

A Comprehensive Assessment of Water Quality Status of Kerala State

(Ground Water Component)

Purpose Driven Study
Hydrology Project (Phase II)

By

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&

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INTRODUCTION

The development and management of the water resources of a region has to be evolved together with that of land and biomass, giving due weightage to the specific socio-economic and environmental features. Kerala is having both abundance and scarcity as far as water resources is concerned. Though it has 44 so called rivers, most of them are monsoon fed and dry up during summer. Kerala is having the maximum density of open wells, but several of them do not yield during summer.

Salinity propagates not only to the downstream reaches of rivers but also into the groundwater aquifers of the thickly populated coastal belt. The estuaries near the industrial areas and thickly populated towns and cities are facing pollution problems, which becomes all the more severe by the reduction in summer flows.

The groundwater issues of the aquifers of the State are location specific and time variant. Hence, in order to achieve sustainable utilization and management of groundwater resources in terms of both quality and quantity, it is essential to establish a groundwater information system with all relevant components for easy visualization, access, retrieval and utilization.

Topographically, Kerala is divided into three distinct geomorphic zones. The highland zone is defined as the area covered by the altitudinal zone with elevation greater than 75 m above mean sea level. The midland region falls between altitudinal zones between 7.5 and 75 m. The coastal land is characterised by lagoons and ancient or modern dunes with altitudes upto 7.5 m above mean sea level.

The total land area is geologically more or less monotonous. The highland zone i.e., western ghat zone-is formed by the oldest rocks of Pre-cambrian age, belonging to the granulite facies of metamorphism. Charnockite, gneisses, basic dykes, quartz and pegmatite veins are typical of the Pre-cambrian rocks. Most of these rocks are very rich in elements like O, Si, Al, Fe, Ca, Na, K, Mg in the order of abundance.

These rocks have undergone weathering and have transformed themselves into laterite. Laterite in Kerala coastal belt has also formed out of the transformation of sedimentary rocks of Tertiary age, and occurs as cappings. Further weathering of laterite has given rise to lateritic soil. Laterite is very rich in either oxides of iron or aluminium, and in the latter case sometimes qualifies as an ore of Aluminium. In the midland zone large and extensive outcrops of laterite derived from the Precambrian rocks as well as laterite derived from the sedimentary rocks of Tertiary age have been noticed.

The coastal zone on the other hand is the result of the late tertiary and quaternary processes of sedimentation, and dispersal of sediments. Effects of Neotectonics are also noticed in this tract. The coastal land zone is characterised by the presence of lagoons which link the river channels with the Laccadive sea.

Relevance of the study

The major groundwater quality problems reported in Kerala are due to the presence of excess salinity, iron, fluoride, hardness and coliforms. The causes of contamination can be attributed to sea water intrusion, domestic sewage, mineralogical origin and agricultural and industrial activities.

The water quality problems in the coastal areas are mainly because of the presence of excess chloride.

Along the midland region, concentration of iron and chloride were found to be on higher side in bore wells. Abnormal values of pH and electrical conductivity were also noticed in few wells. However, about 50 % of the wells are contaminated by coliforms. Palghat region is reported to have fluoride contamination along with high concentration of iron and calcium.

The highland zone mostly yields good quality water. However, high concentration of iron and coliform are reported from Idukki district.

However, the above studies were conducted in isolation, covering smaller study areas. Necessary data on water quality status on a State scale are not available for proper planning and management of the groundwater resources. Vulnerability of water resources to pollution, needs to be addressed in a regional scale. By considering the above facts, the State Government of Kerala has proposed the present project with the coordination of the National Institute of Hydrology under the ongoing Hydrology Project (Phase II):

- to identify the regional water quality problems
- to develop quality indices
- to evolve strategies to protect the existing water bodies by conducting public awareness programmes
- to adopt appropriate preventive and remedial measures

On the serious issue of water quality, more investigations are required to assess the real situation in order to devise remedial measures and management options. Vulnerability of precious sources of water to pollution needs to be addressed in a regional scale. Any investigations without addressing quality issues in the right perspective may not yield sustainable results. Keeping in view of the above facts, the objectives of the proposed 3-year Purpose Driven Study are listed as below:

- To ascertain the existing pollution level of rivers, lakes, ponds, streams, wells, water taps and other water bodies in Kerala.
- To evolve water quality index for the surface water bodies and quality modeling for the selected river reaches.
- To develop vulnerability index for groundwater resources and to carry out quality modeling for selected blocks.
- To create awareness among the people about the locations & causes of pollution and thereby to initiate proper pollution control practices.

GROUND WATER QUALITY ANALYSIS

Kerala State Ground Water Department has selected 991 monitoring stations to understand the major water quality problems and to identify critical areas, covering all 14 districts of the State. The monitoring locations include dug wells and bore wells. The water samples were collected and the analyses were conducted for 4 seasons; February 2008, May 2008, October 2008 and April 2009.

Parameters monitored by the State Ground Water Department are:

- 1) Turbidity
- 2) PH
- 3) Electrical Conductivity
- 4) Total hardness (as CaCO₃)
- 5) Sodium (Na)
- 6) Chlorine (Cl)
- 7) Fluoride (F)
- 8) Iron (as Fe)
- 9) T-Coli forms & F-Coli form

METHODOLOGY

Sampling Techniques and Preservation

Sampling is one of the most important step in collection of representative water samples for ground water quality studies. Moreover, the integrity of the sample must be maintained from the time of collection to the time of analysis. Factors involved in the proper selection of sampling sites depend on the objectives of the study, accessibility, chemical source locations, manpower and facilities available to conduct the study. Further more, the hydrologist must be aware of the locations of point and non point sources of chemical and physical constituents, such as industrial complexes, sewage out falls, agricultural wastes etc. The use of a few strategic locations and enough samples to define the results in terms of statistical significance is usually much more reliable than using many stations with only a few samples from each.

The quantity of samples to be collected varies with the extent of laboratory analysis to be performed. A sample volume between two and three litres is normally sufficient for a fairly complete analysis. The samples were collected from both open and bore wells, which are being extensively used for drinking and other domestic purposes. Depth integrated samples were collected by lowering the container in the open wells. The depth of the water in the respective wells was also measured with Hand held Water level indicator. The samples were collected in clean polyethylene containers fitted with screw caps. One container of 500 ml sample was acidified with nitric acid for analysis of metal ions. Some parameters like pH and temperature were measured in the field at the time of sample collection using portable kits and the other chemical parameters were analysed in the laboratory.

Methods of Analysis

The quality of water depends on a large number of individual hydrological, physical, chemical and biological factors. Some parameters are of special importance and deserve frequent attention and observation, whereas other gives a rough picture of water body and its quality status.

During the present study, the chemical properties and the constituents of water analysed are pH, Specific conductance (EC), Temperature, Total Dissolved Solids, Alkalinity (carbonates and bicarbonates), Hardness and major cations and anions.

Chemical parameters of the samples were analysed in the laboratory by standard methods recommended in the manuals. Some of the parameters like pH and temperature were measured in the field by using portable kits, at the time of sample collection. The list of equipments used and methods of analysis are presented in Table I.

Table I. Analytical Methods and Equipments used in the study

Sl.No	Parameters	Methods	Equipments
1.	PH	Electrometric	pH Meter (AQUA LYTIC)
2.	Total Dissolved Solids	Electrometric	
3.	Conductivity	Electrometric	
4.	Temperature	Thermometric	T 100 N LCD - Thermometer
5.	Calcium	Titration by EDTA	Volumetric glassware
6.	Magnesium	Titration by EDTA	Volumetric glassware
7.	Sodium	Flame emission	Flame Photometer (Model Chemito 1000)
8.	Potassium	Flame emission	Flame Photometer (Model Chemito 1000)
9.	Carbonate	Titration	Volumetric glassware
10.	Bicarbonate	Titration	Volumetric glassware
11.	Chloride	Titration by Silver nitrate	Volumetric glassware
12.	Sulphate	Turbidimetric	
13.	Hardness	Titration by EDTA	Volumetric glassware

pH

The pH value of water is a measure of hydrogen ion concentration. The pH value may be determined potentiometrically by a wide variety of pH meters which are battery operated or run by standard-line power. They are equipped with glass and reference electrodes which require standardizing with standard buffer solutions before each measurement.

Temperature

The temperature of the water is measured at the time of sample collection by using mercury thermometers calibrated to 0.1 to 0.5°C. Water temperature is also measured by electrical instruments equipped with thermistor-type sensors.

Electrical Conductivity

The electrical conductivity is the measure of capacity of water to carry an electrical current and is directly related to the concentrations of ionized substances in the water. The cell constant of the instrument is determined with the standard KCl solution. The instrument is set at the cell constant, immerse the electrode in the water sample and record the reading.

Total Dissolved Solids

In water sources, the dissolved solids, which usually predominate, consist mainly of inorganic salts and small amount of organic matter. Take 100 ml of water sample in a borosil beaker and evaporate the whole water to dryness. The residue left in the beaker is then weighed and expressed in mg/l as TDS.

Alkalinity

Total alkalinity is the measure of capacity of water to neutralise a strong acid. The alkalinity in the water is generally imparted by the salts of carbonates, bicarbonates, borates, nitrates and silicates. Take 50 ml of water sample in a conical flask, add 2-3 drops of phenolphthalein indicator. Titrate it against 0.02N H_2SO_4 till the pink colour just disappears. Then to same solution, add 2-3 drops of methyl orange indicator, continue the titration with 0.02N H_2SO_4 till the pink colour reappears. Calculate phenolphthalein (P) alkalinity and methyl orange (M) alkalinity.

Sulphate

Sulphate appears in natural water in a wide range of concentrations. Sulphate ions are precipitated in acetic acid solution with barium chloride so as to form a uniform suspension of barium sulphate crystals. The absorbance of the suspension is measured by a Photoelectric Colorimeter and the sulphate concentration is determined by comparison of the reading with a standard curve.

Chloride

The chloride ions are always present in water in one or more forms like CaCl_2 , MgCl_2 and NaCl etc. It is determined volumetrically by Mohr's method, titrating against standard silver nitrate solution in the presence of potassium chromate indicator. Take 100 ml of water sample in a conical flask, add a pinch of potassium chromate indicator. Titrate against standard silver nitrate solution till the colour of the solution changes from yellow to brick red.

Total Hardness

Total hardness can be estimated volumetrically by titrating against EDTA solution. Take 50 ml of water sample in a conical flask, and add 2 to 3 drops of Eriochrome Black T indicator and 2-3 ml of ammonia buffer solution. Titrate with standard EDTA, till colour changes from wine red to blue.

Calcium

Hardness of water is caused by the presence of bivalent metallic ions with cations and anions of Ca^{++} . It can be determined volumetrically by titration with EDTA. Take 50 ml of water sample in a conical flask. Add 1 ml of 2N NaOH solution and a pinch of murexide indicator, so that the colour will be pink. Titrate it with EDTA till colour changes from pink to purple.

Magnesium

Hardness of water is caused by the presence of bivalent metallic ions with cations and anions of Mg^{++} . Magnesium is determined by subtracting the value of calcium from the total hardness value.

Sodium & Potassium

Sodium and potassium can be determined by flame emission photometry at a wavelength of 589 and 766.5 nm respectively. The sample is sprayed into a gas flame and excitation is carried out under carefully controlled and reproducible conditions. The desired spectral line is isolated by the use of interference filters or by a suitable slit arrangement in light-dispersing devices such as prisms or gratings. The intensity of light is measured by a photo tube potentiometer or other appropriate circuit. The standard calibration curve is prepared and concentration of sample is determined from the calibration curve.

Diagrammatic Representation of Geochemical data

Geochemical studies often involve synthesis and interpretation of a mass of analytical data. The objective of interpretation may be to aid in the classification of waters of different geochemical characteristics for utilitarian purposes, solving problems of saline water intrusion, or ascertaining various factors on which the chemical characteristics of waters depend. The examination of tabular statements of geochemical data of a large number of samples is not only a tedious and irksome process, but also fails to bring geochemical aspects. Piper's diagram has been extensively used to understand problems about the geochemical evolution of groundwater. The diagram consists of three distinct fields - two triangular fields and a diamond shaped field. In the triangular fields, plotted separately, are the percentage eqm values of cations, Ca and Mg (alkaline earths) and Na (alkali), and anions, HCO₃ (weak acid) and SO₄ and Cl (strong acid). The overall characteristic of the water is represented in the diamond-shaped field by projecting the position of the plots in the triangular fields. Minor alkalis like potassium, and strong acids like iodide, fluoride and nitrate are clubbed with the major ones.

Different types of groundwater can be distinguished by the position of their plottings occupy in certain areas of the diamond shaped field.

- Area 1 - alkaline earths exceed alkalies
- Area 2 - alkalies exceed alkaline earths
- Area 3 - weak acids exceed strong acid
- Area 4 - strong acids exceed weak acids
- Area 5 - carbonate hardness exceeds 50 %, i.e. chemical properties of the water are dominated by alkaline earths and weak acids
- Area 6 - non-carbonate hardness exceeds 50%
- Area 7 - non-carbonate alkali exceeds 50%, i.e.chemical properties are dominated by alkalies and strong acids-ocean water and many brines plot near the right-hand vortex of the subarea
- Area 8 - carbonate alkali exceeds 50% - here plot the waters which are inordinately soft in proportion to their content of dissolved solids
- Area 9 - no one cation-anion pair exceeds 50%.

Piper's diagram has been widely used to study similarities and differences in the composition of waters and to classify them into certain chemical types. The water types demonstrated by the piper diagram, as described by Karanth (1987) show the essential chemical character of different constituents in percentage reacting values, expressed in milligrams equivalent. Based on Piper's diagram, (Figures 5 to 8), it can be classified basically under four major categories, in both Virudh nagar and Coimbatore districts. However, the samples mainly exhibit a type dominated by chloride type or Cl-SO₄-HCO₃ type representing strong acids exceed weak acids which represent non-carbonate alkali exceed 50%. Piper diagram is highly useful as it allow comparisons to be made among numerous analyses but this does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms so the diagram lacks certain logic. Piper suggested the method

of encircling the plotted points in the central diamond field with its area proportional to the absolute concentration. This method is not very convenient when plotting large volume of data.

Chadha's Diagram

The Chadha's diagram is a modified version of the piper diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in each triangle and the type of water is determined on the basis of position of the data plot in the respective cationic and anionic triangular fields. The plotting from triangular fields is extended further into the central diamond field, which provides the overall character of the water.

In contrast, in the Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium) expressed as percentage reacting values is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (Chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y coordinates. The milliequivalent percentage differences between alkaline earths and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the proposed diagram.

The square or rectangular field describes the overall character of the water. the proposed diagram has all the advantages of the diamond-shaped field of the Piper diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type as follows:

1. Alkaline earths exceed alkali metals.
2. Alkali metals exceed alkaline earths
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. This kind of water has temporary hardness. The position of data points in the diagram represent Ca^{2+} - Mg^{2+} - HCO_3^- type, Ca^{2+} - Mg^{2+} -dominant HCO_3^- type, or HCO_3^- -dominant Ca^{2+} - Mg^{2+} type waters
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The positions of data points in the proposed diagram represent Ca^{2+} - Mg^{2+} - Cl^- type, Ca^{2+} - Mg^{2+} -dominant Cl^- type or Cl^- -dominant Ca^{2+} - Mg^{2+} type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in the proposed diagram represent Na^+ - Cl^- type, Na_2SO_4 -type Na^+ -dominant Cl^- -type, or Cl^- -dominant Na^+ -type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause

foaming problems. The positions of data points in the proposed diagram represent Na⁺- HCO₃⁻ -type, Na⁺-dominant HCO₃⁻ -type, or HCO₃⁻ -dominant Na⁺-type waters.

U.S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The SAR is calculated using the formula:

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

A diagram for use in studying the suitability of groundwater for irrigation purposes, named after Wilcox (1955), is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in $\mu\text{S}/\text{cm}$. The chemical analysis data of all the water samples have been plotted on Wilcox diagram.

1.0 GROUND WATER QUALITY OF KASARAGOD DISTRICT

Kasaragod is the northernmost district of Kerala, bordering Karnataka state. Kasaragod district is divided into two taluks (Kasaragod and Hosdrug) and 75 villages. The district has one revenue division, 4 block Panchayats (Manjeshwar, Kasaragod, Kanhangad and Nileshwar) and 39 Grama Panchayats. The population is mainly agrarian and the major crops raised are coconut, arecanut, cashew nut, paddy and pepper with coconut and paddy as the major crops. However, in the recent reports it is stated that the paddy cultivation has reduced from 5512 hectares in 1994-1995 to 2367 hectares in 2003-2004. About 75% of the area of the district is covered by laterites. Because of the highly porous nature of the laterite, the dug wells tapping laterite get recharged fast in the initial stages of monsoon showers itself, however, this water escapes as sub-surface flow and the water level falls quite fast especially in wells located on topographic high and slopes. Further the delay in monsoon and deficit summer showers badly affect the crops and drinking water availability. In the recent years farmers started growing bananas and vegetables in paddy fields (CGWB, 2005).

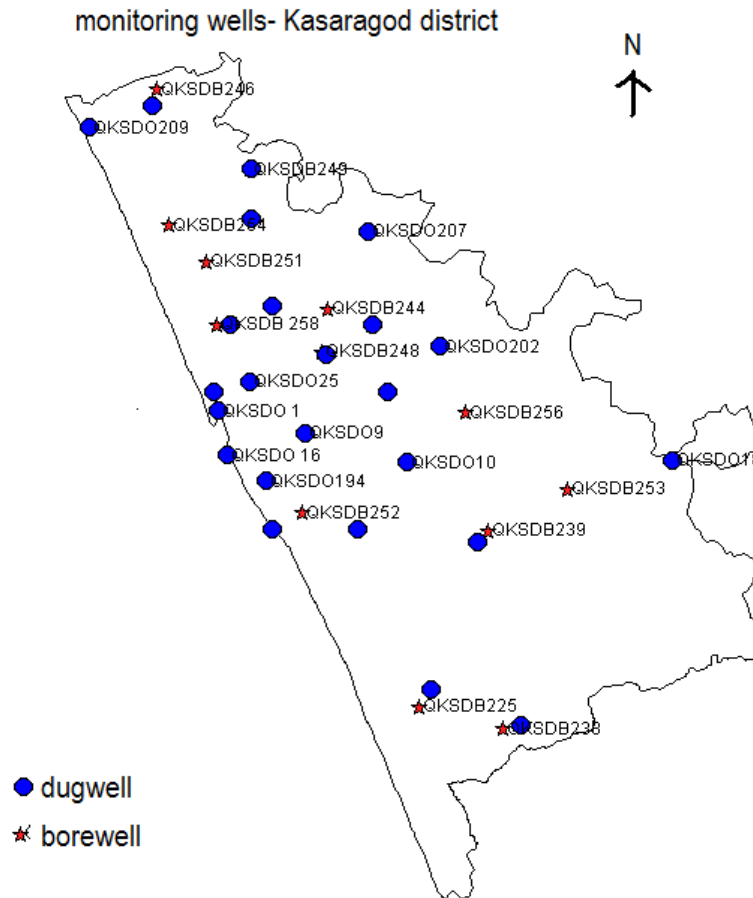


Figure 1: Groundwater Sampling locations of Kasaragod district

Rainfall & Climate

The district receives an average of about 3500 mm rainfall annually. The major source of rainfall is southwest monsoon from June to September which contributes nearly 85.3% of the total rainfall of the year. The northeast monsoon contributes nearly 8.9% and balance of 5.8% is received during the month of January to May as pre monsoon showers. Out of the 106 rainy days in a year, 87 rainy days occur during south west monsoon season.

Temperature

The temperature is more during the months of March to May and is less during December and January. The average mean monthly maximum temperature ranges from 29.2 to 33.4⁰ C and minimum temperature ranges from 19.7 to 25⁰ C.

Relative Humidity

Relative humidity is more during morning hours and is less during evening hours. During the morning hours it ranges from 87.1 to 98.7% and during evening hours it ranges from 54.4 to 86.5%.

Evaporation

Evaporation is more during summer months of March to May. In general, it ranges from 2.2 to 6.3 mm/day. During south west monsoon season it ranges from 2.2 to 3.7 mm/day.

Sunshine Hours

Sunshine ranges from 3.2 to 10.2 hours/day. Maximum sunshine is during the month of February. The months of June to August record the minimum sunshine due to the cloudy sky. Generally good sunshine hours are recorded in the months of November to May.

Wind

The wind speed ranges from 2.1 to 3.3 km/hour. The wind speed is high during the months of March to June and less during the months of September to December.

Potential Evapotranspiration (PET)

PET values are lower than the monthly rainfall during the month of May to October indicating water surplus for possible recharge into groundwater regime during these months. The monthly PET ranges from 119.3 to 177.0 mm.

Geomorphology and Soil Types

Geomorphically the district can be divided into three distinct units viz. the coastal plains, the mid-lands and the eastern high-land regions. The coastal plains with an elevation of less than 10m occur as narrow belt of alluvial deposits parallel to the coast. To the east of coastal belt is the midland and highland region with altitude ranging from 10 to 300 m amsl. There are four major soil types encountered in the district. They are Lateritic Soil, Brown hydromorphic Soil, Alluvial Soil and Forest Loam. Lateritic soil is the most predominant soil type of the district and it occurs in the midland and hilly areas and it is derived from laterites. Brown hydromorphic soil is confined to the valleys between undulating topography in the midlands and in the low lying areas of the coastal strip.

Ground water Quality Analyses

Groundwater occur under water table conditions in alluvium, laterites and weathered mantle of the crystallines, where as in the deeper fractured crystallines the groundwater occurs under semi confined to confined conditions. Since the physiographic set up and geological formations are same for all the blocks, alluvium occurs as narrow strips parallel to the coast and the width increases from the northern part of Kanhangad block to southern part of

Nileshwar block and around Trikaripur of Nileshwar block. In Kasaragod and Manjeshwar blocks alluvium occur as isolated patches close to the coast and have limited thickness.

Ground water quality problems are reported from different parts of the district. Keeping this in mind, 133 samples were collected and analysed during the pre-monsoon and 78 samples were subjected to chemical analysis of post monsoon seasons of 2008. It is observed that pH values are very low in many parts of the district indicating a highly acidic nature of the rocks, In some parts of the district and water was alkaline. pH value varied between 5.01 and 8.27 during the pre-monsoon. Acidic nature of water was exhibited in many locations with a minimum of 5.01 (Bekal) and the maximum of 8.27 was noticed in the parts of central and eastern part of the district. The electrical conductivity varied between 40 and 630 during pre-monsoon with a mean of 151 and a standard deviation of 104. The concentration of chloride in the district varied between 9.78 mg/l and 84.73 mg/l.

Apart from the major ions like chloride and sodium, other water quality problems encountered in the district was with regard to iron concentration. Iron content was high in majority of the wells. More than 80% of the wells were having the Iron concentration which exceeds the permissible limit. Higher values were observed at Badiyaka (9.21 mg/l), Beemanady (8.68 mg/l), Panayal (5.70 mg/l) and Kooliyad (4.67 mg/l). It was also observed that the Endosulphane content was reported and many villagers were affected physically due to the chemical contamination. Tables 1a, 1b,1c and 1d show the statistical analysis of groundwater samples collected during 2008 and 2010.

