{3-}, CO_3^{2-} and F^-. The correlation matrix shows that magnesium is the main contributor for alkalinity than calcium. DO and NO_3^- were not correlated with any parameters. Most of the correlated pairs are the result of natural processes than the anthropogenic inputs.

Groundwater Chemistry

Groundwater Types

The groundwater types were determined by plotting the major cations and anions in the piper diagram (Figure 7). It shows that alkaline earths (Ca^{2+} and Mg^{2+}) significantly exceed the alkalis (Na^+ and K^+) and strong acids (Cl^- and SO_4^{2-}) significantly exceed the weak

Figure 7: Water Type Chemical Parameters Through Piper Diagram

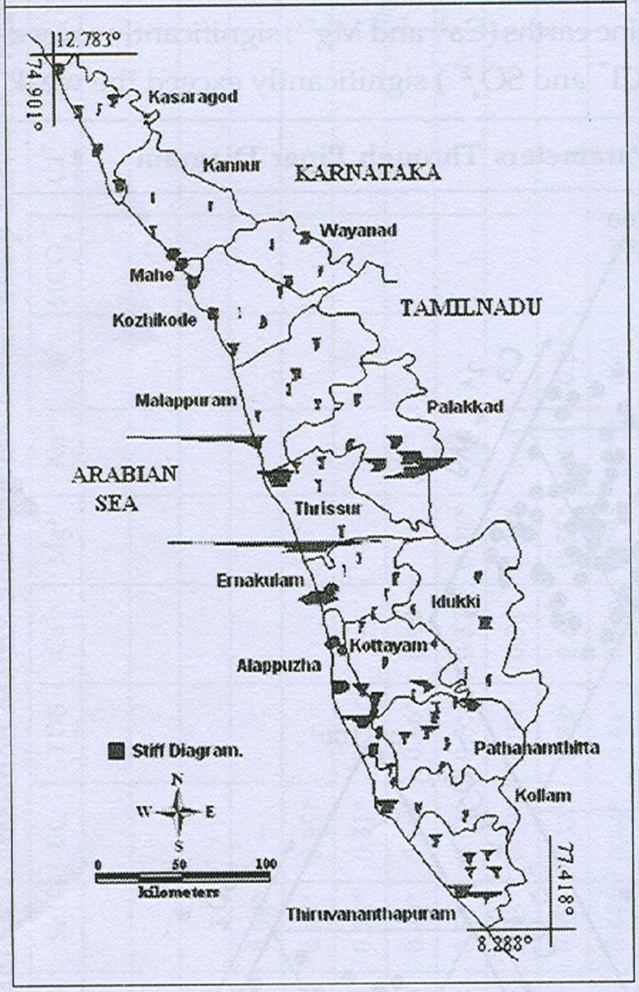


acids (HCO_3^- and CO_3^{2-}). Most of the samples were of mixed Ca-Mg-Cl type, followed by Na-Cl, Ca-HCO_3, Ca-Cl, mixed Ca-Na-HCO_3 and Na-HCO_3 types.

Spatial Trend in Groundwater

Stiff diagram (Figure 8) shows that Central Kerala had the highest amount of major ions than the other regions of Kerala, in particular, Kodungallur (Thrissur) with Na^+ plus K^+ (cations) and Cl^- (anions) and Ponnani (Malappuram district) with Na^+ plus K^+. It reveals that both Kodungallur and Ponnani groundwater is influenced by weathering, sea water intrusion, and anthropogenic activities like industrial wastewater and irrigation drainage. The other places having higher amount of ions, especially cations, and a few places also with anions are Palakkad, Thiruvananthapuram, Ernakulam, Alappuzha, Idukki, Kottayam and Kollam districts.