Table 1a: Statistical analysis of Pre-monsoon samples (2008)

Parameters	Minimum	Maximum	Mean	Std. dev.
pH	5.01	8.27	6.82	0.47
EC	40	630	151.28	104.36
TH	6	190	39.89	29.75
Cl	9.78	84.73	20.54	12.62
Na	1.4	50.3	8.49	6.90
Fe	0.01	8.96	0.78	1.22

Table 1b: Statistical analysis of Post-monsoon samples (2008)

parameters	No.	minimum	maximum	mean	St. Deviation
pH	78	6.09	7.83	7.20	0.36

EC	78	50	605	152.64	102.57
TH	78	10	150	38.65	25.91
Cl	78	6.69	75.5	15.83	11.56
Na	78	2.5	42.1	8.97	7.27
Fe	78	0.03	9.21	0.60	1.37

**Table 1c: Descriptive Statistics of Groundwater
Pre monsoon 2010**

Parameters	minimum	maximum	mean	SD
pH	6.9	8.4	7.54	0.51
EC	68	405	159.77	106.62
T.Hardness	20	180	60.38	43.90
Alkalinity	17.1	152.3	43.97	37.73
TDSolids	41	243	95.87	63.95
CO3	0	10.8	1.39	3.48
HCO3	17.08	163.8	51.40	40.43
Cl	5.14	55.5	20.96	12.50
SO4	0.32	5.37	1.81	1.71
NO3	0.025	7.85	1.05	2.11
Ca	4	32.8	12.12	9.22
Mg	2.43	25.8	7.31	5.85
Na	1.9	28.6	7.88	6.73
K	0.5	4.9	1.63	1.24
F	0.01	0.87	0.35	0.23
Fe	0.03	8.4	1.39	2.29

Parameters	minimum	maximum	mean	SD
pH	5.1	8.4	7.48	0.66
EC	47	328	111.80	68.59
Total Hardness	15.15	78.75	38.41	19.47
Alkalinity	7.65	79.04	24.47	19.97
Total Dissolved Solids	28.2	196.8	67.08	41.15
CO₃	0	2.49	0.12	0.56
HCO₃	7.61	96.43	29.57	24.53
Cl	5.6	81.23	17.99	16.06
SO₄	0.26	12.57	3.20	2.81
NO₃	0.02	9.2	1.30	2.29
Ca	2.52	18.48	7.36	4.73
Mg	0.64	11.99	4.85	2.51
Na	1.4	37.2	8.55	7.71
K	0.2	7.4	1.42	1.60
F	0.07	1.48	0.50	0.40
Fe	0.01	6.95	0.51	1.52

From the correlation matrix (Table 1f), it is observed that during pre-monsoon 2010, electrical conductivity showed high positive correlation with total hardness (0.961), alkalinity (0.864), chloride (0.787), calcium (0.956), Mg (0.837) and sodium (0.70). Moderate correlation was observed with sulphate (0.55) and nitrate (0.578). Chloride exhibited high positive correlation with sodium (0.967) and a moderate relation with potassium (0.694). Nitrate also showed high positive correlation with sodium (0.93) and moderate relationship with potassium (0.742) and calcium (0.613). Sulphate showed moderate correlation with calcium and magnesium

In the post-monsoon of 2010, ground water showed highly acidic character which could be due to the large quantity sediments brought from upper catchments during rainfall events.

pH

The pH in pre monsoon season ranged from 5.01 to 8.27 with a mean value of 6.82 and 0.47 standard deviation. During the pre-monsoon the variation observed was less than 5% indicating that on an average there are no wide variations in water quality parameters. Similar observation was found in the case of Total hardness. The mean value was 29.75 mg/l. During the pre-monsoon season the sodium showed variation between 1.4 and 50.3.1mg/l. Table 1c and 1d shows the results of chemical analysis carried out for the samples collected during the 2008.

The pH in post monsoon season ranged from 6.09 to 7.83 with a mean value of 7.2 and 0.36 standard deviation. During the post-monsoon the variation observed was less than 5% indicating that on an average there are no wide variations in water quality parameters. Similar observation was found in the case of Total hardness. The mean value was 20.53mg/l. During the post-monsoon season the sodium showed variation between 2.5 and 42.1mg/l. From the study it is evident that, the study area was dominated by acidic water during the pre-monsoon. Alkaline water was observed only in few patches viz. north, eastern and southern sides. However, during post-monsoon, wide variation was noticed and a reverse trend was observed. i.e. in the majority of the area slightly acidic to moderate alkaline water was noticed. This variation could be attributed to rainfall pattern. The seasonal variation of pH in waters during 2008 and 2010 are given in Figures 1a & 1b.

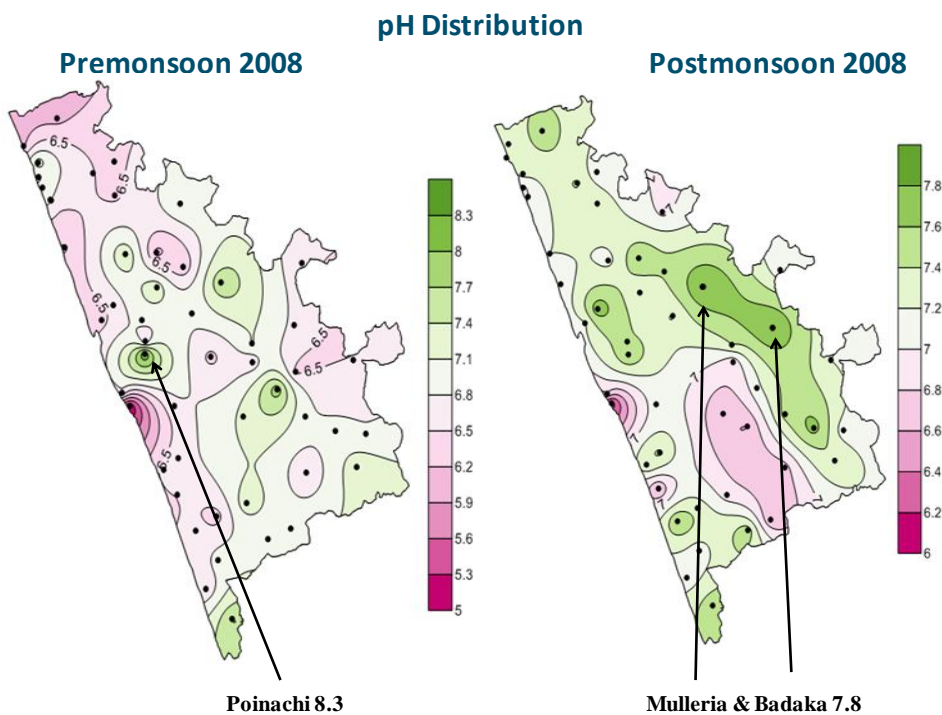


Figure 1a: Spatial variation of pH in Groundwater of Kasaragod district (Year:2008)

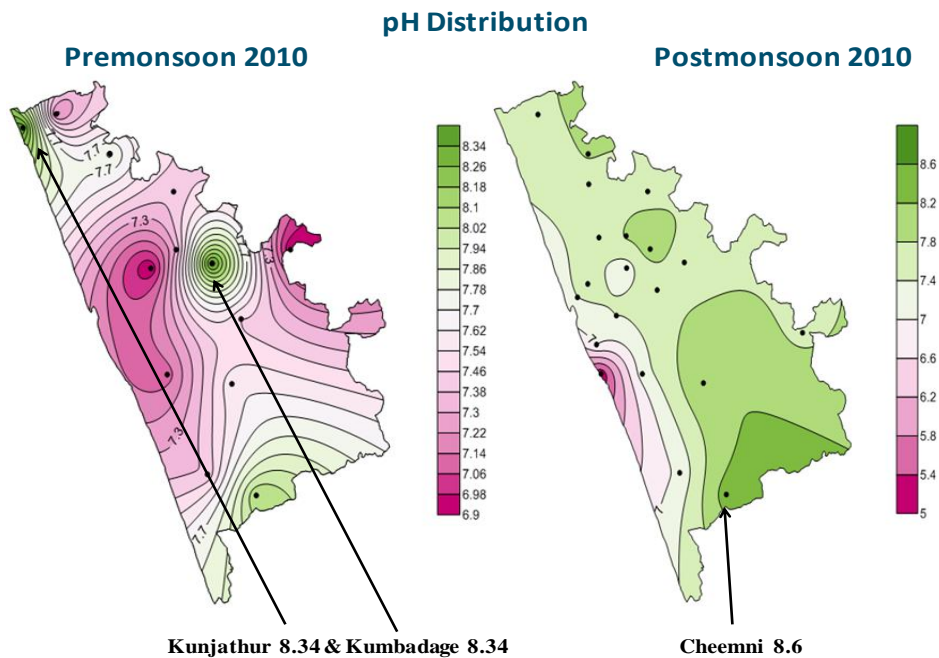


Figure 1b: Spatial variation of pH in Groundwater of Kasaragod district (Year:2010)

Electrical conductivity

Electrical conductivity of the samples varied from 40.0 micro-siemens/cm to 640 micro-siemens/cm during pre-monsoon and 40 to 580 micro-siemens/cm during 2008. Similar trend was noticed in the year 2010. The EC varied from 60 to 420 micro-siemens/cm in the pre-monsoon and 40 to 310 micro-siemens/cm during post-monsoon. From the analysis, it is clear that there is no significant variation in electrical conductivity. Further, it is evident that the water is suitable for all purposes including drinking as per BIS specifications. Figures 1c & 1d shows the variation of Electrical conductivity during 2008 and 2010.

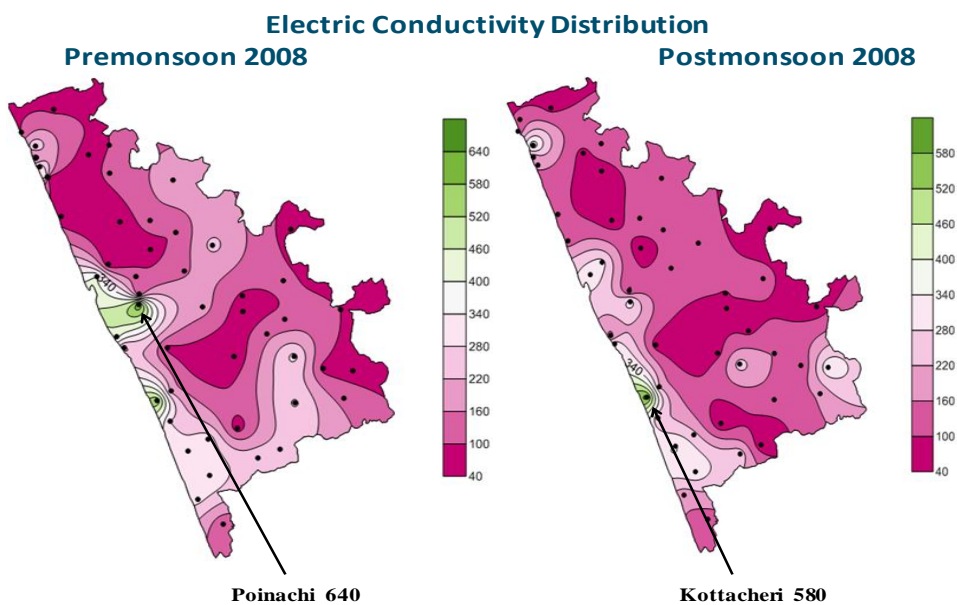


Figure 1c: Spatial variation of EC in Groundwater of Kasaragod district (Year:2008)

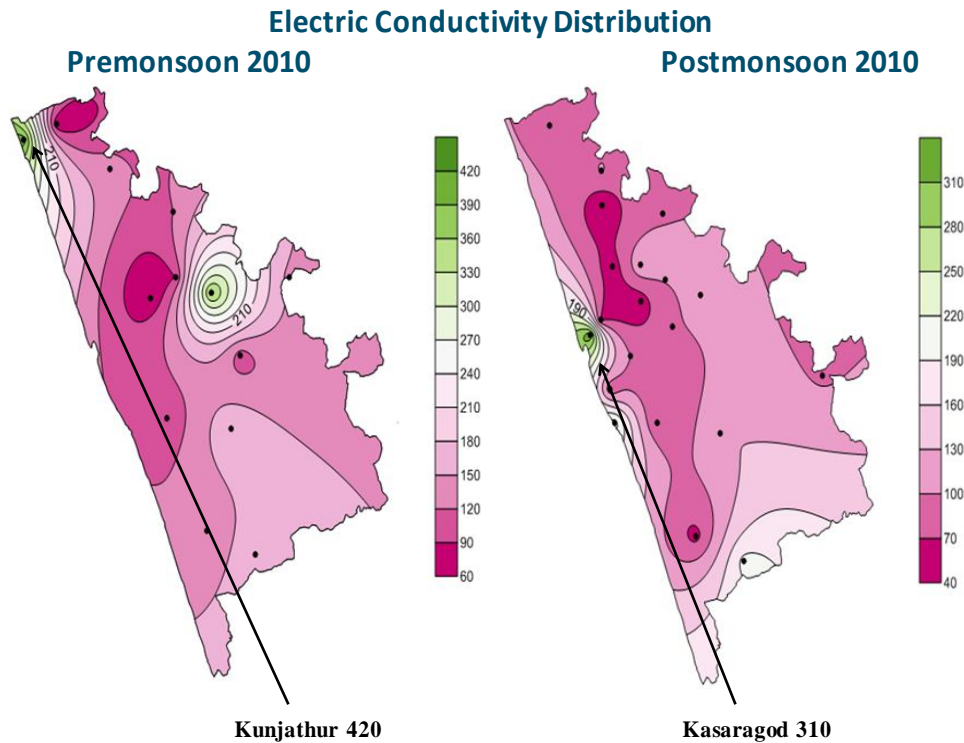


Figure 1d: Spatial variation of EC in Groundwater of Kasaragod district (Year:2010)

Total Dissolved Solids

The concentration of TDS during 2008 and 2010 were analysed and found that the values are much below the desired limits. Total Dissolved Solids varies from 40 to 240 mg/l during 2010 and 20 to 200 mg/l during post-monsoon. The result shows that, in general, the study area is quite stable and no erosional activities are prevailing in these areas. The seasonal variation of TDS during 2010 is depicted in Figure 1e.

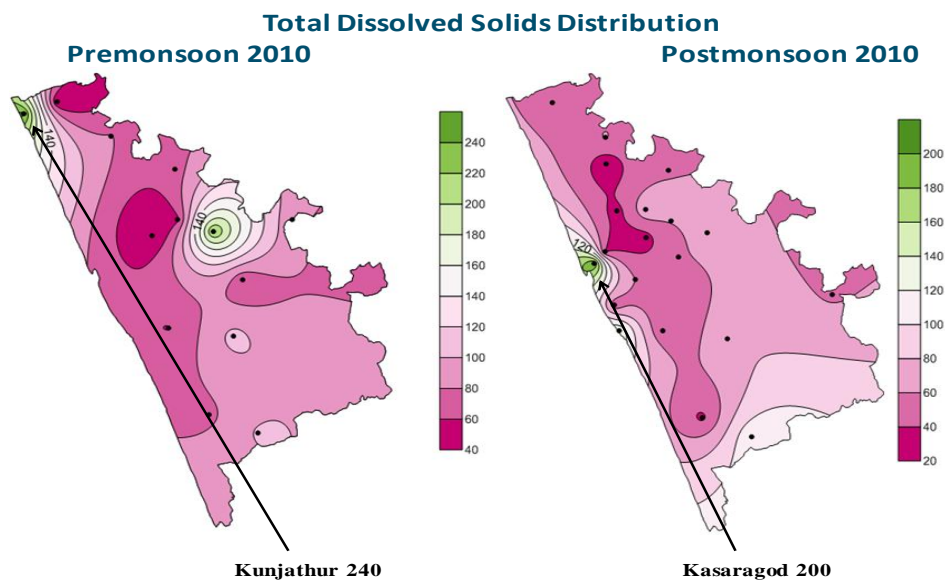


Figure 1e: Spatial variation of TDS in Groundwater of Kasaragod district (Year:2010)

Total Alkalinity

In the study area, it is found that the alkalinity varied between 10 mg/l and 150 mg/l during pre-monsoon and in the post-monsoon, it varied from 5 mg/l to 75 mg/l. It is noticed that the carbonate is absent in majority of the places. Bicarbonate concentration also showed a similar trend. The variations of bicarbonates during pre-monsoon and post-monsoon were quite minimal. The total alkalinity of the water samples were found to be within the permissible limit for all the samples as per BIS (1991). Figure 1f and 1g shows the variation of Total alkalinity and bicarbonates respectively.

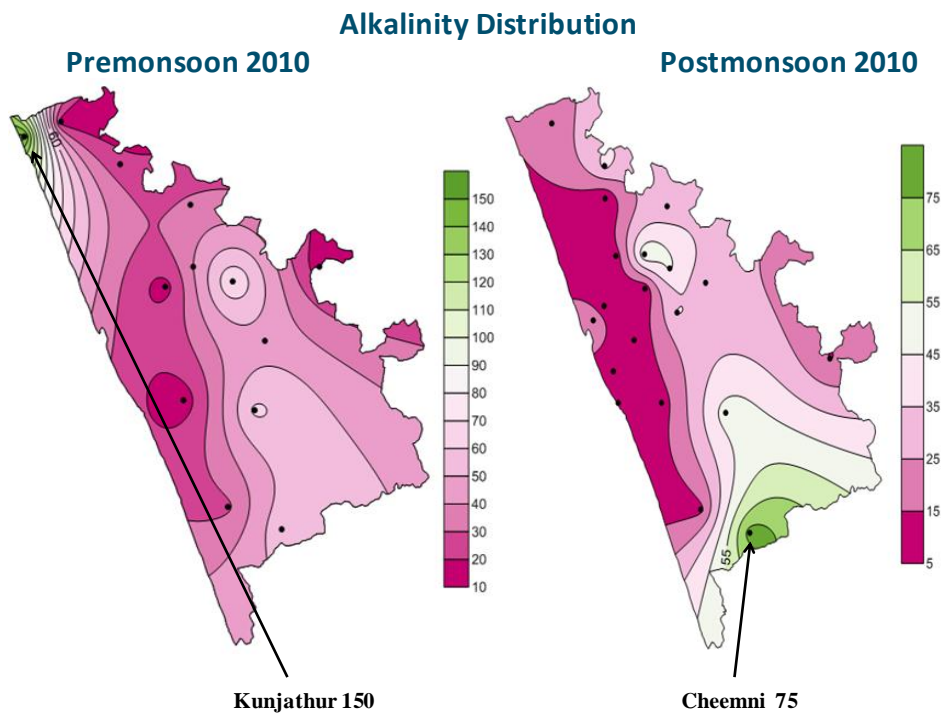


Figure 1f: Spatial variation of Total Alkalinity in Groundwater of Kasaragod district (Year:2010)

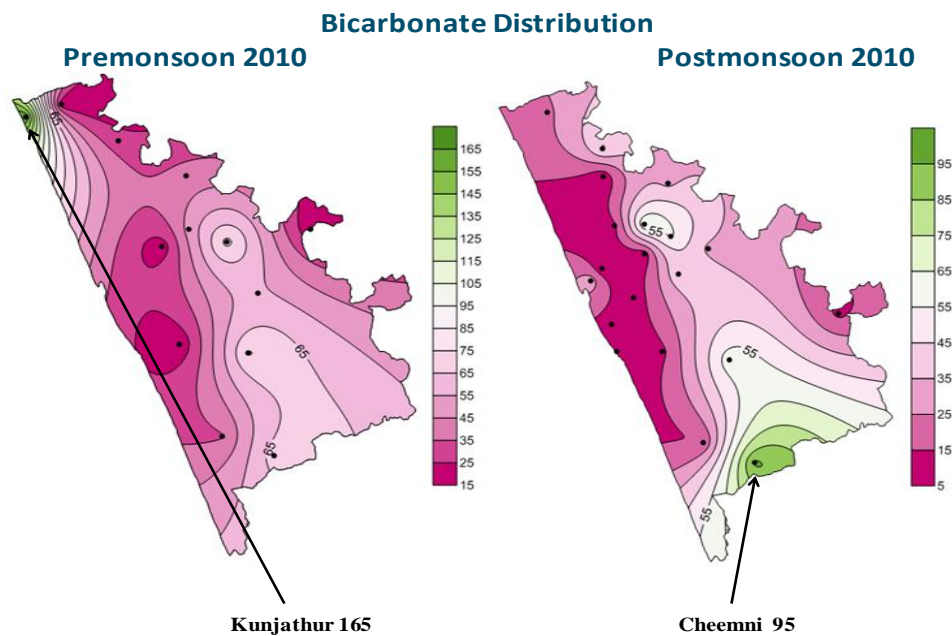


Figure 1g: Spatial variation of Bicarbonates in Groundwater of Kasaragod district (Year:2010)

Chlorides

In the district it is found that the chloride concentration is much below the permissible limits. The maximum chloride content observed in the ground water samples varied from 10 mg/l to 80 mg/l during pre-monsoon and 6 to 66 mg/l during post-monsoon of 2008. The observations made during the year 2010, in a limited number of wells showed that the chloride content varied between 4 and 56 mg/l in the pre-monsoon and 5 to 85 mg/l in the post-monsoon. Figures 1h and 1i show the variation of chlorides in Kasaragod district.