Figure 8: Stiff Diagram Reflecting the Variability of Major Ions



Conclusion and Suggestions

The study provides a comprehensive understanding of Kerala groundwater quality and its hydrochemical process. In drinking water context, the physicochemical parameters are not affected by anthropogenic activities, which is supported by the low nitrate and sulphate values. The problem in Kerala groundwater arises due to low pH and infestation with fecal coliform bacteria. Bacterial contamination arises from the unhygienic practices. The groundwater of Kerala can be considered for potable usage if the bacterial contamination is curbed and the pH levels are maintained within the desirable limit. Health hazard due to coliform contamination could be minimized by maintaining better hygiene with good sanitation facilities and practices such as chlorination, boiling and filtration of drinking water prior to use, and constructing the septic tanks away from the drinking water source (well). Periodical checking of drinking water quality of wells, checking for leakage from drinking water and septic tank pipelines will ensure safe drinking water. Government, non-governmental organizations, and local institutions can come forward to give free analysis of some important water quality parameters to provide health and hygienic condition. Also, conducting awareness programs to maintain hygienic condition around the drinking water source by the concerned government, non-government organizations, and local institutions would lead to safer drinking water forever.

Acknowledgment: This work was funded by *Malayala Manorama* as a part of 'Palathulli' project. The authors thank Ajith Babu, Thomas Mathew and local reporters of the *Malayala Manorama* newspaper for their assistance during the field work. They are grateful to Ahalya, K V Gururaja, Sudhira, K G Avinash and Malvikaa for their help during the field work and laboratory analysis, and Alakananda and Supriya for useful comments.

References

1. APHA (1995), *Standard Methods for the Examination of Water and Wastewater*, 19th Edition, American Public Health Association, Washington DC.
2. Aravindan K P (1989), "A Study of Epidemic Diarrhoeal Deaths", Proceedings of the First Kerala Science Congress, pp. 361-366, STEC, Thiruvananthapuram.
3. Babu K N, Padmalal D, Maya K, Sreeja R and Arun P R (2007), "Quality of Surface and Ground Water Around Tile and Brick Clay Mines in the Chalakudy River Basin, Southwestern India", *Journal of the Geological Society of India*, Vol. 69, No. 2, pp. 279-284.
4. BIS (1991), *Indian Standard: Drinking Water-Specification, IS: 10500* (Reaffirmed *1993*). Bureau of Indian Standards, New Delhi.
5. Bordalo A A and Savva-Bordalo J (2007), "The Quest for Safe Drinking Water: An Example from Guinea-Bissau (West Africa)", *Water Research*, Vol. 41, No. 13, pp. 2978-2986.
6. Calvert P and Andersson I (2000), "The Compost Toilet: A Positive Experience in Kerala, India", *Global Environment Sanitation Initiative*, Water Supply Sanitation Collaborative Council, Geneva.
7. Chang H (2004), "Water Quality Impacts of Climate and Land Use Changes in Southeastern Pennsylvania", *The Professional Geographer*, Vol. 56, No. 2, pp. 240-257.
8. Comly H H (1945), "Cyanosis in Infants Caused by Nitrates in Well Water", *Journal of the American Medical Association*, Vol. 129, No. 2, pp. 112-116.
9. Einax J, Zwanziger H W and Geiss S (1997), *Chemometrics in Environmental Analysis*, Wiley-VCH.
10. Freeze R A and Cherry J A (1979), *Groundwater*, Prentice-Hall, London.

11. George A and Prakasam V R (2008), "Distribution of Fluoride in Kerala with Special Reference to Edamulackkal Grama Panchayat, Kollam District", *Indian Journal of Environmental Protection*, Vol. 28, No. 4, pp. 340-344.

12. Gilly G, Corrao G and Favilli S (1984), "Concentrations of Nitrates in Drinking Water and Incidence of Gastric Carcinomas, First Descriptive Study of the Piemonate Region, Italy", *Science of the Total Environment*, Vol. 34, Nos. 1-2, pp. 35-48.

13. Gopinath G and Seralathan P (2006), "Chemistry of Groundwater in the Laterite Formations of the Muvattupuzha River Basin, Kerala", *Journal of the Geological Society of India*, Vol. 68, No. 4, pp. 705-714.

14. Guler C, Thyne G D, McCray J E and Turner K A (2002), "Evaluation of Graphical and Multivariate Statistical Methods for Classification of Water Chemistry Data", *Hydrogeology Journal*, Vol. 10, No. 4, pp. 455-474.