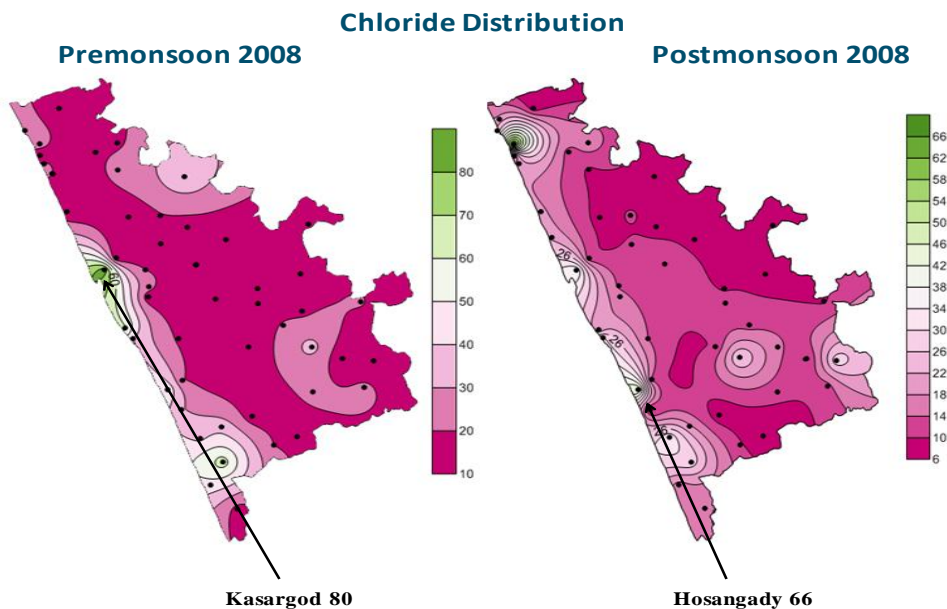


Figure 1h: Spatial variation of Chloride in Groundwater of Kasaragod district (Year:2008)

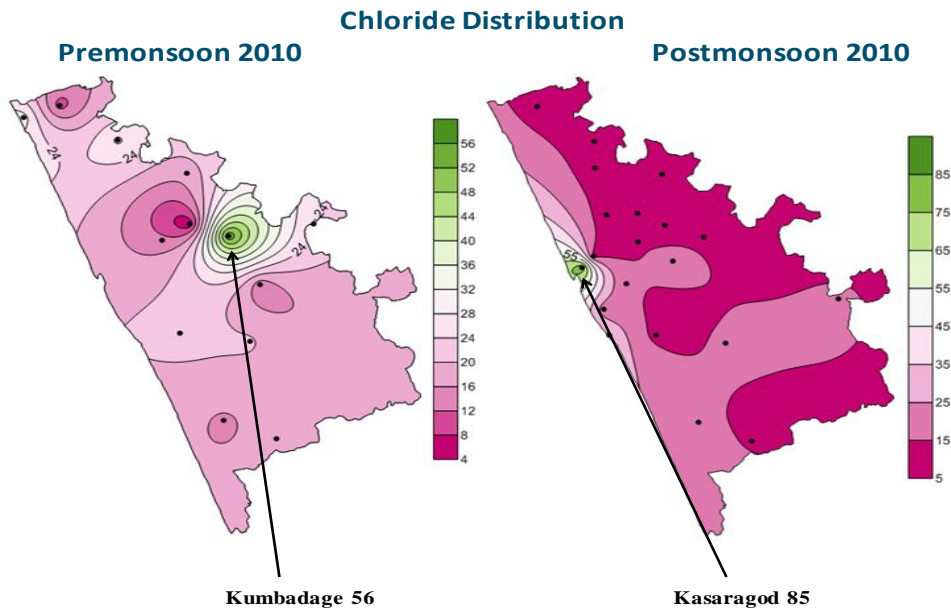


Figure 1i: Spatial variation of Chloride in Groundwater of Kasaragod district (Year:2010)

Fluoride

The maximum concentration of fluoride observed was 0.84 mg/l during pre-monsoon and 1.45 mg/l during post-monsoon 2010. Fluoride concentration was found to be within the permissible limit during all the seasons. However, there is a sudden increase in the concentration of fluoride during post-monsoon, which could be due to the external sources entering wells due to overland flow. Figure 1j shows the spatial distribution of fluoride in Kasaragod district.

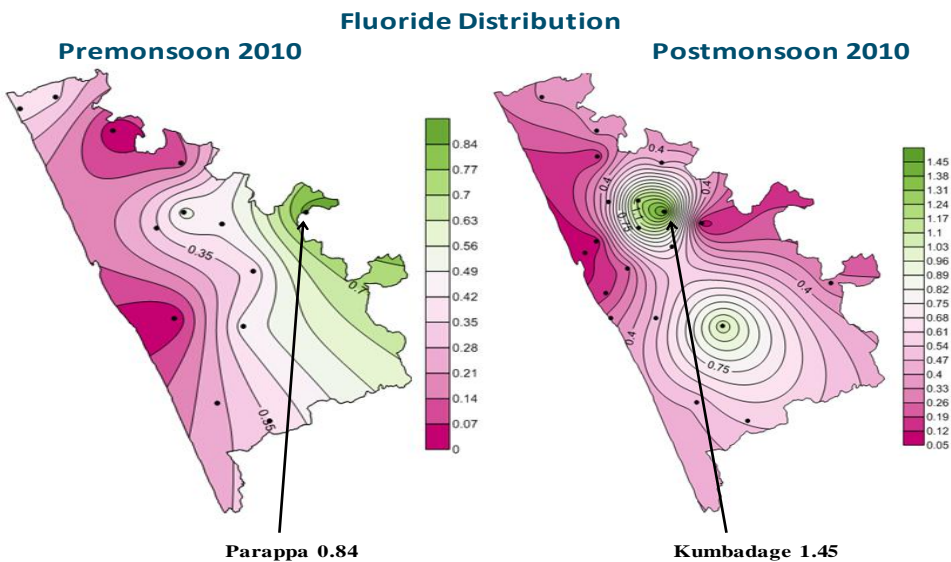


Figure 1j: Spatial variation of Fluoride in Groundwater of Kasaragod district (Year:2010)

Sulphates

The sulphate concentration ranged from 0.2 mg/l to 5.4 mg/l during pre-monsoon and in the post-monsoon, it varied between 0.8 mg/l and 12.8 mg/l. The increase in sulphate during the post-monsoon is a clear indication of external inputs brought by rainwater. Figure 1k shows the variation of sulphates

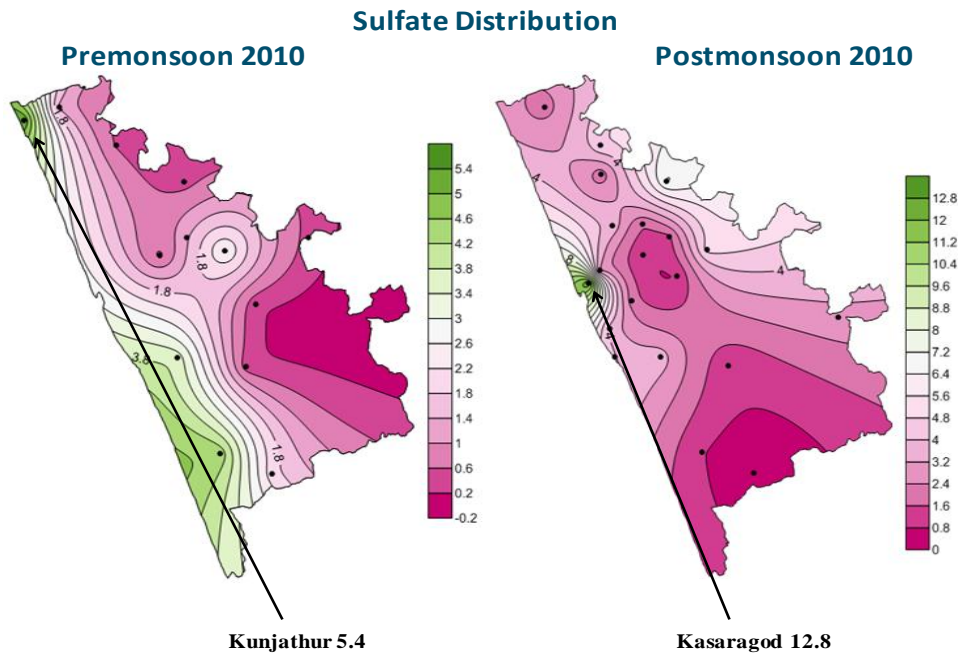


Figure 1k: Spatial variation of Sulphates in Groundwater of Kasaragod district (Year:2010)

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.3 mg/l to 8.4 mg/l during pre-monsoon and in the post monsoon it ranges between 0.8 mg/l and 8.8 mg/l. Therefore, it is further confirms that there is no scope for ground water pollution at this stage. Figure 1l shows the variation of nitrates in Kasaragod district in the year 2010.

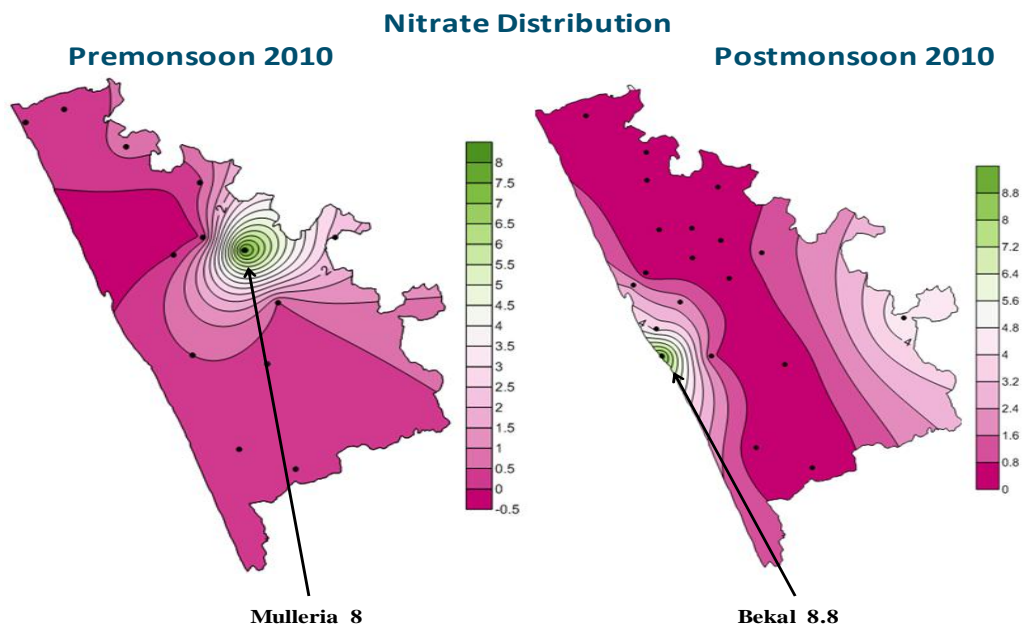


Figure 1l: Spatial variation of Nitrate in Groundwater of Kasaragod district (Year:2010)

Total Hardness

Total hardness of the water samples varied from less than 20 mg/l to more than 180 mg/l during pre-monsoon and 10 mg/l to 150 mg/l in the post-monsoon of year 2008. Analysis carried out during the year 2010 showed a decline showing the variation between 20 mg/l and 70 mg/l (pre-monsoon) and 15 mg/l to 75 mg/l (post-monsoon). The seasonal variation of total hardness is represented in Figures 1m & 1n. Total hardness showed a very high positive correlation with calcium and magnesium suggesting the major contributor of hardness.

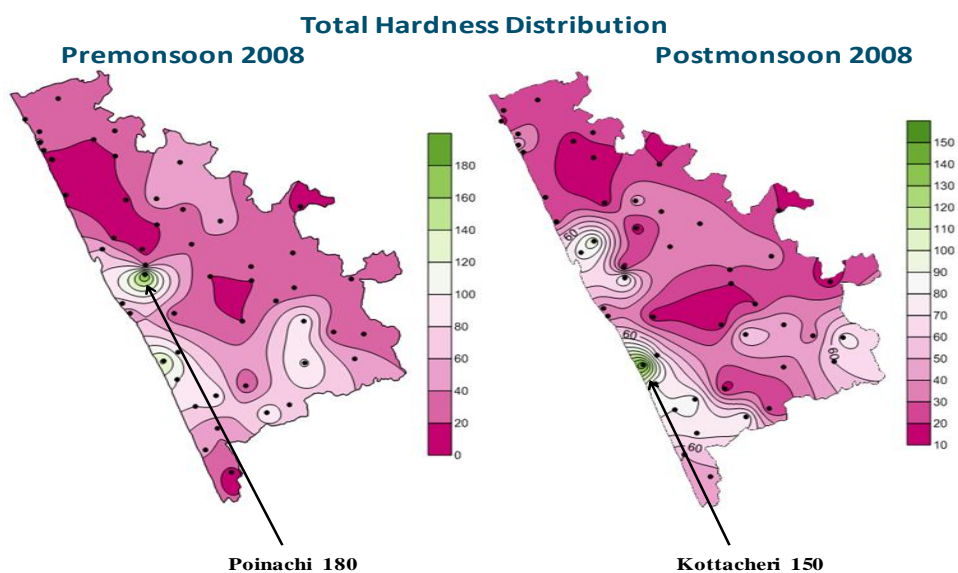


Figure 1m: Spatial variation of Total hardness in Groundwater of Kasaragod district (Year:2008)

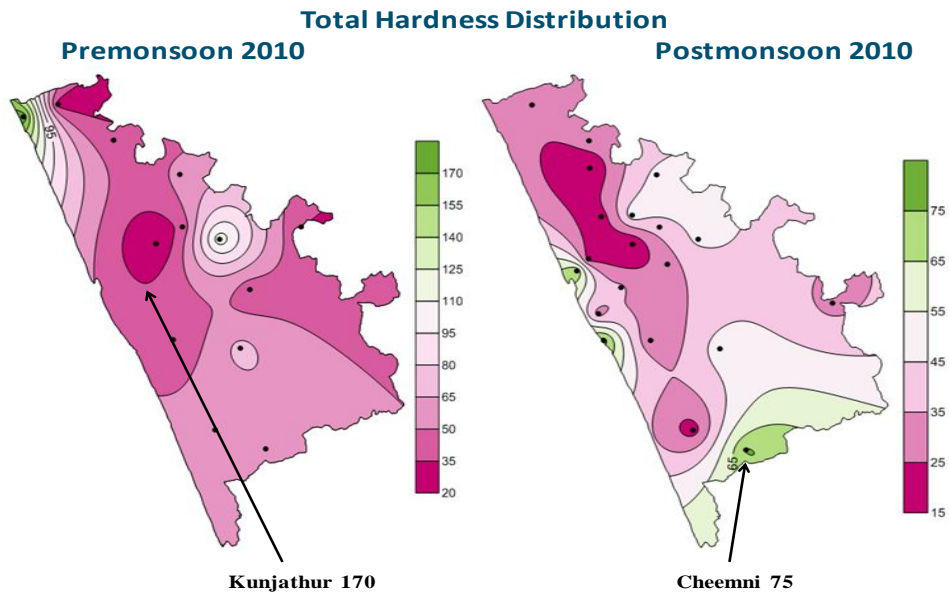


Figure 1n: Spatial variation of Total Hardness in Groundwater of Kasaragod district (Year:2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (fig.1o & 1p). It is observed that both calcium and magnesium concentrations are much below the permissible limit. The concentration of calcium varies between 4 mg/l and 31 mg/l during pre-monsoon and in the post monsoon it varies from 2 mg/l to 18 mg/l. The concentration magnesium varies from 2 mg/l to 26 mg/l during pre-monsoon and 0.5 mg/l to 11.7 mg/l in the post-monsoon of 2010. It is also noticed that the proportion of magnesium concentration is relatively higher than normally expected.

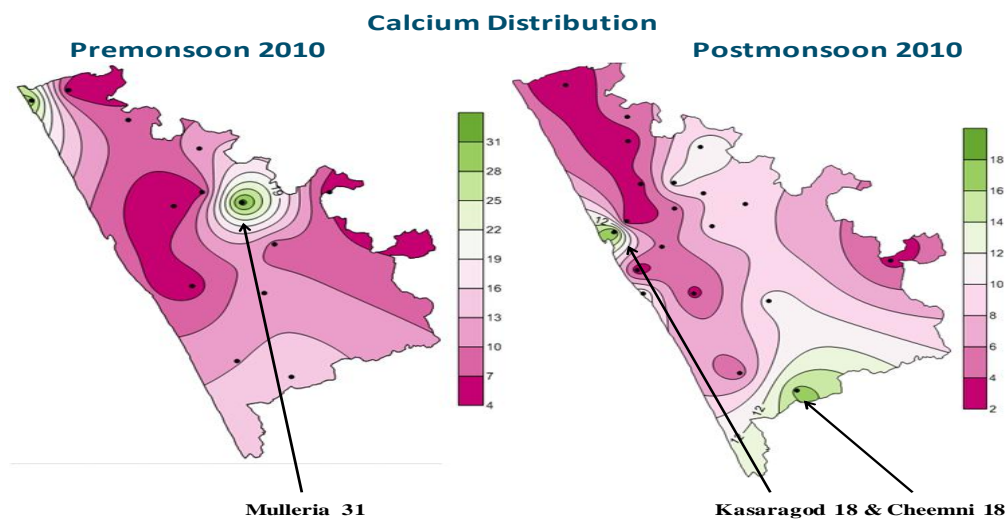


Figure 1o: Spatial variation of Calcium in Groundwater of Kasaragod district (Year:2010)

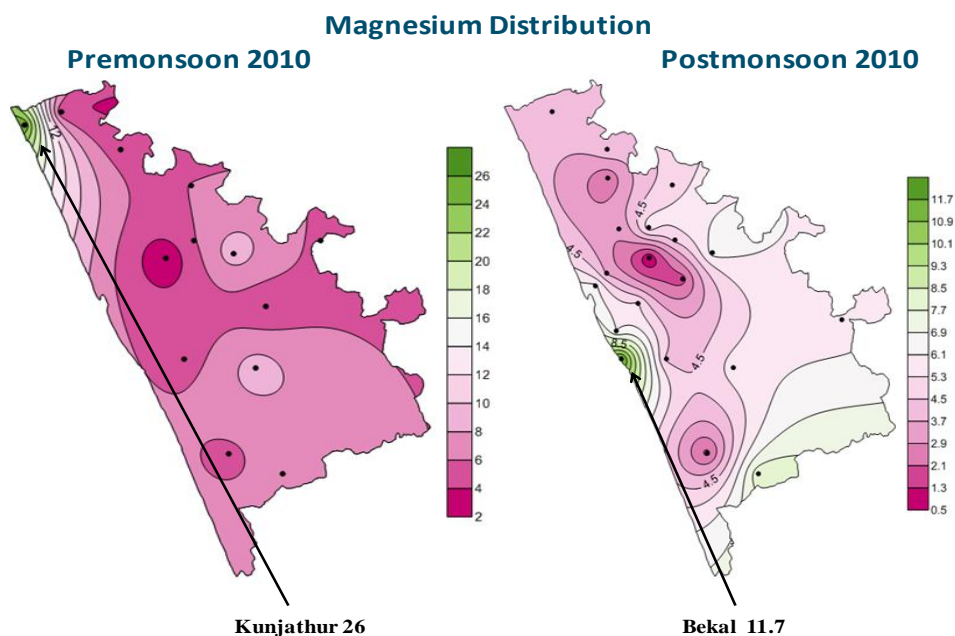


Figure 1p : Spatial variation of Magnesium in Groundwater of Kasaragod district (Year:2010)

Sodium and Potassium

Analysis of sodium concentration in the ground water samples from 2008 to 2010, shows that there is no significant change in the content during the study period. The observed concentration is much below the permissible ranges. Similar observation was found in the case of potassium also. The concentration of sodium varies between 2.0 mg/l to 50 mg/l, during pre-monsoon and 2 mg/l to 42 mg/l during post-monsoon of 2008. A drastic reduction in the concentration of sodium was noticed in the year 2010. During the year 2010, concentration varied from 1 mg/l to 29 mg/l (pre-monsoon) and 2 mg/l to 36 mg/l (post-monsoon). The potassium concentration varied from 0.4 mg/l to 4.9 mg/l during the pre-monsoon and 0.5 mg/l to 7.5 mg/l during post-monsoon 2010. The seasonal variation of sodium and potassium concentration is represented in figures 1q & 1r.

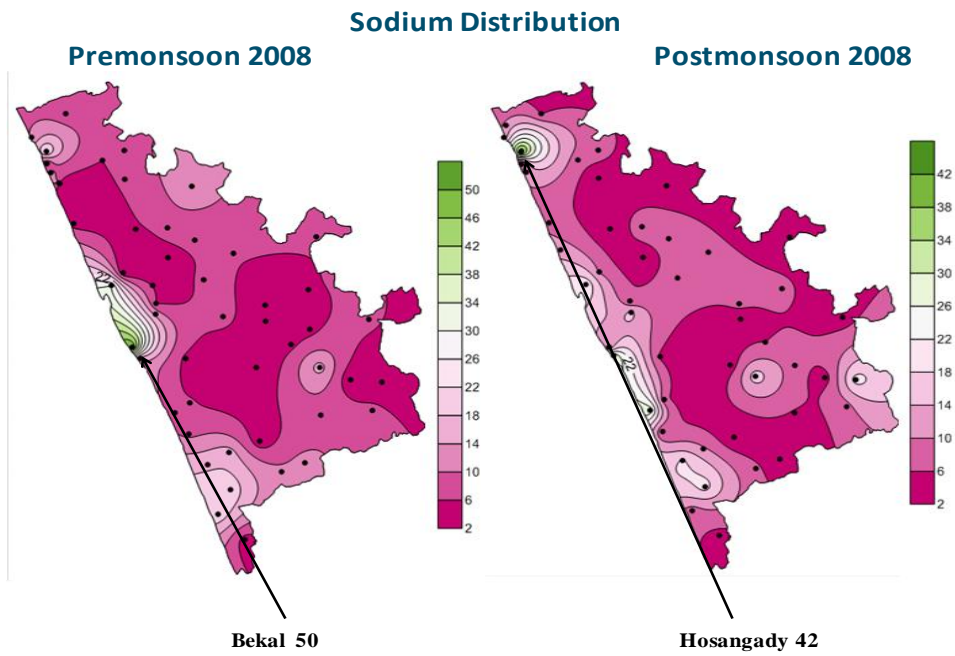


Figure 1q : Spatial variation of Sodium in Groundwater of Kasaragod district (Year:2008)

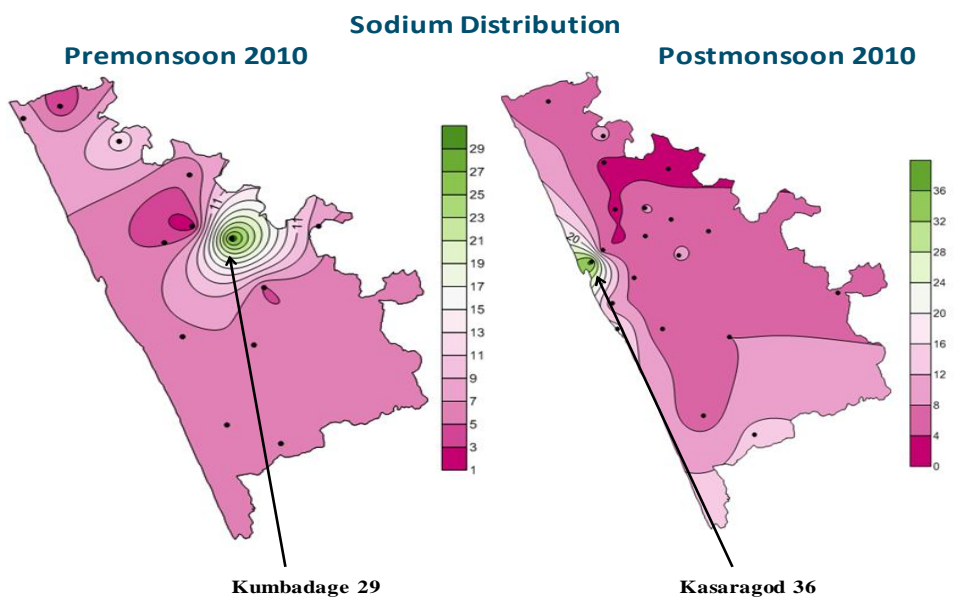


Figure 1r: Spatial variation of Sodium in Groundwater of Kasaragod district (Year:2010)

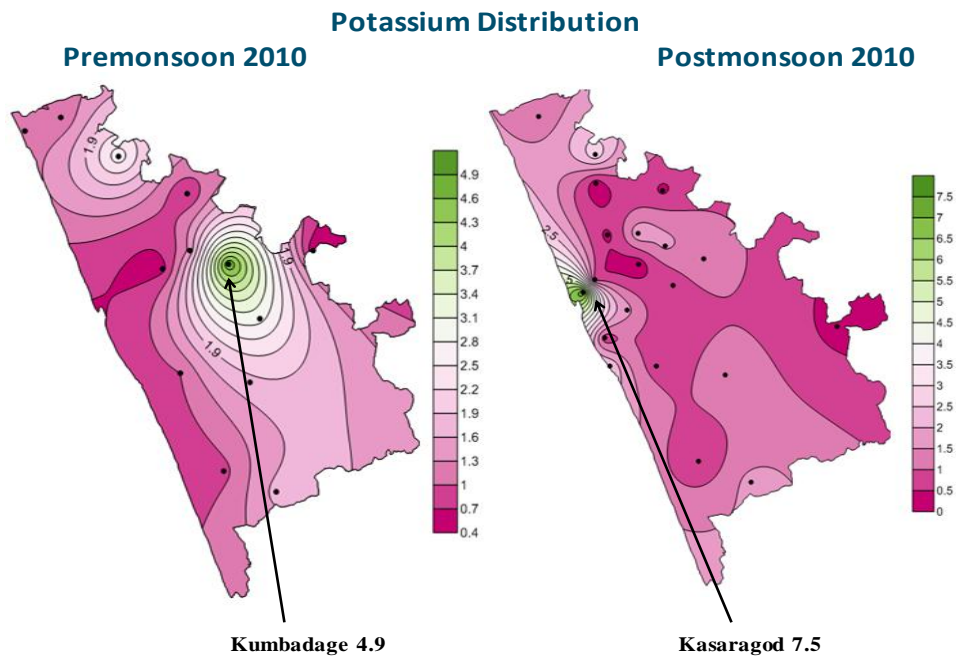


Figure 1s: Spatial variation of Potassium in Groundwater of Kasaragod district (Year:2010)

Iron

The excess iron is one of the most common ion which is present in excess in ground water of Kerala. The maximum concentration of iron in the study area during 2008 is found to vary from 0.5 mg/l to 7 mg/l in the pre-monsoon and 0.5 mg/l to 9.3 mg/l during post-monsoon. In the year 2010, concentration showed variation between 0.4 mg/l and 8.1 mg/l during pre-monsoon and 0.2 mg/l to 6.5 mg/l in the post-monsoon. This wide spread occurrence of iron in this part of the state is quite common as the rocks are iron rich laterites extended over large areas.

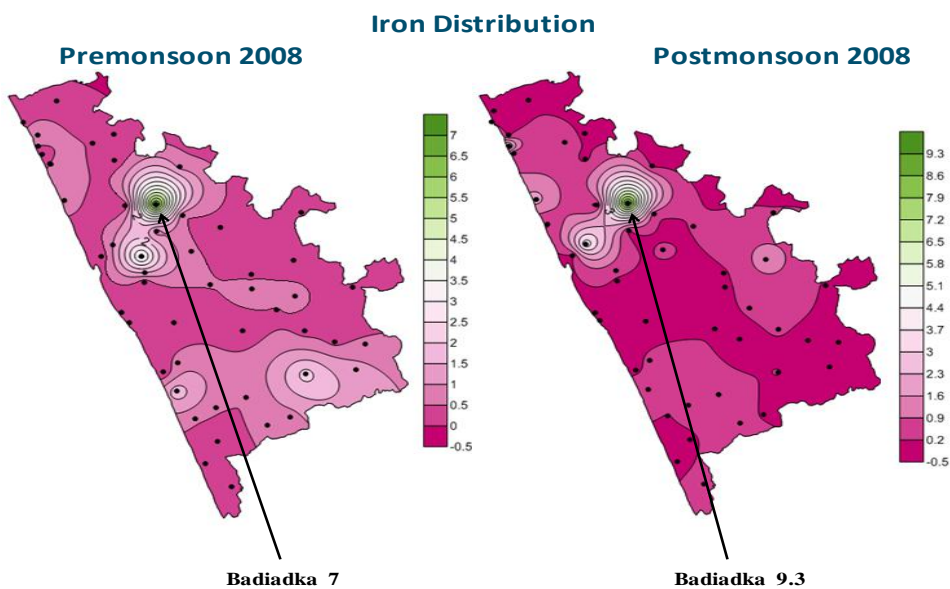


Figure 1t: Spatial variation of Iron in Groundwater of Kasaragod district (Year:2008)

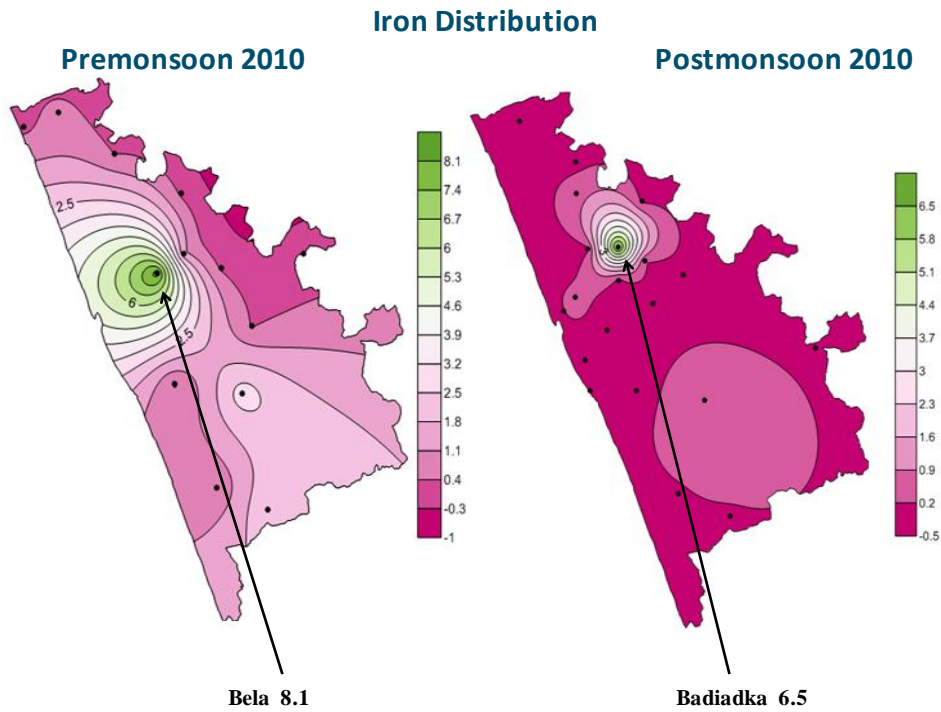


Figure 1u: Spatial variation of Iron in Groundwater of Kasaragod district (Year:2010)

Table 1e to 1h shows the correlation between various anions and cations during the pre-monsoon and post-monsoon of 2008 and 2010.

Table 1e: Correlation between measured water quality parameters of Kasargod (pre-monsoon, 2008)

Parameters	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	0.122	1				
TH	0.194	0.791	1			
Cl	-0.218	0.689	0.355	1		
Na	0.08	0.027	-0.013	0.07	1	
Fe	-0.068	0.1	0.211	-0.113	-0.053	1

Table 1f: Correlation between measured water quality parameters of Kasaragod post-monsoon (2008)

Parameters	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	-0.023	1				
TH	0.196	0.868	1			
Cl	-0.237	0.759	0.409	1		
Na	-0.165	0.839	0.502	0.929	1	
Fe	0.261	0.009	0.113	-0.127	-0.066	1

The correlation (Table 1g & h) between the parameters showed a slightly higher value as compared to the pre-monsoon due to the improvement of some of the parameters due to dilution effect.

Table 1g : Correlation Premonsoon 2010

parameters	pH	EC	TH	ALK	TDS	CO ₂	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F
pH	1														
EC	0.850	1													
TH	0.836	0.961	1												
ALK	0.797	0.864	0.948	1											
TDS	0.849	1.000	0.961	0.864	1										
CO ₂	0.740	0.942	0.944	0.865	0.942	1									
HCO ₃	0.805	0.849	0.935	0.998	0.849	0.836	1								
Cl	0.650	0.787	0.609	0.395	0.787	0.668	0.377	1							
SO ₄	0.435	0.550	0.638	0.538	0.550	0.623	0.511	0.277	1						
NO ₃	0.430	0.578	0.363	0.141	0.578	0.472	0.128	0.863	0.097	1					
Ca	0.895	0.956	0.929	0.819	0.956	0.884	0.813	0.762	0.557	0.613	1				
Mg	0.667	0.837	0.935	0.945	0.837	0.875	0.928	0.380	0.631	0.073	0.736	1			
Na	0.633	0.703	0.506	0.297	0.703	0.583	0.284	0.967	0.174	0.928	0.725	0.226	1		
K	0.630	0.478	0.314	0.242	0.478	0.353	0.255	0.694	-0.049	0.742	0.558	0.037	0.810	1	
F	-0.106	0.168	0.093	0.129	0.168	0.122	0.132	0.010	-0.185	0.249	0.051	0.121	0.013	-0.048	1
Fe	-0.285	-0.274	-0.274	-0.165	-0.273	-0.217	-0.157	-0.266	-0.293	-0.236	-0.260	-0.252	-0.206	-0.23	0.03

Table 1h: Correlation matrix between various parameters during post-monsoon, 2010.

Table 1h: Correlation Postmonsoon 2010																
	pH	EC	TH	ALK	TDS	CO ₂	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1															
EC	0.046	1														
TH	0.055	0.976	1													
ALK	0.396	0.885	0.863	1												
TDS	0.046	1.000	0.976	0.885	1											
CO ₂	0.34	0.966	0.925	0.833	0.966	1										
HCO ₃	0.401	0.879	0.855	1.000	0.879	0.826	1									
Cl	-0.037	0.983	0.944	0.805	0.983	0.957	0.798	1								
SO ₄	0.035	0.982	0.963	0.834	0.982	0.971	0.826	0.974	1							
NO ₃	-0.417	0.356	0.455	0.183	0.356	0.239	0.167	0.335	0.336	1						
Ca	0.302	0.713	0.784	0.784	0.713	0.555	0.779	0.634	0.677	0.546	1					
Mg	0.020	0.977	0.932	0.885	0.977	0.970	0.881	0.948	0.952	0.307	0.621	1				
Na	-0.023	0.979	0.941	0.817	0.979	0.942	0.812	0.993	0.958	0.324	0.635	0.942	1			
K	0.013	0.970	0.920	0.830	0.970	0.993	0.825	0.969	0.969	0.200	0.539	0.972	0.961	1		
F	0.358	0.155	0.104	0.411	0.155	0.175	0.420	0.095	0.086	-0.309	0.160	0.192	0.106	0.179	1	
Fe	0.156	0.001	0.001	0.145	0.001	-0.02	0.120	-0.031	-0.047	-0.116	0.058	0.028	-0.017	-0.010	0.382	1

Classification of Groundwater

The most commonly methods for ground water classification is Piper's trilinear and Chaddas' diagram. As there were limited parameters monitored during 2008 and 2009, previous data of the district have been screened and used for classification. Figures 1v and 1w shows the Piper's classification of ground water in the year 2007.

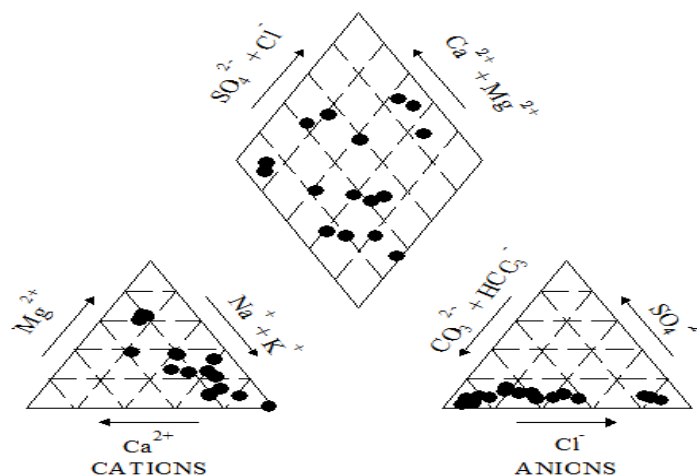


Figure 1v: Piper's classification of Ground water of Kasaragod district (Pre-monsoon 2007)

In the pre-monsoon water samples, it is found that 37.5% falls under group nine indicating no one cation-anion pair exceeds 50%. The second dominating group (25%) is Area 5 which

shows carbonate hardness exceeds 50%, i.e. chemical properties of the water are dominated by alkaline earths and weak acids. About 18.75% of the samples are covered in area 4. This indicates that strong acids exceed weak acids. The area 7 which covers 12.5% shows that non-carbonate alkali exceeds 50%, i.e. chemical properties are dominated by alkalies and strong acids. Area 8 (6.25%) is an indication of carbonate alkali exceeds 50%.

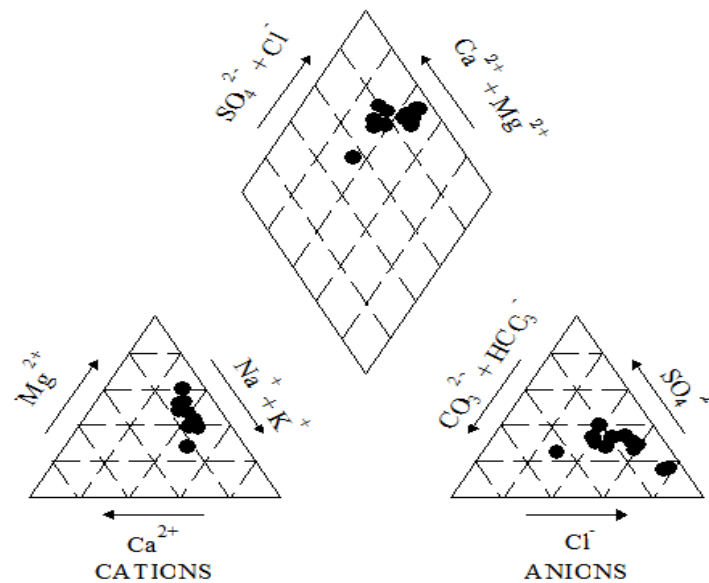


Figure 1w: Piper's classification of Ground water of Kasaragod district (Post-monsoon 2007)

Post-monsoon samples of the district shows that majority of the samples, 75% of the samples fall under area 4 indicating that strong acids exceed weak acids. 25% of the samples belong to area 7, where the non-carbonate exceeds 50%.

Figures 1x and 1y show the Piper's classification of groundwater during the year 2010.

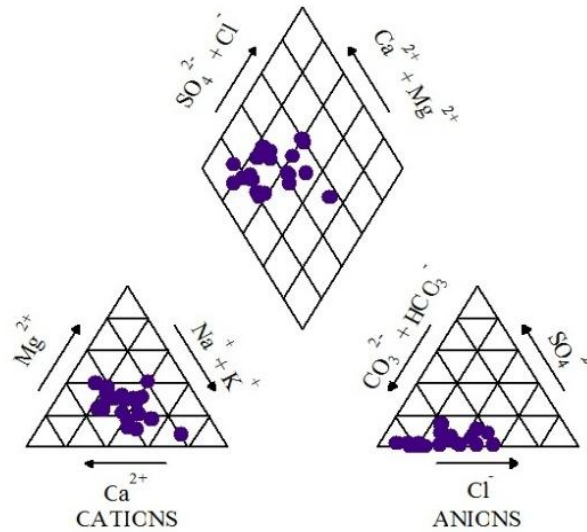


Figure 1x: Piper's classification of Ground water of Kasaragod district (Pre-monsoon 2010)

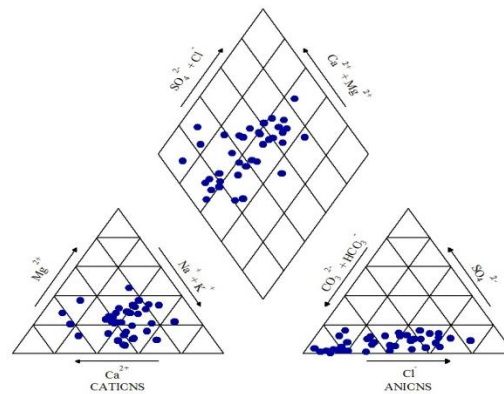


Figure 1y: Piper's classification of Ground water of Kasaragod district (Post-monsoon 2010)

According to Chadhas's classification, the ground water samples of Pre-monsoon, can be classified under following category.

Area 8: Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions represent Na- HCO₃ type, Na dominant HCO₃ type, or HCO₃ – dominant Na type waters. This area is followed by area 5 (25%), i.e. alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. 18.75% area is covered by alkaline earths and strong acidic anions and it is followed by alkali metals exceed alkaline earth's and strong acidic anions exceed weak acidic anions.

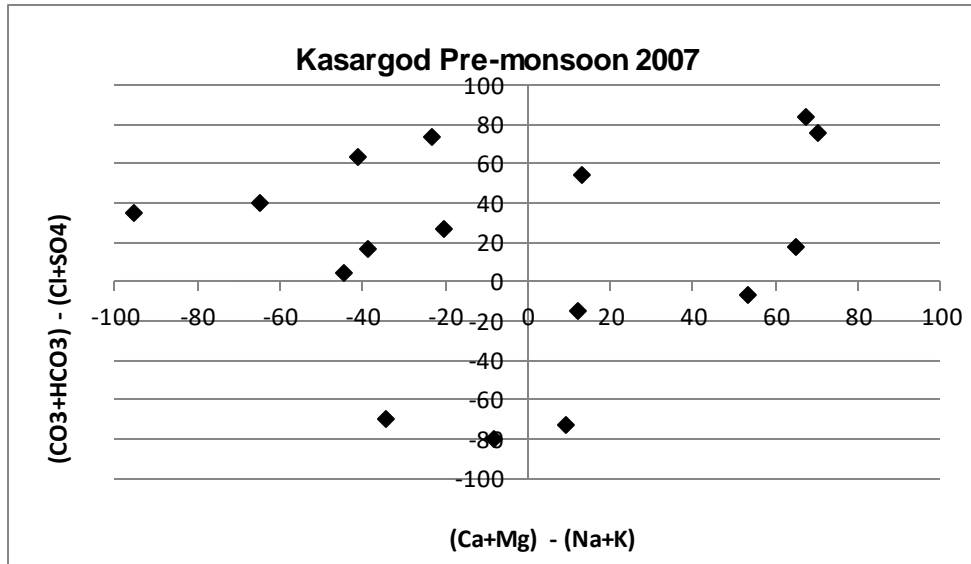


Figure 1z: Chadha's diagram of Kasargod district (Pre-monsoon, 2007)

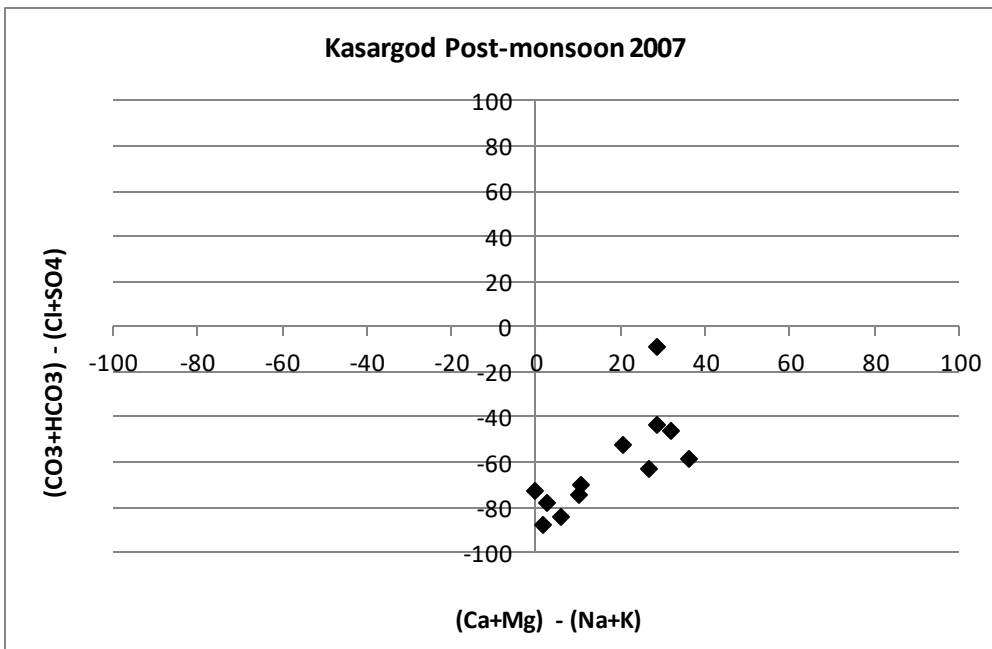


Figure 1zz: Chadha's diagram of Kasargod district (Post-monsoon, 2007)

During the post-monsoons season, it is found that more than 90% falls under area 6 indicating Ca- Mg-Cl type, i.e. Ca – Mg dominant Cl type or Cl- dominant Ca Mg type waters. Only about 8% area indicated alkali metals exceed alkaline earths.