15. Hammer O, Harper D and Ryan P (2001), "Past: Paleontological Statistics Software Package for Education and Data Analysis", *Paleontologia Electronica*, Vol. 4, No. 1, pp. 1-9.

16. Harikumar P S, Madhavan K and Khan A B (2000), "Water Quality Problems of Kerala with Special Reference to Fluoride", *Ecology, Environment and Conservation*, Vol. 6, No. 2, pp. 245-249.

17. Harikumar P S and Kokkal K (2009), "Environmental Monitoring Program on Water Quality", *Kerala State Council for Science, Technology and Environment*, Govt. of Kerala, p. 174.

18. http://censusindia.gov.in/Tables_Published/A-Series/A-Series_links/t_00_003.aspx. Accessed August 05, 2010.

19. http://www.epa.gov/safewater/hfacts.html. Accessed August 05, 2010.

20. http://www.kerala.gov.in/. Accessed August 05, 2010.

21. ISI (1983), *Indian Standard Specification for Drinking Water*, IS: 10500, Indian Standard Institute.

22. Jain C, Bandyopadhyay A and Bhadra A (2010), "Assessment of Ground Water Quality for Drinking Purpose, District Nainital, Uttarakhand, India", *Environmental Monitoring and Assessment*, Vol. 166, Nos. 1-4, pp. 663-676.

23. Jaiswal R K, Mukherjee S, Krishnamurthy J and Saxena R (2003), "Role of Remote Sensing and GIS-Techniques for Generation of Groundwater Prospect Zones Towards Rural Development: An Approach", *International Journal of Remote Sensing*, Vol. 24, No. 5, pp. 993-1008.

24. Jeevanandam M, Kannan R, Srinivasalu S and Rammohan V (2007), "Hydrogeochemistry and Groundwater Quality Assessment of Lower Part of the Ponnaiyar River Basin, Cuddalore District, South India", *Environmental Monitoring and Assessment*, Vol. 132, Nos. 1-3, pp. 263-274.

25. Kerala Water Authority (1991), "The Bacterial Quality of Water in Selected Wells in Kerala, Socioeconomic Units, Kerala", Integrated Water Supply and Sanitation Program.

26. Kunhikannan T P and Aravindan K P (2000), "Health Transition in Rural Kerala, 1987-1996." Discussion Paper No. 20. Shaji, H (Eds.), Kerala Research Program on Local Level Development, Centre for Development Studies, Thiruvananthapuram, p. 40, available at http://www.krpcds.org/kunhikannan.pdf

27. Laluraj C M and Gopinath G (2006), "Assessment on Seasonal Variation of Groundwater Quality of Phreatic Aquifers: A River Basin System", *Environmental Monitoring and Assessment*, Vol. 117, Nos. 1-3, pp. 45-57.

28. Laluraj C M, Gopinath G and Dineshkumar P K (2005), "Groundwater Chemistry of Shallow Aquifers in the Coastal Zones of Cochin, India", *Applied Ecology and Environmental Research*, Vol. 3, No. 1, pp. 133-139.

29. Laluraj C M, Gopinath G, Kumar P K D and Seralathan P (2006), "Seasonal Variations in Ground Water Chemistry of a Phreatic Coastal and Crystalline Terrain of Central Kerala, India" *Environmental Forensics*, Vol. 7, No. 4, pp. 335-344.

30. Panicker S, Basi E, Alexander P K and Ravindran P C (2000), "Assessment of Bacteriological Quality of Potable Water and Evaluation of Water Purification Technique", Proceedings of XII Kerala Science Congress, pp. 75-76.

31. Panikar P G K and Soman C R (1984), "Health Status of Kerala: The Paradox of Economic Backwardness and Health Development", Centre for Development Studies, Trivandrum, p. 159.

32. Pillai M G and Ouseph P P (2000), "Water Quality Management in Wells: A Case Study", Das M R (Eds.), Proceedings of the XII Kerala Science Congress, STEC, Thiruvananthapuram, pp. 17-22.

33. Piper A M (1944), "A Graphic Procedure in the Geochemical Interpretation of Water Analyses", Transactions-American Geophysical Union, No. 25, pp. 914-923.

34. R Development Core Team (2008), *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, available at http://www.R-project.org

35. Radhakrisnan A, Dina S, Shaji C, Thankamani V and Calvert P (1996), "Bacteriological Quality of Water from a Coastal Village – Pulluvila (Kerala)", Proceedings National Seminar on Rural Water Supply and Sanitation, pp. 147-148, Trivandrum.

36. Rahiman K M M, Chandran A and Hatha A A M (2003), "Bacteriological Quality of Well Water Samples of Ponnani, a Village at Sea Coast of Kerala", *Indian Journal of Microbiology*, Vol. 43, No. 2, pp. 141-142.

37. Ramachandra T V and Kumar U (2008), "Wetlands of Greater Bangalore, India: Automatic Delineation Through Pattern Classifiers", *Electronic Green Journal*, Vol. 1, No. 26.

38. Reddy P R, Kumar K V and Seshadri K (1996), "Use of IRS-1 C Data in Groundwater Studies", *Current Science*, Bangalore, No. 70, pp. 600-605.

39. Rejith P G, Jeeva S P, Vijith H, Sowmya M and Hatha A A (2009), "Determination of Groundwater Quality Index of a Highland Village of Kerala (India) Using Geographical Information System", *Journal of Environmental Health*, Vol. 71, No. 10, pp. 51-58.

40. Roy M K P (2004), "Water Quality and Health Status in Kollam Municipality", Discussion Paper 56. Nair P R G, Shaji H (Eds.), Kerala Research Program on Local Level Development, Centre for Development Studies, Thiruvananthapuram, p. 56, http://www.esocialsciences.com/data/articlesDocument1168200520.8355524.pdf

41. Russell D L (2006), *Practical Wastewater Treatment*, John Wiley and Sons.

42. Shaji C, Nimi H and Bindu L (2009), "Water Quality Assessment of Open Wells in and Around Chavara Industrial Area, Quilon, Kerala", *Journal of Environmental Biology*, Vol. 30, No. 5, pp. 701-704.

43. Shaji E, Bindu, Viju J and Thambi D S (2007), "High Fluoride in Groundwater of Palghat District, Kerala", *Current Science*, Vol. 92, No. 2, pp. 240-245.

44. Subramani T, Elango L and Damodarasamy S R (2005), "Groundwater Quality and Its Suitability for Drinking and Agricultural Use in Chithar River Basin, Tamil Nadu, India", *Environmental Geology*, Vol. 47, No. 8, pp. 1099-1110.

45. Varghese J and Jaya D S (2009), "Assessment of the Bacteriological Quality of Groundwater Around the Sewage Farm in Muttathara-Valiathura Area, Thiruvananthapuram District", *Indian Journal of Environmental Protection*, No. 29, pp. 430-434.

46. Vijith H and Satheesh R (2007), "Geographical Information System-Based Assessment of Spatiotemporal Characteristics of Groundwater Quality of Upland Sub-Watersheds of Meenachil River, Parts of Western Ghats, Kottayam District, Kerala, India", *Environmental Geology*, Vol. 53, No. 1, pp. 1-9.

47. Weiner E R (2000), *Applications of Environmental Chemistry: A Practical Guide for Environmetnal Professionals*, Lewis Publishers, Florida.

48. WHO (2008), *Guidelines for Drinking-Water Quality: Incorporating First and Second Addenda*, Vol. 1, Recommendations (3rd Ed.), Geneva, available at http://www.who.int/water_sanitation_health/dwq/fulltext.pdf. Accessed December 31, 2010.

49. Winston R B (2000), "Graphical User Interface for MODFLOW", Version 4: US Geological Survey Open-File Report 00-315, p. 27.

50. Yanggen D A and Born S M (1990), "Protecting Groundwater Quality by Managing Local Land Use", *Journal of Soil and Water Conservation*, Vol. 45, No. 2, pp. 207-210.

51. Zaporozec A and Miller J C (2000), *Groundwater Pollution*, UNESCO, Paris, France.

Reference # 63J-2012-02-04-01