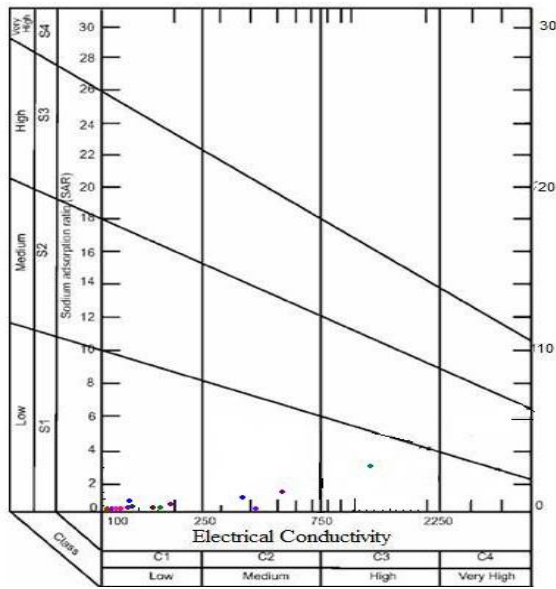


Figure 1aa: USSL classification of Ground water of Kasaragod district (Pre-monsoon 2010)

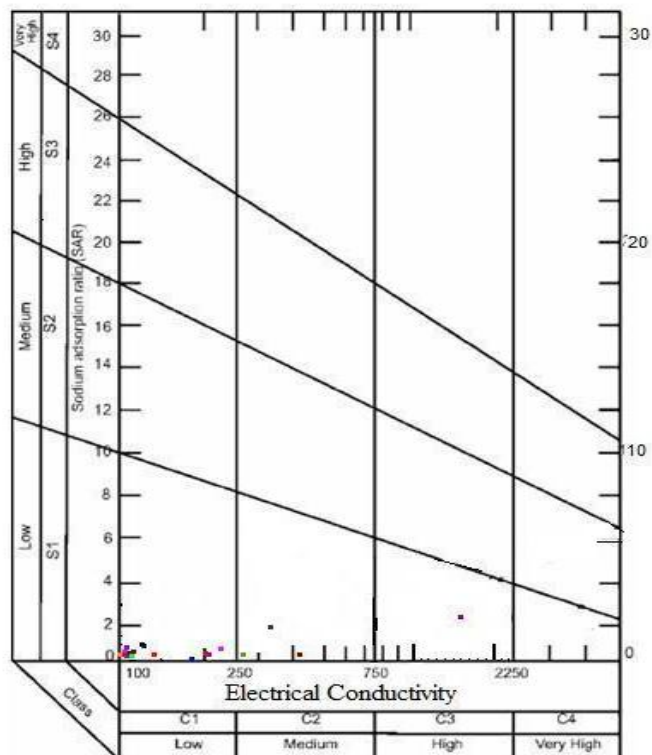


Figure 1bb: USSL classification of Ground water of Kasaragod district (Post-monsoon 2010)

Heavy Metals in Groundwater of Kasaragod District

The heavy metals were determined for selected wells in Kasaragod district. Five wells have been identified based on field investigations which are most prone to heavy metal contamination. Though there are indications of heavy metal presence in some selected wells, no contamination is observed in four of the five wells observed. However, in a well (QKSDO1) the contamination of Cadmium was noticed.

Well No	Ortho Phosphate	Zinc	Cadmium	Arsenic	Copper	Lead	Mercury	Nickel
QKGDO12	0.04	0.556	0/0.01	0/0.05	0.208	0.024	0	0
QKSDO 1	0.03	0.491	0.04	0	0.016	0.021	0	0.0047
QKSDO 14	0.04	4.14	0	0	0.035	0.11	0	0.0053
QKSDO 15	0.04	3.226	0	0	0	0.01	0	0
QKSDO 16	0.03	0.453	0.005	0	0.011	0.015	0	0.0024

2.0 GROUNDWATER QUALITY OF KANNUR DISTRICT

2.1 General features and Characteristics of the District

Kannur (Cannanore) district is one of the northern maritime districts of Kerala. It covers an area of 2966 sq km bounded by the North latitudes 11°40'00" and 12°20'27" and East longitudes 75°10'00" and 75°56'30". It is bounded by Kasaragod district in the north, Kozhikode district in the south, Coorg district of Karnataka and Wayanad district in the east and the Lakshadweep Sea in the west. Kannur district is divided into 3 taluks (Taliparambu, Kannur and Thalassery), 5 municipalities (Payyanur, Taliparambu, Kannur, Azhikode and Koothuparambu), 9 blocks (Payyanur, Kannur, Thalassery, Taliparambu, Edakkad, Irikkur, Iritty, Peravur and Koothuparambu), 81 panchayats and 129 villages. Kannur district is mainly drained by the Valapattanam and Anjarakandy rivers. The other rivers are Kuppam, Mahe, Thalassery etc. Dendritic is the common drainage pattern. The Valapattanam river, which is the longest in the district originates from Brahmagiri Reserve forest in Coorg district of Karnataka. The drainage area of the river in Kerala is 1321 sq.km. The Anjarakandy river originates from the Kanoth Reserve forest. The drainage area of the river is 412 sq.km.

Kannur district has 16,835 ha. area under irrigation, which accounts about 3.24% of the gross irrigated area of the state. Kannur district is provided with one major irrigation project along with some minor irrigation projects. The major irrigation scheme of the district is Pazhassi project. The command area fixed for Pazhassi project was 11525 ha of land. However, only 8125 ha of land has been benefitted through this project. Ground water is also used for irrigation purposes. In addition to this, there are private tanks to facilitate the irrigation sector.

Rainfall & Climate

Kannur district receives a total annual rainfall of around 3453 mm. District experiences heavy rainfall during the South West monsoon season followed by North East monsoon. South West monsoon during June to September contributes 70 % of the total rainfall of the year. The northeast monsoon contributes only about 30%. The distribution of rainfall during year 2000 to 2005 is shown in Table 1. Rainfall is considerably less during the period from January to May. The highest monthly rainfall was received in the month of June 2003 and lowest in the month of March 2005 (CGWB District report).

Table 2a: Monthly rainfall in Kannur district (Period 2000-2005) Year

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
2000	37.4	-	4.4	81.8	286.4	916.2	674.1	587.6	74.9	411.8	52.0	131.6	3258.2
2001	-	-		69.1	340.4	1191.8	902.7	509.8	175.0	376.0	49.7	2.0	3616.5
2002	-	2.2		8.6	13.3	1117.5	369.5	621.8	171.0	646.0	52.0	22.3	3024.2
2003	9.3	-	97.4	101.9	194.7	1396.0	445.2	417.9	145.9	345.2	70.8	1.8	3226.1
2004		-			4.0	69.2	828.0	1097.4	1163.8	55.5	127.6	97.6	3443.1
2005	-	2.8	1.4	12.2	84.8	1108.5	944.0	611.0	589.6	389.0	60.9	606	3864.8

The year to year variability of annual rainfall is around 28.2%. In general, the rainfall increases from the coast to the eastern hilly regions. Kannur district falls under wet type of climate based on Thornthwaite's climatic classification.

Meteorological Parameters

Temperature

The temperature is more during the months of March to May and is less during December and January. The average mean monthly maximum temperature ranges from 28.4 to 36.9⁰ C and minimum temperature ranges from 19.7 to 23.9⁰ C.

Relative Humidity

Relative humidity is more during south west monsoon season (ie June to September). It is more during morning hours and is less during evening hours. Humidity ranges from 77 to 88 % in the district.

Evaporation

Evaporation is more during summer months of March to May and low during the months of June to November. The mean evaporation ranges from 2.6 to 5.7 mm/day.

Sunshine Hours

Generally good sunshine hours are recorded in the month of November to May. January to March records the maximum sunshine hours of more than 9.1 hours/day. The months of June to August records the minimum sunshine due to cloudy sky.

Wind

Wind speed ranges from 2.1 to 3.3 km per hour with mean speed of 2.6 km/hr. The wind speed is high during the period from March to June and low during the period from September to December.

Potential Evapotranspiration (PET)

The monthly PET ranges from 124.5 to 170.6 mm. PET values are lower than the monthly rainfall during the months of May to October indicating water surplus for possible recharge into groundwater regime during these months.

Geomorphology

Kannur district can be divided physiographically into three distinct geomorphologic units viz the coastal plains and lowlands in the western part, the central undulatory terrain comprising the midland region and eastern highland region. The coastal plains occurs as a narrow belt of alluvial deposits running parallel to the coast with a maximum width of about 15 km. Midland region forms a plateau land at certain places covered by a thick cover of laterites. The hilly tract in the eastern part consists of highly rugged terrains. The Ezhimala peak (259.69m) with the characteristic N-S alignment is a distinct physiographic unit in the coastal plains. Minor cliffs of laterite generally rising to an elevation of 50 to 60 m above mean sea level are found at Mahe, Thalasserry and Bekal coast. The midland region presents a plateau land covered by a thick cover of laterite. This is immediately to the east of the coastal strip, rising from 40 to 100 m above msl. The valleys in the plateau are gorge like and V shaped cut by youthful streams. The hilly tract along the eastern part of the district constitutes the highland region and is highly rugged. Development of bad land topography along the margins of the valley is a common feature observed in the district.

Soil types

There are mainly four types of soil observed in the district.

- (1) Lateritic soil
- (2) Brown hydromorphic soil
- (3) Coastal and river alluvium
- (4) Forest Loamy soil

(1) Lateritic soil – The predominant soil in the district is lateritic soil, which is the weathered product derived under humid tropical conditions. It occurs mainly in the midland and hilly areas characterized by rugged topography. They range from sandy loam to red loam.

(2) Brown hydromorphic soil – These are confined to the valleys between undulating topography in the midlands and in the low lying areas of the coastal strip in the district. These soils are brown in colour and the surface texture varies from sandy

loam to clay. They have been formed as a result of transportation and deposition of materials from adjoining hill slopes and also through deposition by rivers.

- (3) Coastal and river alluvium – The coastal alluvium is seen in the western coastal tract of the district. The coastal plain is characterized by secondary soils, which are sandy and sterile with poor water holding capacity. The width of the zone is more in the central part i.e., in the Kannur area and it is almost narrow in both north and southern areas of the district. The marshy soil in the coastal plain supports mangrove vegetation and is found at the estuaries and backwater extending inland along their courses. The soil is composed of recent deposits predominantly marine with some fluvial sediments along the coastline. These soils are immature with high sand content. River alluvium is found along river valleys cutting across the extensive lateritic soils. The soil is very deep with surface texture ranging from sandy loam to clay. It is fertile, having water holding capacity and plant nutrients which are regularly replenished during floods.

- (3) Forest Loamy soil – These soils are found in the eastern hilly areas of the district and are characterised by a surface layer rich in organic matter. They are generally acidic and are dark reddish brown to black in colour with loam to silty loam texture.

In Kannur district Groundwater occurs under phreatic conditions in weathered mantle of the crystalline rocks, laterites and unconsolidated coastal sediments. It occurs under semi confined to confined conditions in the deep-seated fractured aquifers of the crystalline rocks and Tertiary sediments.

The major rock types found are charnockites, pyroxene granulites, garnetiferous gneisses, hornblende biotite gneisses and schistose rocks overlain by Tertiaries and coastal alluvium along the coast ranging in age from Archaean to Recent. These rocks have undergone weathering and lateritisation. The hydrogeological units encountered in the district are (i) consolidated formations (weathered and fractured crystallines) (ii) Semi consolidated sediments equivalent to Warkalies of Southern Kerala and Laterite formations and (iii) unconsolidated formations (Recent alluvium occurring along the coast).

2.2 Ground Water Quality of Kannur district

The spatial and temporal distribution of various ions are discussed below.

PH

The pH values of the samples collected from selected locations of Kannur district varied from 6 to 7.6 during pre-monsoon and 6 to 8.1 during post-monsoon in the year 2008. In general, in majority of the places water was found to be acidic except in a small patch near to the eastern border. In order to understand the overall changes based on land use/land cover changes, analysis were also carried out during the year 2010. The analysis indicated that there is reverse distribution during the post-monsoon, i.e. larger areas exhibited neutral to alkaline water and in few localities acidic to neutral water. Therefore, it indicates the temporary nature of groundwater which depends mostly on the recharge factors. The seasonal variation of pH in waters during 2008 and 2010 are given in figures 2a & 2b.

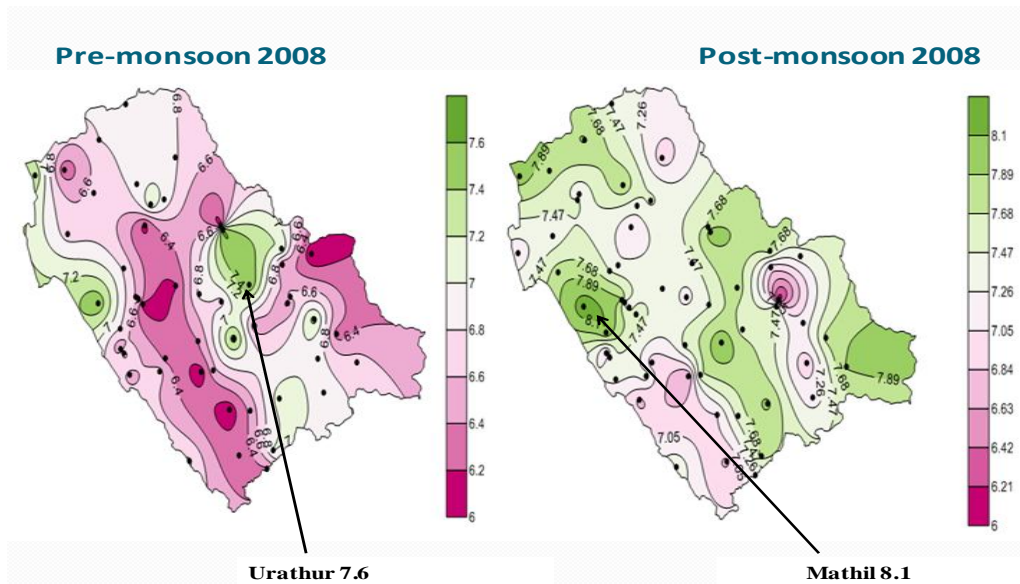


Figure 2a: Spatial variation of pH in Groundwater of Kannur district (Year:2008)

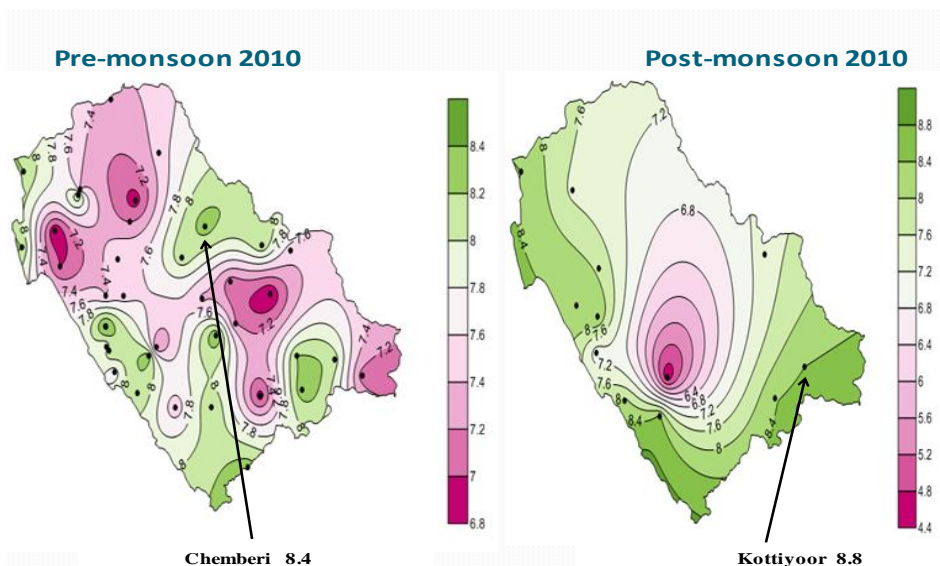


Figure 2b: Spatial variation of pH in Groundwater of Kannur district (Year:2010)

Electrical conductivity

Electrical conductivity of the samples varied from less than 70.0 micro-siemens/cm to 700 micro-siemens/cm during pre-monsoon of 2008. However, the highest value of 700 micro-siemens/cm was observed near the coastal area of Thalassery. In the post-monsoon season of 2008, the EC showed a decline which ranged between 60 micro-siemens/cm and 560 micro-siemens/cm. In the year 2010, during pre-monsoon, there was a considerable increase in the EC (maximum was 1000 micro-siemens/cm) was noticed at Mathil. During the post-monsoon, it was reduced to 310 micro-siemens/cm. This is one of the clear indications that the water is suitable for all purposes including drinking as per BIS specifications. Figures 2c & 2d show the variation of Electrical conductivity during 2008 and 2010.

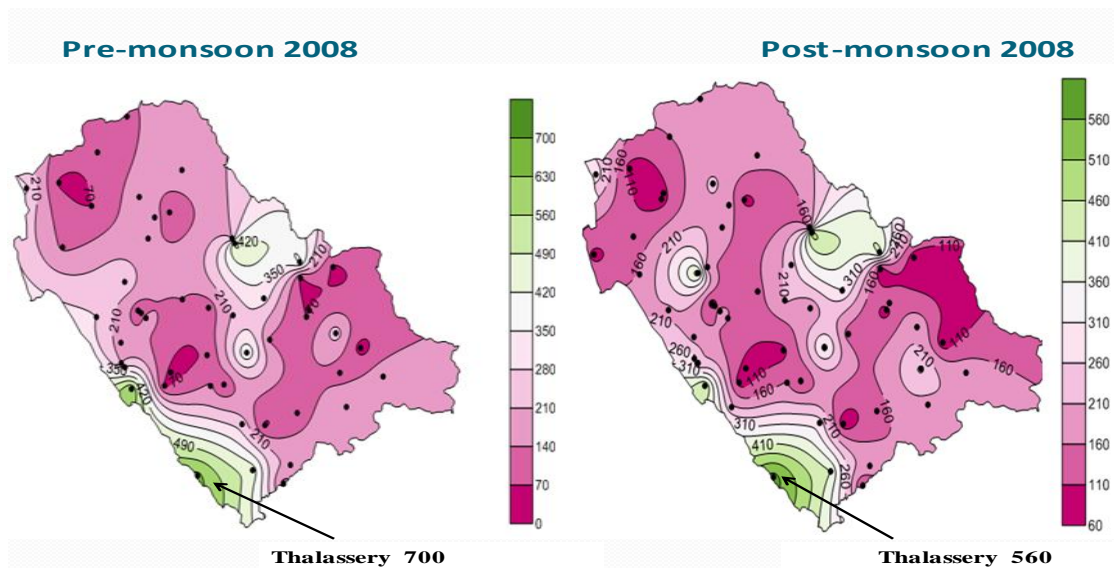


Figure 2c: Spatial variation of EC in Groundwater of Kannur district (Year:2008)

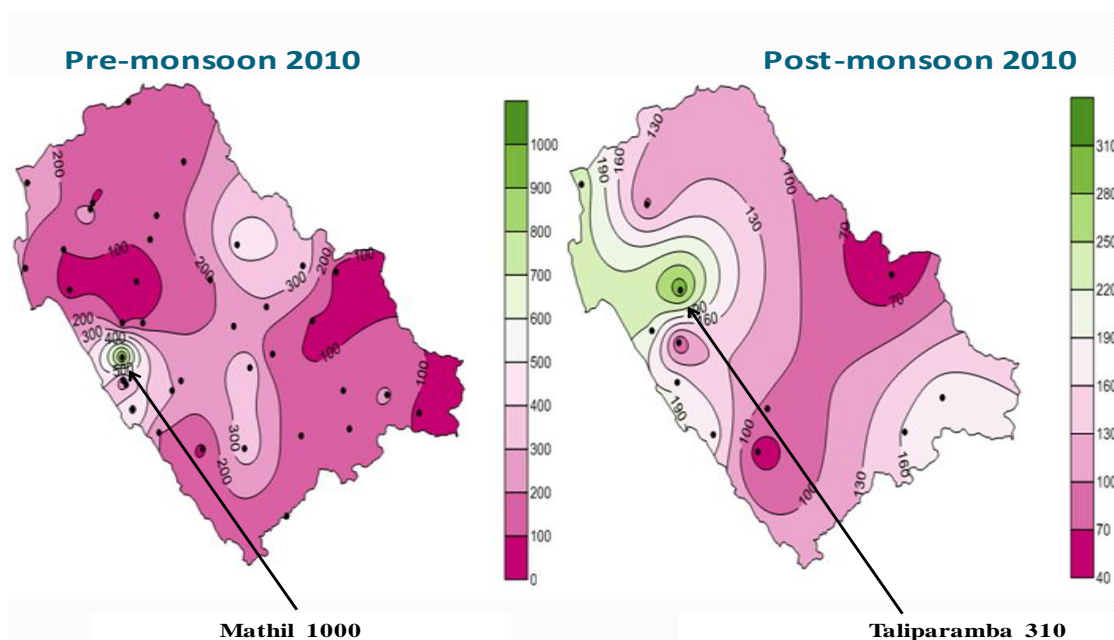


Figure 2d: Spatial variation of EC in Groundwater of Kannur district (Year:2010)
Total Dissolved Solids

The concentration of TDS during 2008 and 2010 were analysed and found that the values are much below the desired limits. The maximum concentration observed during pre-monsoon, was 570 mg/l however, in majority of the area it is found that TDS is below 220 mg/l. Maximum was observed at Mathil. In the post-monsoon Total Dissolved Solids observed was 180 mg/l in an isolated patch near the coastal region. The seasonal variation of TDS during 2010 is depicted in figure 2e.

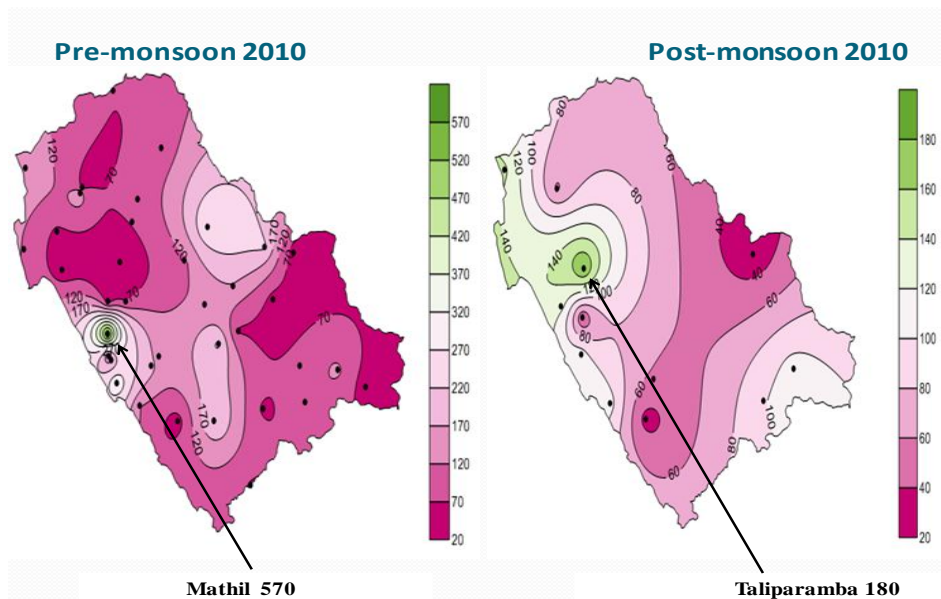


Figure 2e: Spatial variation of Total Dissolved Solids in Groundwater of Kannur district (Year:2010)

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 5 mg/l to 280 mg/l during pre-monsoon and 5 mg/l to 95 mg/l during the post-monsoon of 2010. It is found that there is considerable concentration of carbonates in some parts of the district. The carbonate concentration during pre-monsoon was even higher than 15 mg/l in a location close to the eastern border of the district and it showed a significant decline during the post-monsoon season (maximum was 7.4 mg/l). The concentration of bicarbonates is found to be almost equivalent to Total alkalinity. The variations were found between bicarbonates and alkalinity which need further evaluation. The Total alkalinity of the water samples were found to be within the permissible limit for all the samples as per BIS (1991). The distribution of carbonates, bicarbonates and total alkalinity are shown in figures 2f, 2g and 2h.

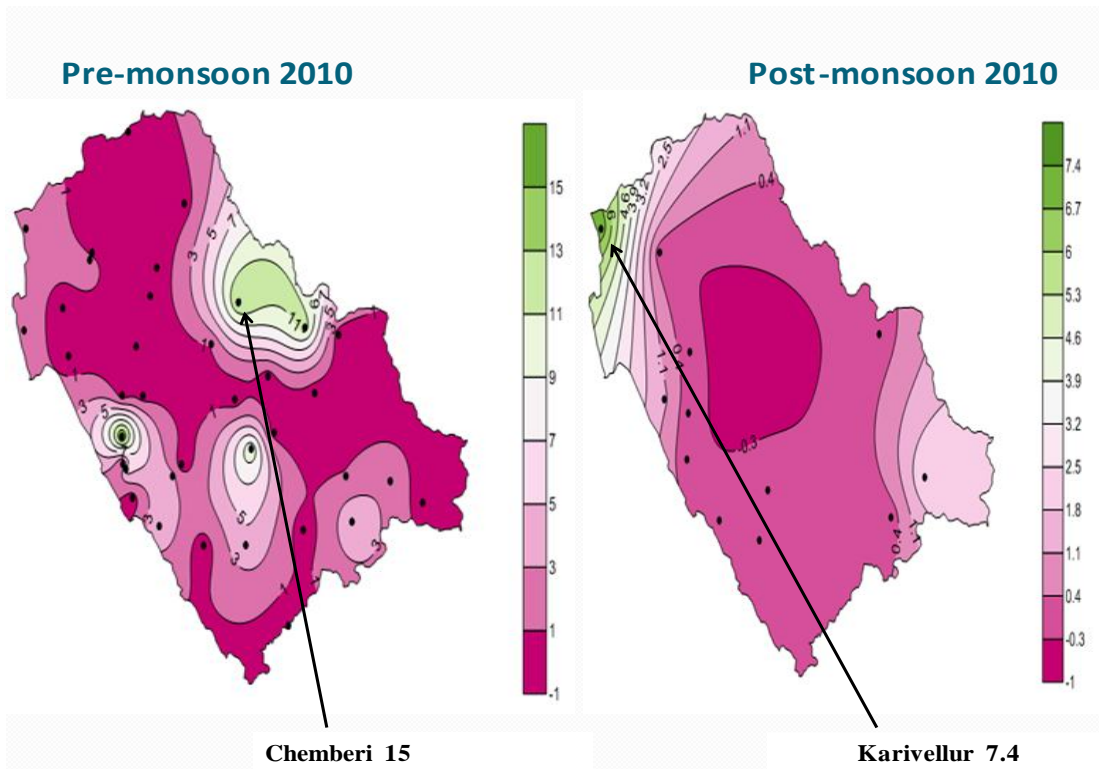


Figure 2f: Spatial variation of Carbonates in Groundwater of Kannur district (Year:2010)

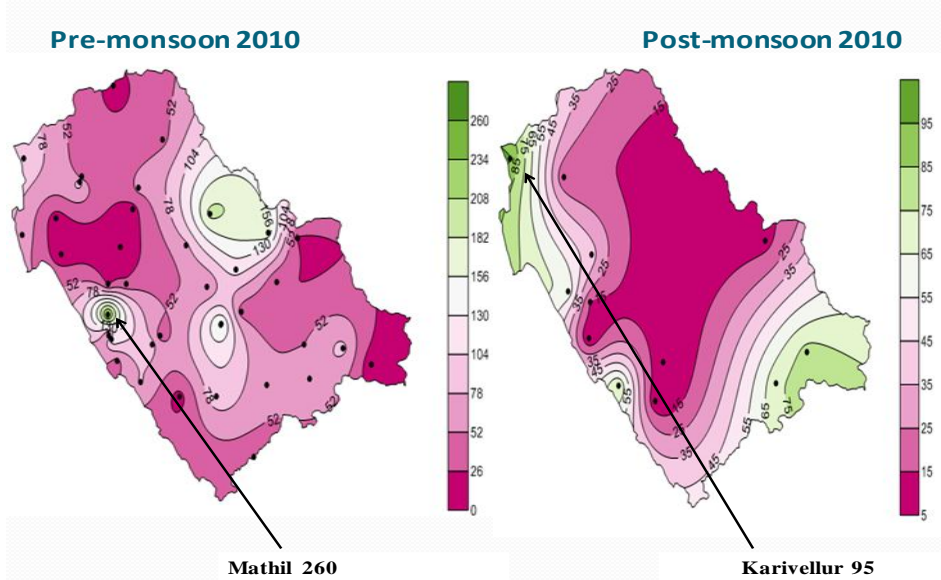


Figure 2g: Spatial variation of Bicarbonates in Groundwater of Kannur district (Year:2010)

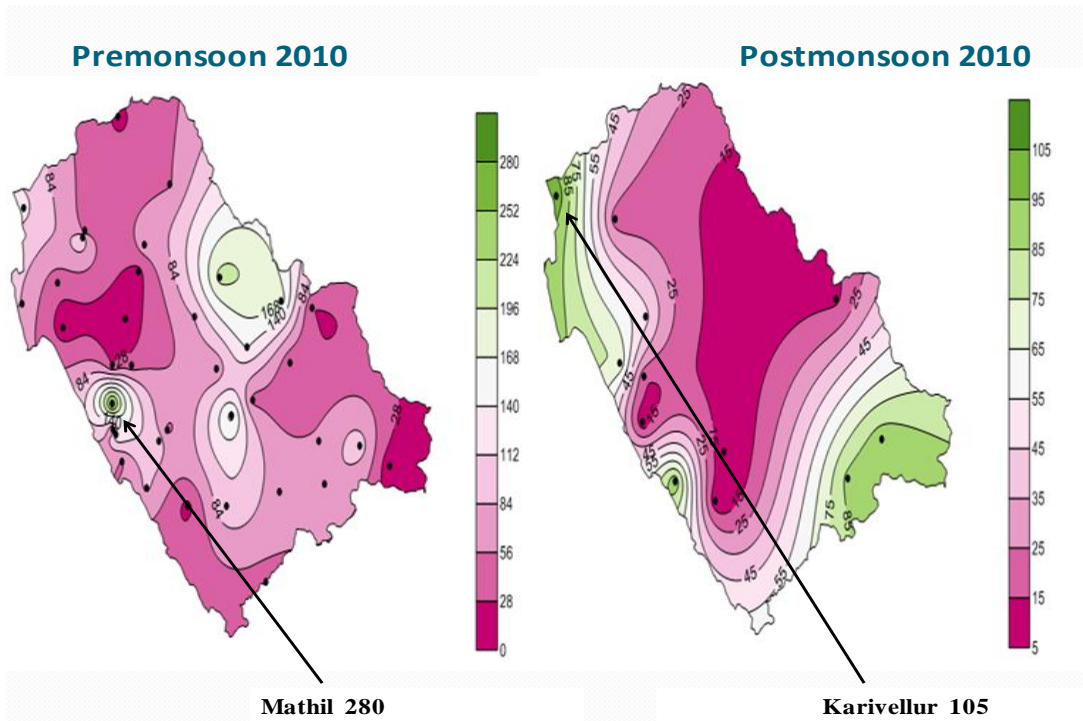


Figure 2h: Spatial variation of Total Alkalinity in Groundwater of Kannur district (Year:2010)

Chlorides

The chloride concentration in the groundwater samples of the district varied from 10 mg/l to a maximum of 82 mg/l during 2008 pre-monsoon and in the post-monsoon, it shows variation between 5 mg/l and 70 mg/l. However in 2010, the chloride concentration increased to 170 mg/l during pre-monsoon and showed a sharp decline to 42 mg/l during the post-monsoon, indicating the temporary nature of fluctuation. Figures 2i and 2j shows the spatial distribution of chloride in Kannur district.

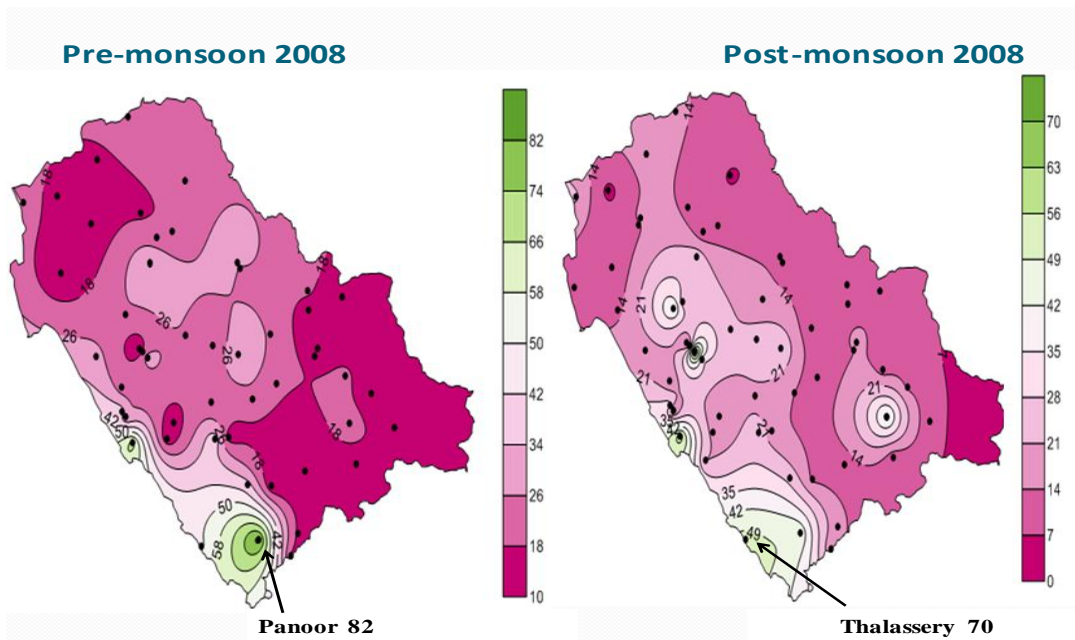


Figure 2i: Spatial variation of Chloride in Groundwater of Kannur district (Year:2008)

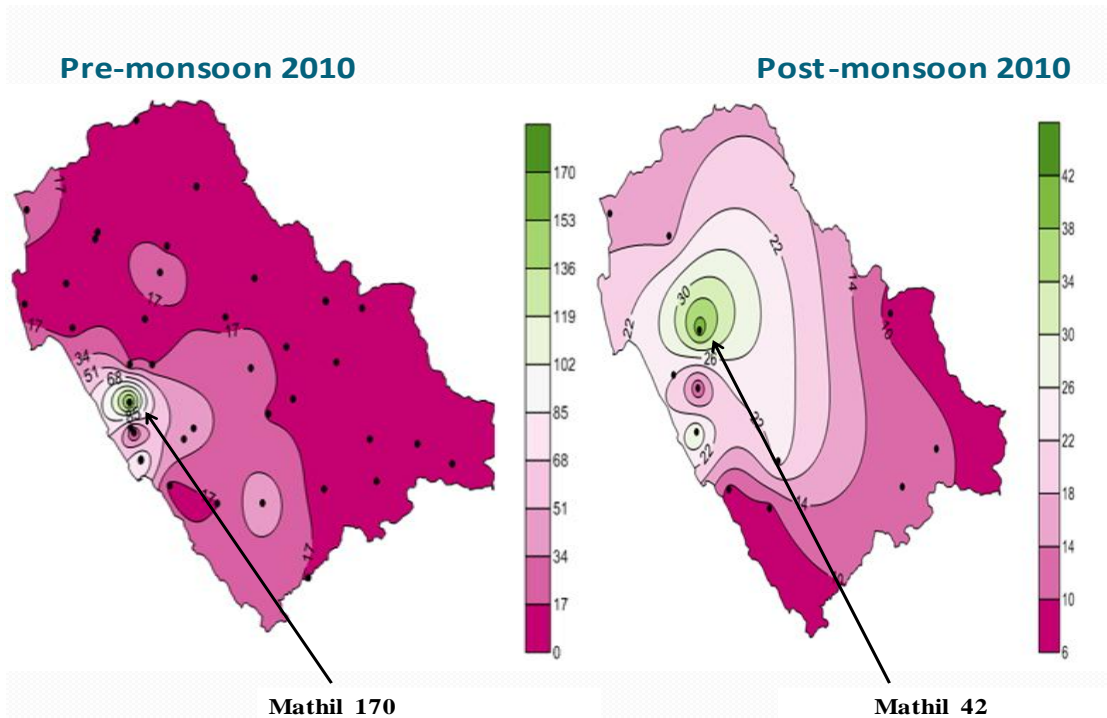


Figure 2j: Spatial variation of Chloride in Groundwater of Kannur district (Year:2010)

Fluoride

The maximum concentration of fluoride observed was 1.8 mg/l during pre-monsoon at Karivellur, a village on the north-western part of the district in the year 2010. In the post-monsoon highest concentration noticed was only 1.19 mg/l which was found in Ancharakandy village. In total, it is evident that the occurrence of fluoride is a seasonal phenomenon. However, it requires continuous monitoring of the wells in this part of the district. Fluoride concentration was found to be within the permissible limit during all the seasons. Figure 2k shows the variation of fluorides in Kannur district.

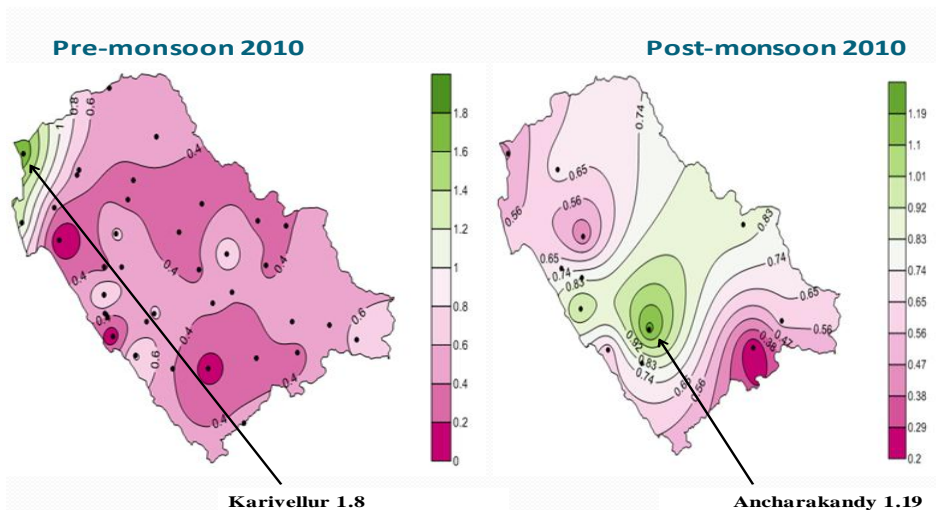


Figure 2k: Spatial variation of Fluoride in Groundwater of Kannur district (Year:2010)

Sulphates

The sulphate concentration ranged from less than 1 mg/l to 37 mg/l during pre-monsoon and in the post-monsoon, it varied between less than 1 mg/l and 6 mg/l. It is found that the variation of sulphate is quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 2l shows the variation of sulphates.

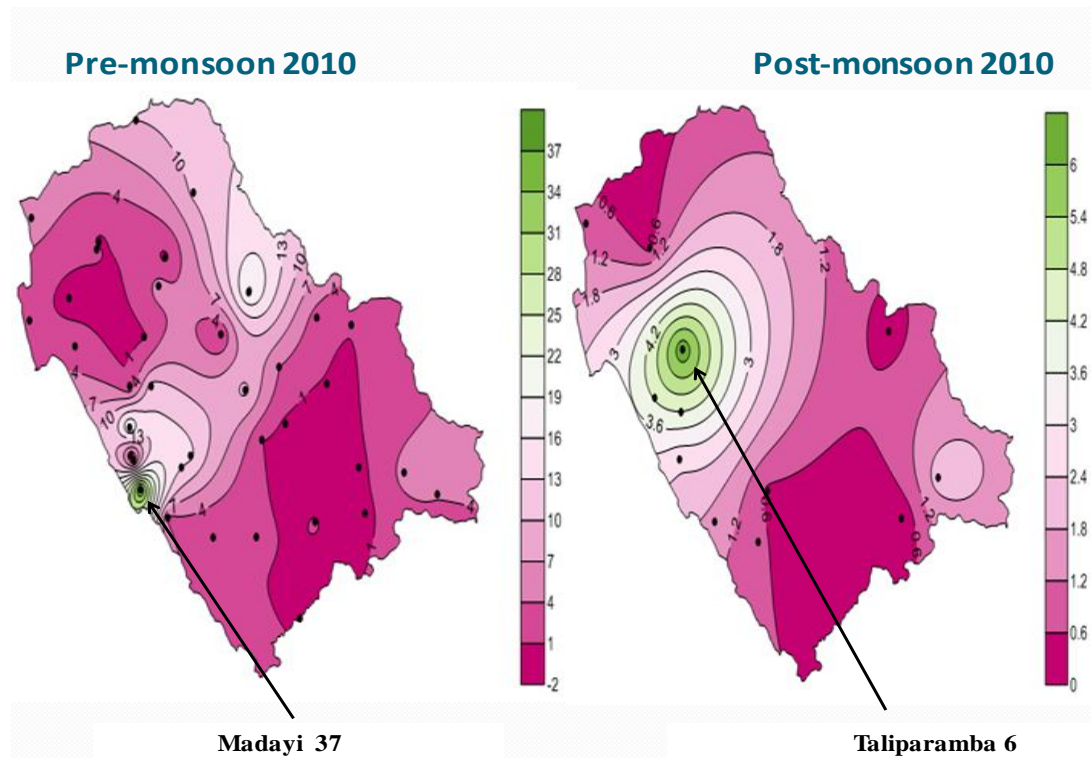


Figure 2l: Spatial variation of Sulphates in Groundwater of Kannur district (Year:2010)

Nitrates

Analysis carried out during the study period show that the Nitrate concentration varies from 0.8 mg/l to 8 mg/l during pre-monsoon and in the post monsoon it ranges between 0.2 mg/l and 3.8 mg/l. Therefore, it is further confirmed that there is no scope for groundwater pollution at this stage. Figure.2m shows the variation of nitrates in Kannur district in the year 2010.

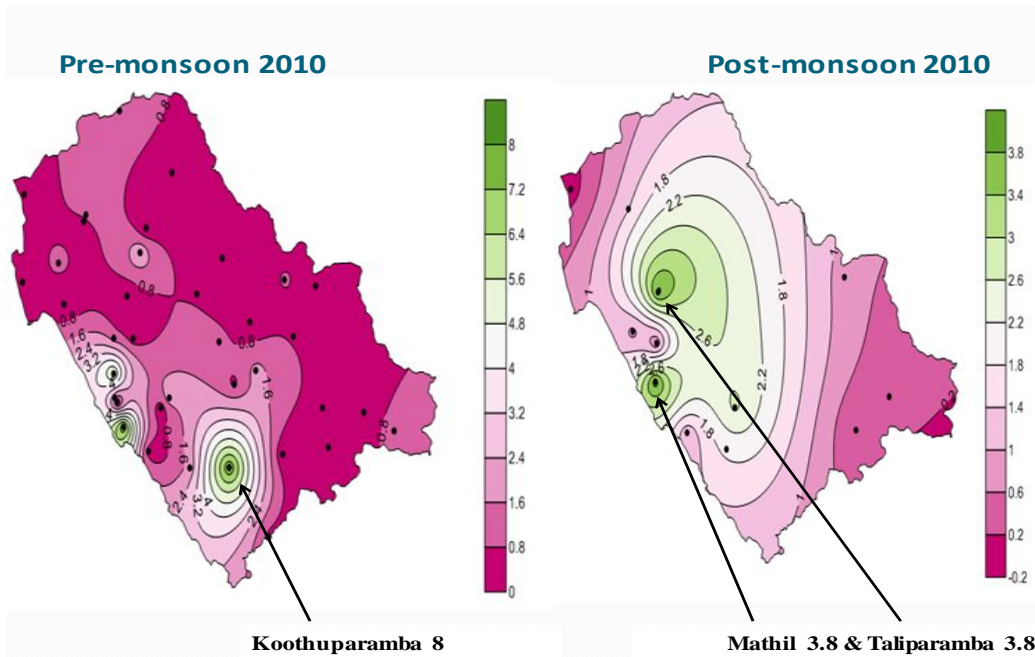


Figure 2m: Spatial variation of Nitrates in Groundwater of Kannur district (Year:2010)

Total Hardness

Total hardness of the water samples varied from less than 10 mg/l to more than 200 mg/l during pre-monsoon. A maximum of 210 mg/l was noticed at Urathur. In the post-monsoon of 2008 the TH varied from 60 mg/l to 580 mg/l which is higher than the desirable range. This is found at Thalassery near the coastal area. In the year 2010, Total hardness showed a slightly higher concentration during pre-monsoon and in the post-monsoon it showed a decline and the maximum observed was 310 mg/L. The seasonal variation of total hardness is represented in Figures 2n & 2o.

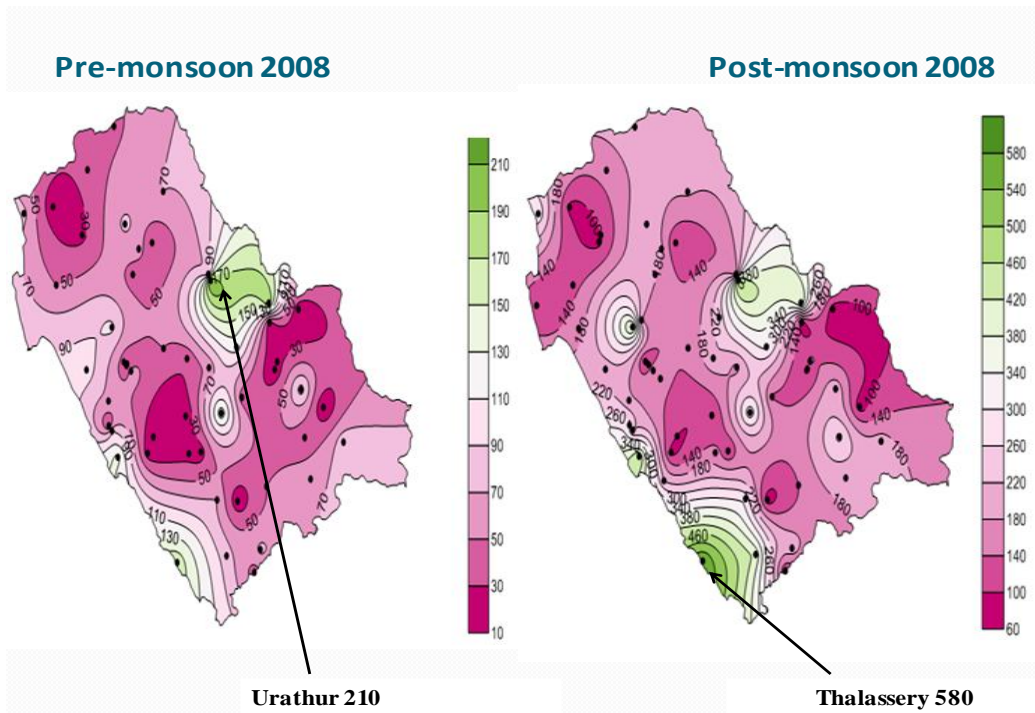


Figure 2n: Spatial variation of Total Hardness in Groundwater of Kannur district (Year:2008)

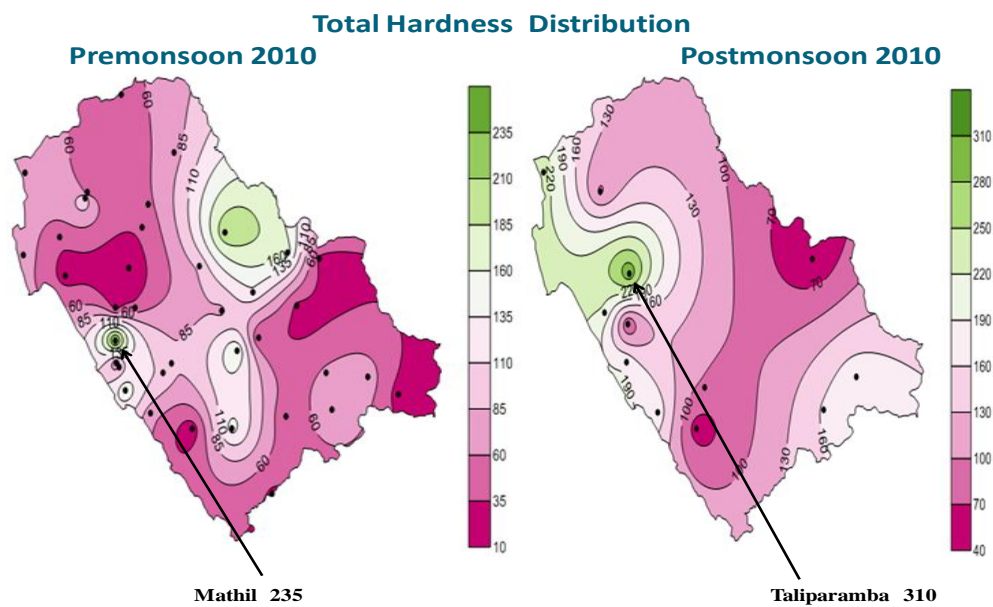


Figure 2o: Spatial variation of Total Hardness in Groundwater of Kannur district (Year:2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (fig. 2p and 2q). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from less than 1 mg/l to 90 mg/l during pre-monsoon and 2 mg/l to 26 mg/l in the post-monsoon. The proportion of magnesium was quite lower than

calcium. It varied between 1 mg/l and 23 mg/l during pre-monsoon and 1 mg/l to 10 mg/l during post-monsoon.

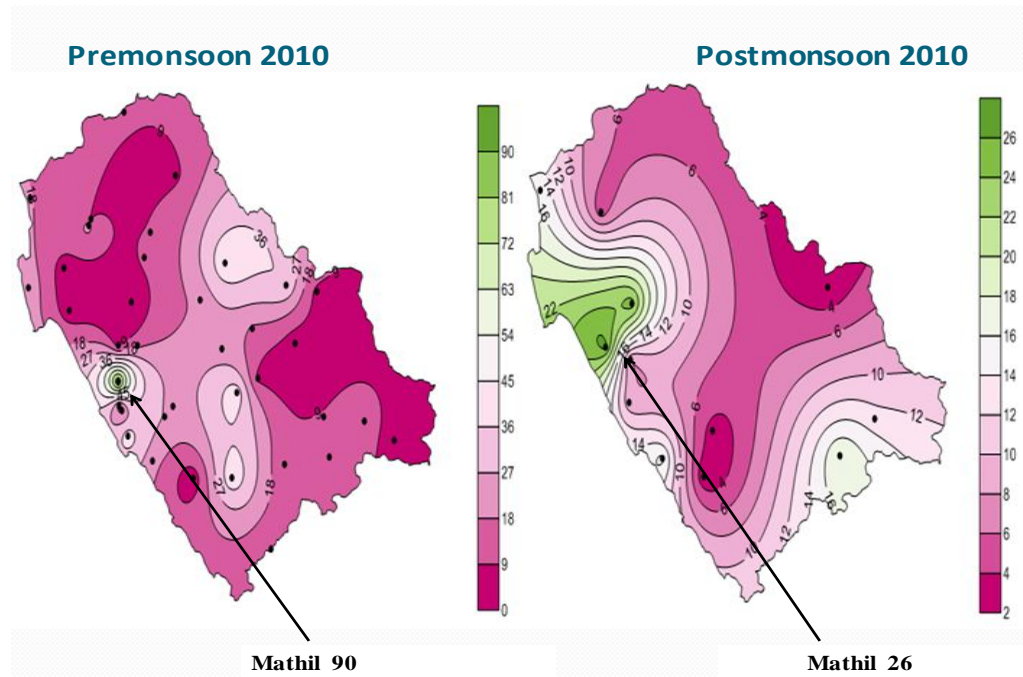


Figure 2p : Spatial variation of Calcium in Groundwater of Kannur district (Year:2010)

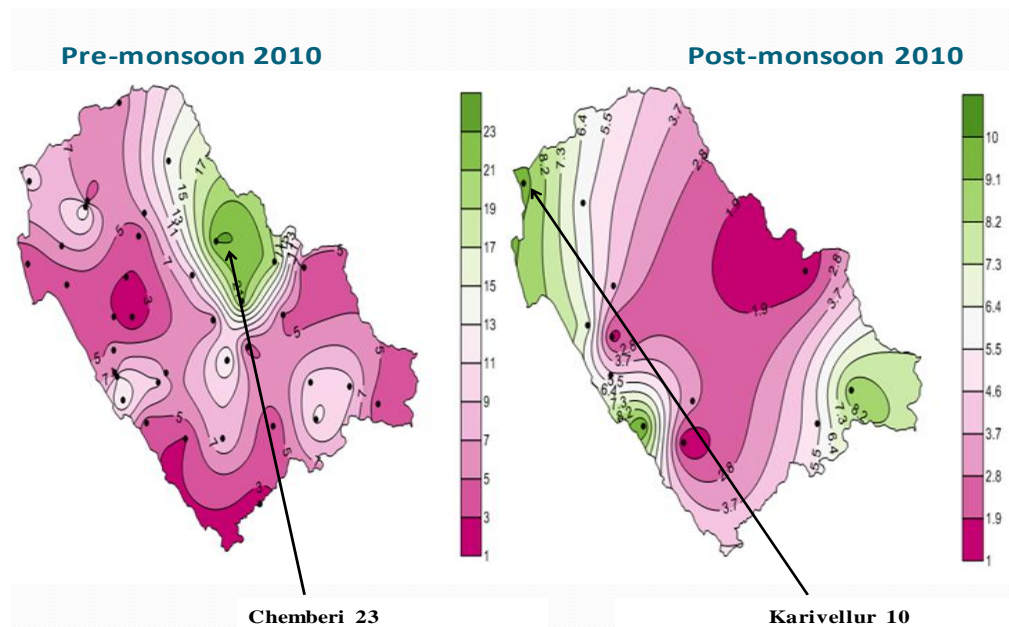


Figure 2q: Spatial variation of Magnesium in Groundwater of Kannur district (Year:2010)

Sodium and Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2008 and 2010. The results show that there is no significant change in the concentration of sodium during the study period. The observed concentration of sodium varied from less than 1 mg/l to 40 mg/l during pre-monsoon and in the post-monsoon maximum concentration found was only 36 mg/l during 2008. In the year 2010, the maximum concentration showed a drastic

change and maximum was 90 mg/l during pre-monsoon with a steep decline during post-monsoon (24 mg/l). The concentration of potassium was observed only during 2010 and it found that the potassium concentration was much below the desirable ranges. The seasonal variation of sodium and potassium concentration is represented in figures 2r, 2s and 2t respectively.

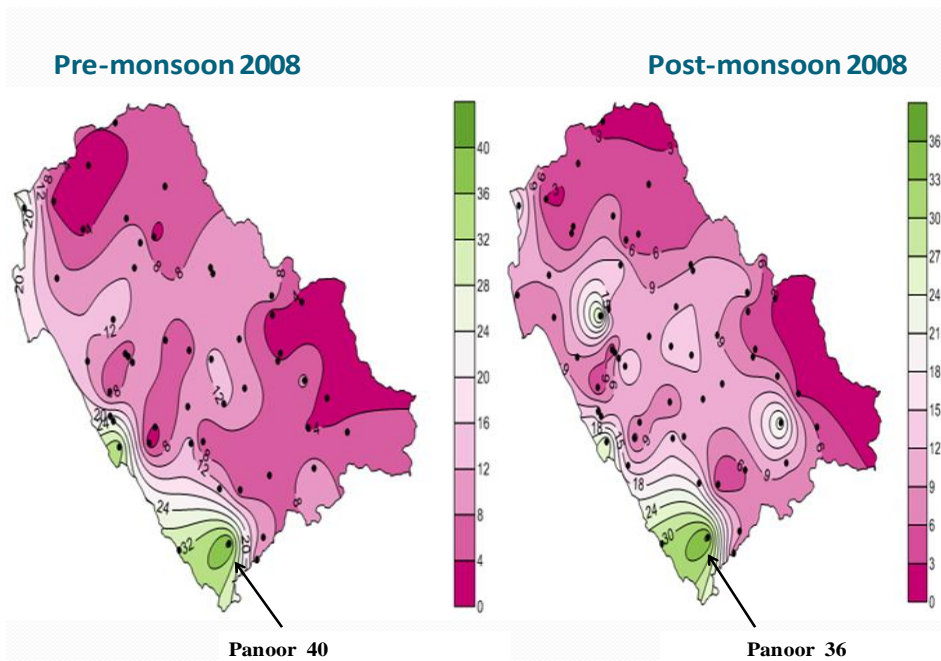


Figure 2r: Spatial variation of Sodium in Groundwater of Kannur district (Year:2008)

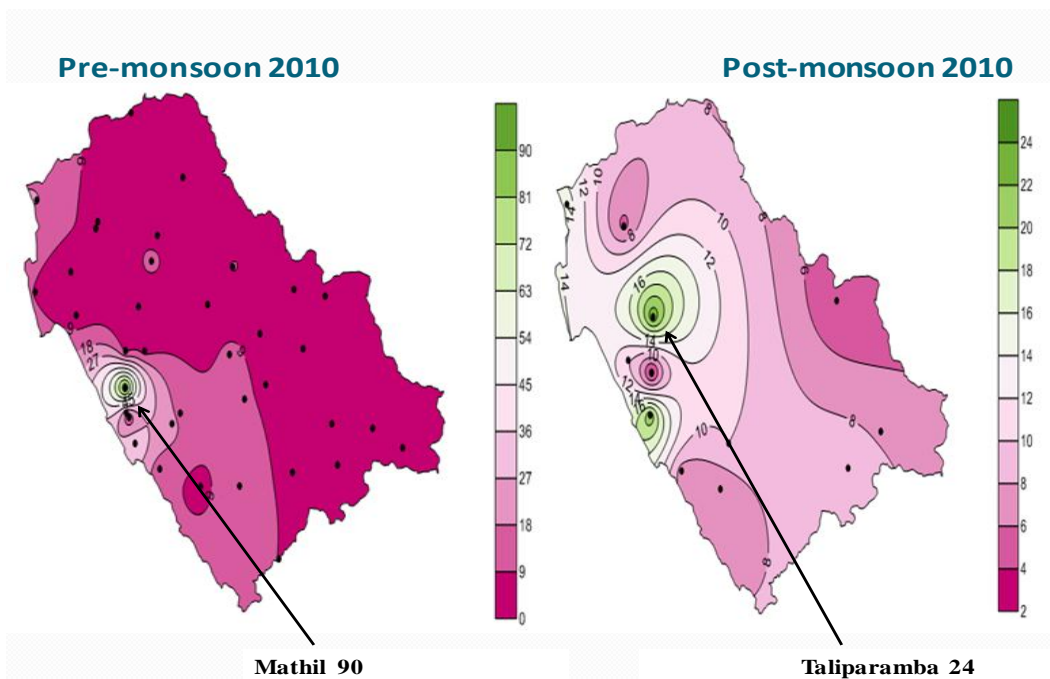


Figure 2s: Spatial variation of Sodium in Groundwater of Kannur district (Year:2010)

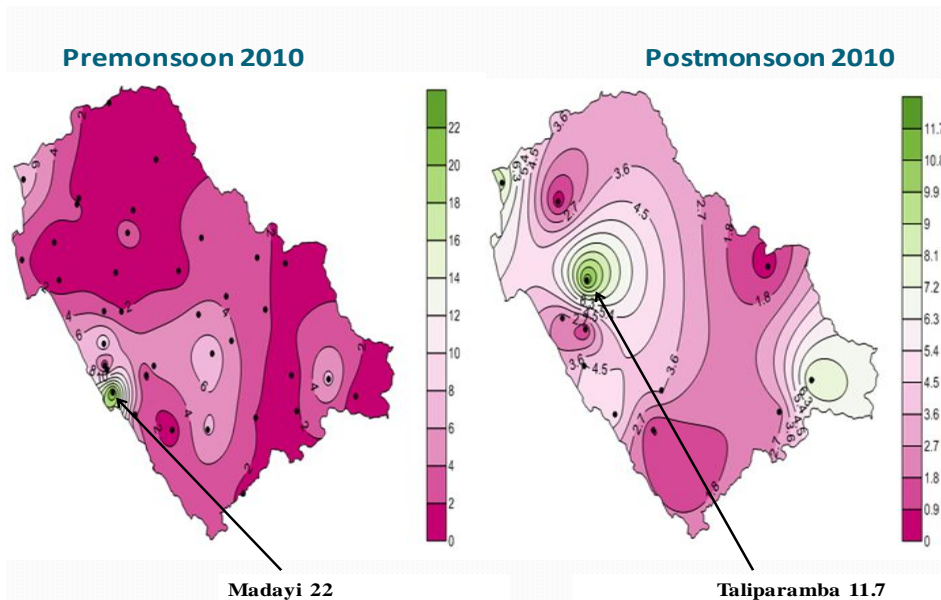


Figure 2t: Spatial variation of Potassium in Groundwater of Kannur district (Year:2010)

Iron

The maximum concentration of iron in the study area during 2008 was 2.3 mg/l which is much higher than the desirable ranges. The maximum concentration was observed at Chavassery during pre-monsoon and in the post-monsoon it was 1.8 mg/l at central polyiuloor. In the year 2010, the concentration showed an increase in a well located at Madayi during the pre-monsoon period. However, in the post-monsoon, it showed a sharp decline and the maximum concentration was found in Edakkad and Kolavallor (2.1 mg/l). The figures 2u and 2v shows the variation of iron in the district.

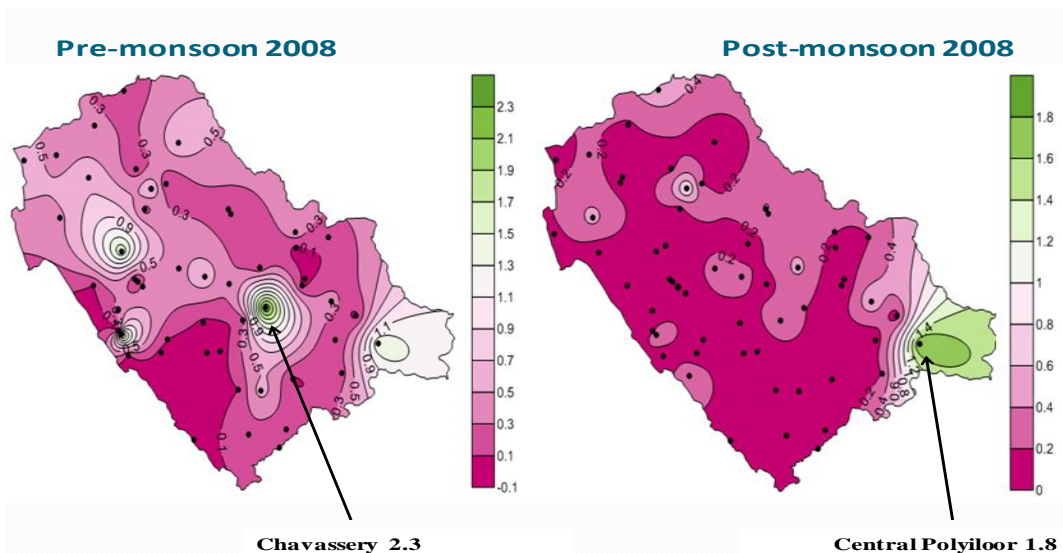


Figure 2u: Spatial variation of Iron in Groundwater of Kannur district (Year:2008)

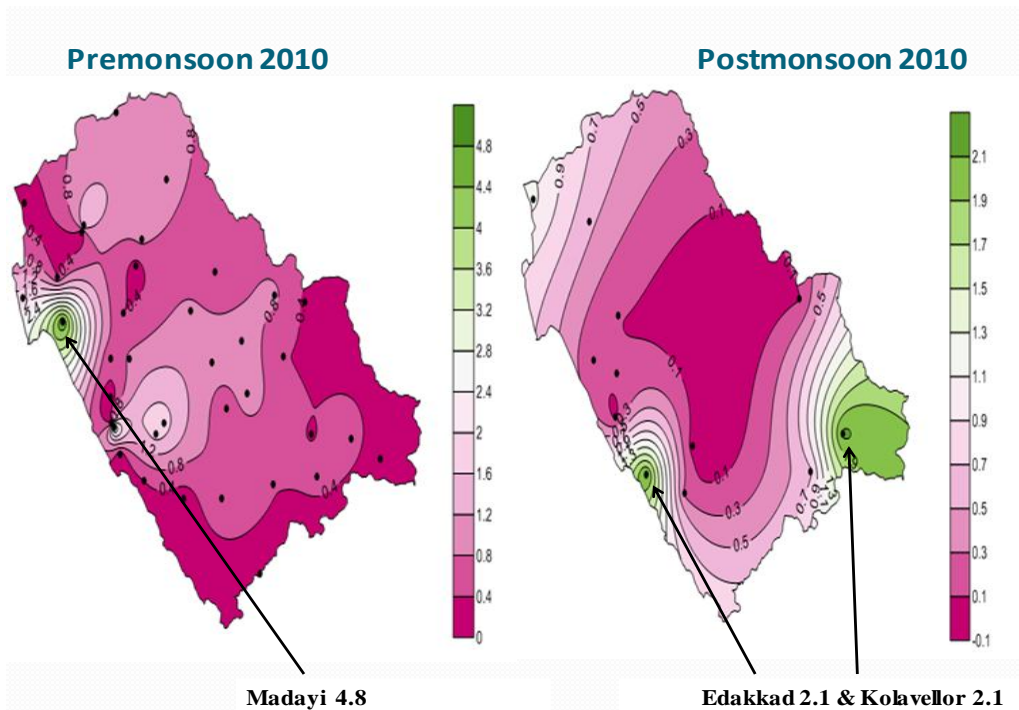


Figure 2v: Spatial variation of Iron in Groundwater of Kannur district (Year:2010)

The statistical analysis of the groundwater quality data show that there is a positive correlation between pH and Total Hardness (0.60), Total hardness and EC (0.9), EC and Cl (0.7), EC and Na (0.79) and Sodium with Chlorides (0.87). Table 2b shows the correlation between various cations and anions.

Table 2b: Correlation between the parameters

Parameters	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	0.40	1.00				
Total Hardness	0.60	0.90	1.00			
Cl	-0.14	0.70	0.39	1.00		
Na	0.04	0.79	0.50	0.87	1.00	
Fe	0.07	0.03	0.10	-0.08	0.13	1.00

Figure 2a shows the cluster analysis of the above matrix indicates a structure of three major groups linking between major ions with total hardness and Electrical conductivity both during pre-monsoon and post-monsoon season of 2008..

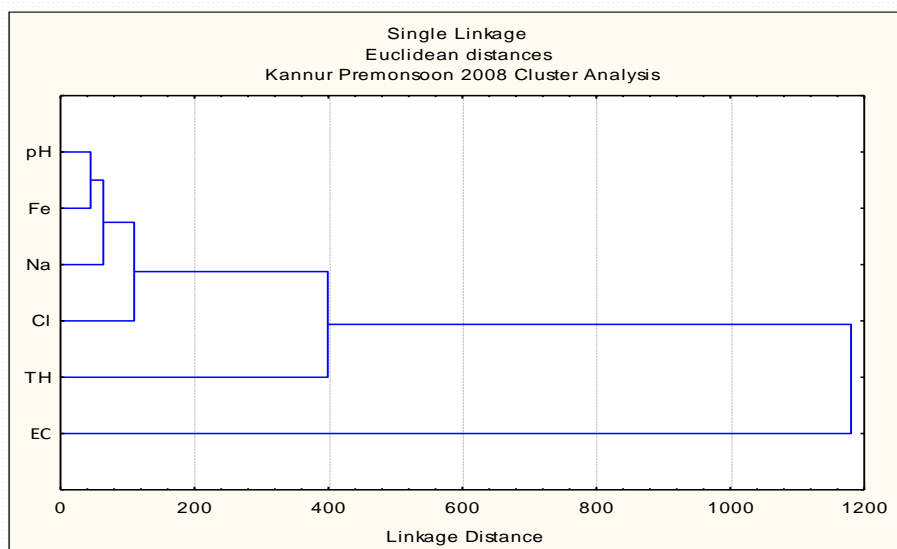


Figure 2w: Cluster Diagram showing the grouping of parameters (pre-monsoon, 2008)

Table 2c: Correlation matrix between parameters (post-monsoon, 2008)

Parameters	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	0.06	1.00				
Total Hardness	0.21	0.92	1.00			
Cl	-0.24	0.51	0.23	1.00		
Na	-0.24	0.76	0.51	0.76	1.00	
Fe	0.14	0.04	0.17	-0.24	-0.17	1.00

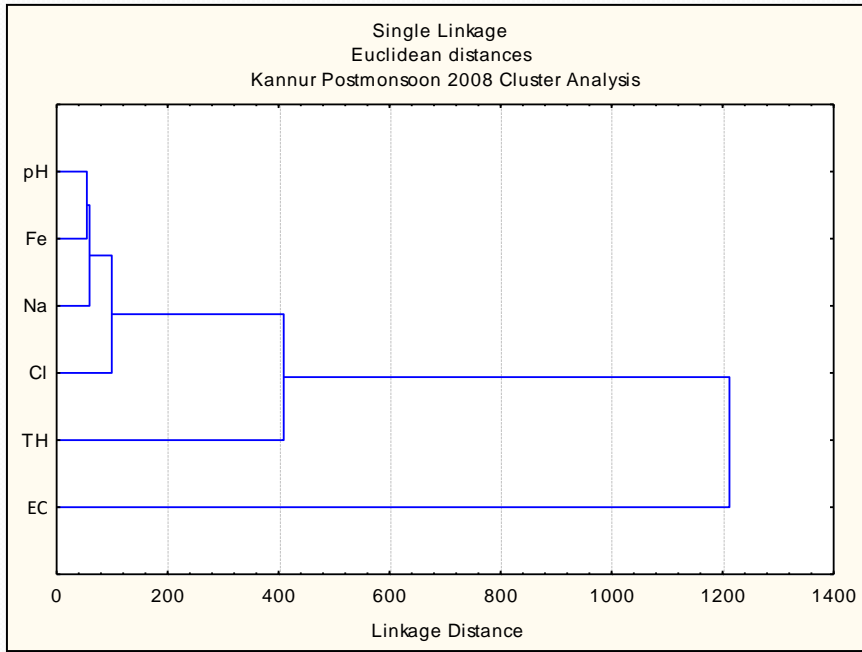


Figure 2x: Cluster Diagram showing the grouping of parameters (post-monsoon, 2008)

In the year 2010, with additional parameters, show a group of clusters indicating the mutual relationship between, anions and cations with Total alkalinity and total hardness and this further linked with TDS and EC.

Table 2d : Correlation Matrix between the parameters (pre-monsoon, 2010)

Parameters	pH	EC	Total Hardness	Alkanity	Total Dissolved Solids	CO ₂	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1.00															
EC	0.55	1.00														
Total Hardness	0.59	0.93	1.00													
Alkanity	0.65	0.85	0.91	1.00												
Total Dissolved Solids	0.55	1.00	0.93	0.85	1.00											
CO ₂	0.66	0.78	0.84	0.92	0.78	1.00										
HCO ₃	0.63	0.85	0.91	1.00	0.85	0.90	1.00									
Cl	0.27	0.83	0.61	0.46	0.83	0.42	0.46	1.00								
SO ₄	0.12	0.61	0.54	0.26	0.61	0.22	0.25	0.63	1.00							
NO ₃	0.11	0.56	0.43	0.15	0.56	0.17	0.15	0.74	0.53	1.00						
Ca	0.58	0.97	0.93	0.85	0.97	0.81	0.84	0.79	0.55	0.56	1.00					
Mg	0.35	0.46	0.70	0.63	0.46	0.52	0.64	-0.01	0.28	-0.01	0.38	1.00				
Na	0.35	0.86	0.63	0.57	0.86	0.51	0.57	0.97	0.57	0.61	0.81	0.02	1.00			
K	0.26	0.67	0.57	0.36	0.67	0.28	0.36	0.63	0.72	0.68	0.59	0.26	0.58	1.00		
F	0.24	0.11	0.04	0.20	0.11	0.07	0.22	0.04	-0.07	-0.25	0.09	-0.06	0.19	0.00	1.00	
Fe	-0.13	-0.13	-0.11	-0.07	-0.13	-0.06	-0.07	-0.15	-0.08	-0.19	-0.12	-0.04	-0.16	-0.14	-0.19	1.00

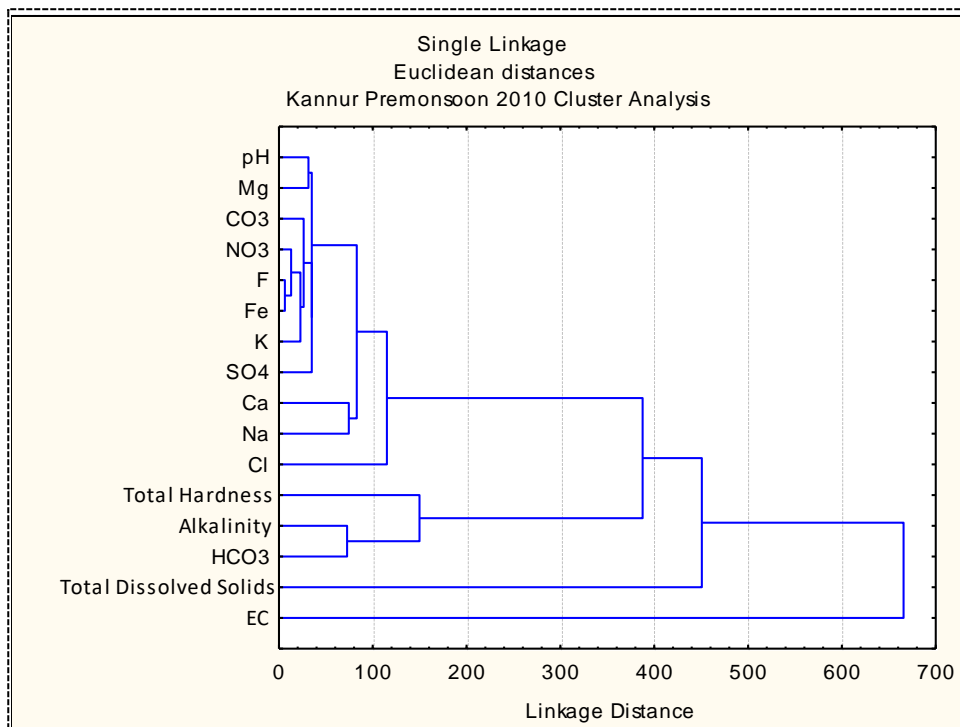


Figure 2y: Cluster Diagram showing the grouping of parameters (pre-monsoon, 2010)

Table 2e: Correlation between the various parameters (post-monsoon, 2010)																
parameters	pH	EC	Total Hardness	Alkalinity	Total Dissolved Solids	CO ₃	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1.00															
EC	0.25	1.00														
Total Hardness	0.42	0.89	1.00													
Alkalinity	0.51	0.64	0.80	1.00												
Total Dissolved Solids	0.25	1.00	0.89	0.64	1.00											
CO ₃	0.28	0.41	0.43	0.65	0.41	1.00										
HCO ₃	0.52	0.64	0.81	1.00	0.64	0.59	1.00									
Cl	-0.33	0.64	0.37	-0.15	0.64	-0.07	-0.15	1.00								
SO ₄	0.25	0.56	0.46	0.02	0.56	-0.11	0.04	0.62	1.00							
NO ₃	-0.49	0.21	-0.15	-0.57	0.21	-0.45	-0.56	0.79	0.41	1.00						
Ca	0.44	0.86	0.95	0.69	0.86	0.23	0.71	0.42	0.61	-0.04	1.00					
Mg	0.27	0.63	0.73	0.85	0.63	0.57	0.84	-0.02	-0.03	-0.33	0.54	1.00				
Na	-0.12	0.78	0.47	0.11	0.78	0.18	0.09	0.88	0.48	0.68	0.48	0.18	1.00			
K	0.07	0.85	0.61	0.52	0.85	0.46	0.51	0.55	0.47	0.26	0.56	0.51	0.72	1.00		
F	-0.71	-0.56	-0.65	-0.73	-0.56	-0.30	-0.75	0.04	-0.15	0.39	-0.66	-0.44	-0.16	-0.39	1.00	
Fe	0.36	0.26	0.37	0.73	0.26	0.38	0.74	-0.43	-0.20	-0.48	0.21	0.79	-0.19	0.38	-0.41	1.00

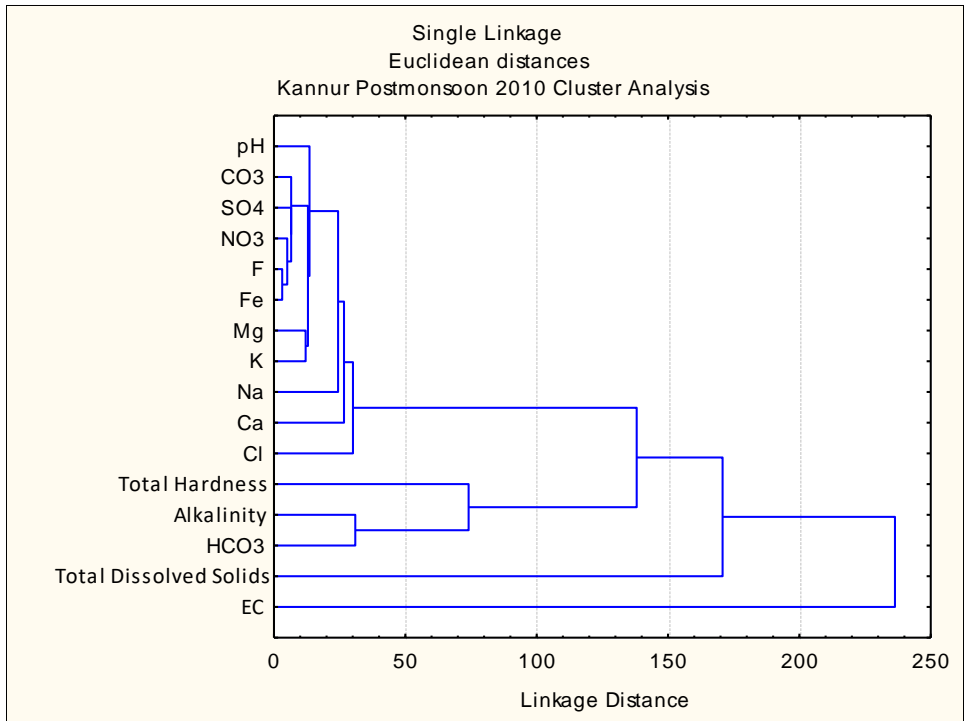


Figure 2z: Cluster Diagram showing the grouping of parameters (pre-monsoon, 2010)

In the above figure it is noticed that there are four groups showing mutual affinity between the parameters. Both major anions and cations are linked basically to the Total hardness, Alkalinity, TDS and Alkalinity.

Classification of Groundwater

Figures 2aa and 2bb show the Piper's classification of groundwater. In general it is evident that there is a dominance of sulphate and chloride ions.

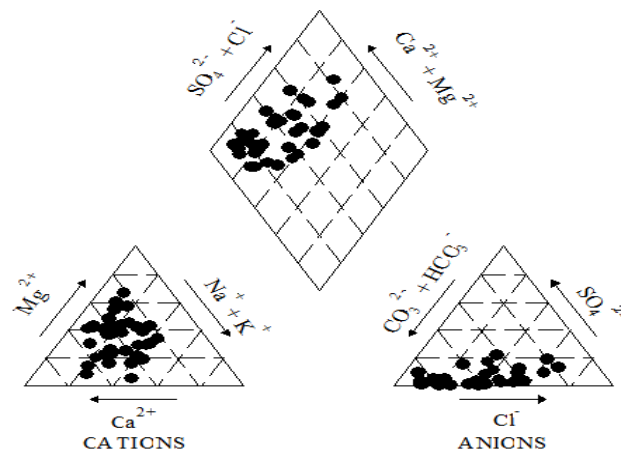


Figure 2aa: Piper's diagram for Groundwater classification (pre-monsoon 2010)

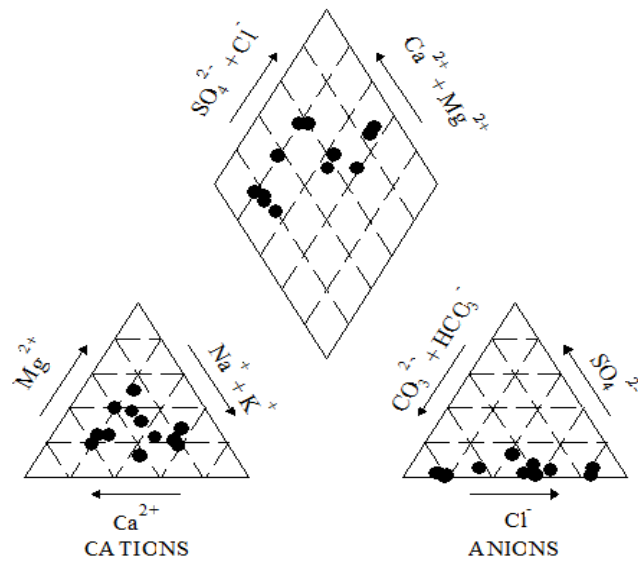


Figure 2bb: Piper's diagram for Groundwater classification (post-monsoon 2010)

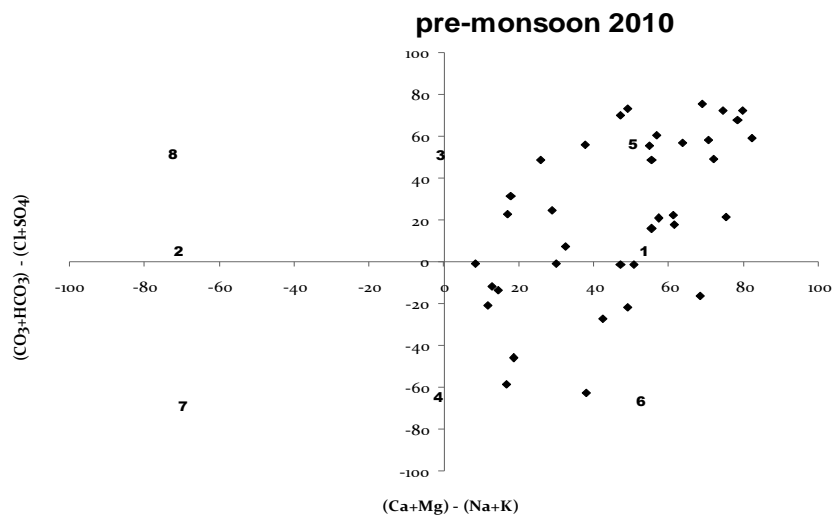


Figure 2cc: Chadha's diagram for Groundwater classification (pre-monsoon 2010)

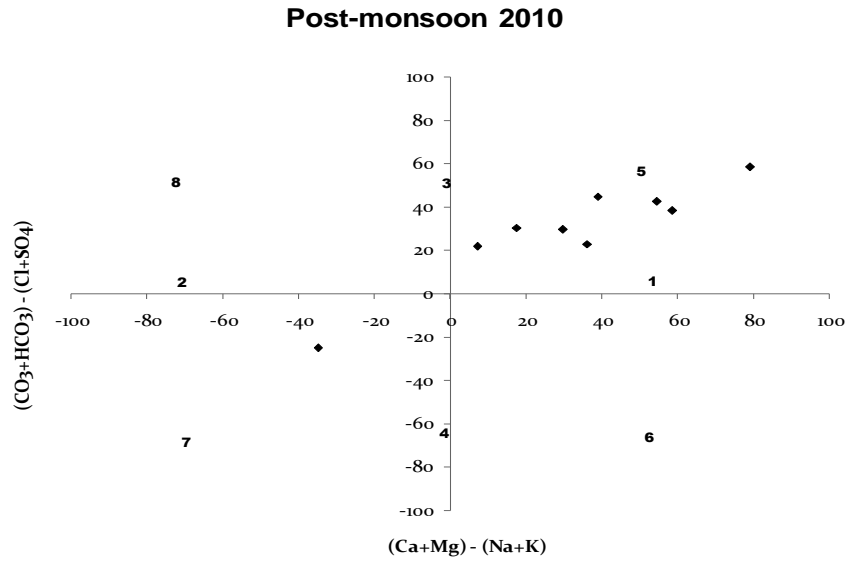


Figure 2dd: Chadha's diagram for Groundwater classification (post-monsoon 2010)

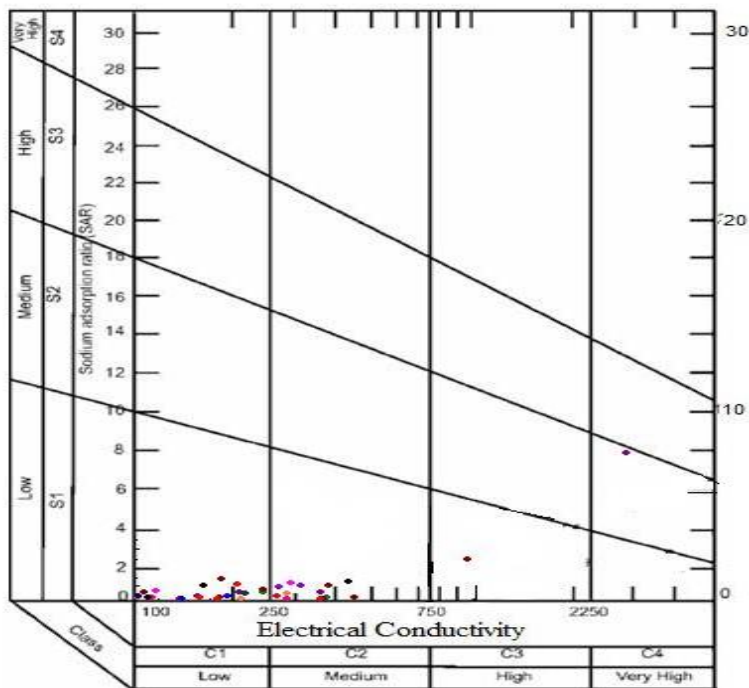


Figure 2ee: USSL classification of groundwater of Kannur district (pre-monsoon 2010)

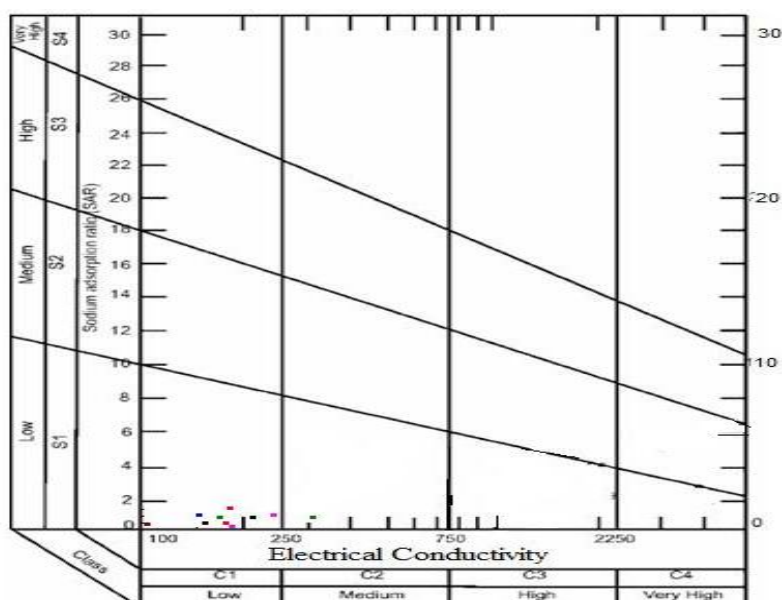


Figure 2ff: USSL classification of groundwater of Kannur district (post-monsoon 2010)

Heavy Metals in Groundwater of Kannur District

The heavy metals were determined for selected wells in Kannur district. Eight wells have been identified based on field investigations which are most prone to heavy metal contamination. In Kannur district it was found that all wells showed the presence of one or the other heavy metals. It was also noticed that heavy metals like As, Cd and Hg were absent in all the observed wells.

Table 2d : Heavy metal concentrations observed in selected wells of Kannur district

well No	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Nickel
QKNR-OW 1	0.15	ND	ND	0.012	ND	0.0019
QKNR-OW2	0.06	ND	ND	0	ND	0
QKNR-OW3	ND	ND	ND	0.004	ND	0
QKNR-OW4	ND	ND	ND	0	ND	0.0032
QKNR-OW5	ND	ND	ND	0.1	ND	0
QKNR-OW6	0.07	ND	ND	0.01	ND	0
QKNR-OW7	ND	ND	ND	0	ND	0.0019
QKNR-OW8	ND	ND	ND	0	ND	0.0054

2.0 GROUNDWATER QUALITY OF WYANAD DISTRICT

2.1 General features and Characteristics of the District

Wayanad District

Wayanad is a small hill district in Kerala with an area of 2131 km² (Fig. 1). Wayanad district came into being on November 1, 1980 comprising of three Tehsils viz. Vythiry, Mananthawady and Sulthan Bathery and three blocks viz. Kalpetta, Mananthawady and Sulthan Bathery. The district is having 25 grama panchayats and one municipality (Kalpetta). It has a population of about 7.86 lakh of which 90% depend upon agriculture for sustenance. There are 40,129 farmers, 74,813 agricultural labourers and 17,413 plantation labourers in the district. Another 37,267 people earn their livelihood from animal husbandry and forest produce (source: District Project Draft Development, Wayanad, 2001, Govt. of Kerala). The district has highest tribal population of about 1.25 lakh consisting 17% of the total population. Even though, the term Wayanad is derived from the word "Vayal Nadu", which means the land of paddy fields now it is famous for its spices and coffee plantations. The major crops grown here are coffee, pepper, tea, cardamom, arecanut etc. These are perennial cash crops.

Till not very long ago, Wayanad had plenty of water. But today the entire region is facing drought due to change in rainfall pattern, unchecked deforestation and large-scale conversion of paddy fields into plantations. In 1980, there were 30,000 hectares of paddy fields in Wayanad. It has shrunk by more than 76 percent to 7000 hectare at present. The ecosystem and environment of the district, is known for its bio-diversity is greatly endangered today. Aforestation, protection of paddy fields, conservation of water resources and artificial recharge to groundwater are to be carried out in the district to protect the ecosystem and environment of Wayanad, which will in turn reduce the impact of drought on agriculture.

Almost the entire Wayanad district is drained by Kabani and its three main tributaries viz. Panamaram, Mananthawady and Tirunelli. Other tributaries include Bavelipuzha and Noolpuzha. Kabani River is one of the three east flowing rivers in Kerala and is an important tributary of Cauvery River. Kabani and its tributaries carved the present landscape of the district. Other drainages in the district are Chaliyar and Valapattanam.

Panamaram river originates from Lakkidi and its main tributaries are Kavadam puzha, Kadaman thodu, Venniyode puzha, Karapuzha and Narassipuzha. Panamaram river joins with Mananthawady rivulet originating from Thodarmudi at an elevation of 1500m amsl. After joining with Mananthawady river, it is known as Kabani. After entering the Karnataka State Kabani joins with Cauvery.

Groundwater occurs in the weathered, fractured, crystalline and alluvial formations in the district. Phreatic conditions exist in weathered formation and are mostly developed by dug wells for domestic and irrigation purposes. Semi-confined conditions exist in deep fractures and storage and movement of groundwater is mainly controlled by the fracture system. Deep bore wells with high yield are located along fractures / lineaments.

Hydrogeology

All the three blocks in the district are having similar hydrogeological conditions. Hence it is not discussed block wise. The major water bearing formations in the district are weathered/fractured crystallines, alluvium and valley fills. Alluvium and valley fills are seen along the river courses and broad valleys. The alluvial aquifers are better represented in Kalpetta and Sulthan bathery blocks and considerable thickness of this formation are seen in and around Muttill, Kainatti, Varadur and in different parts of Panamaram Watershed. The thickness of alluvium varies from 3 to 9m and that of valley fills from 2 to 9m. In these formations groundwater occurs under phreatic condition. Dug wells are suitable abstraction structures for this formation with depth range varying from 3.5 to 7.8 mbgl. The depth to water level varies from 2.6 to 3.7 mbgl during pre monsoon (April) and from 0.70 to 2.60 during post monsoon (November). The yield of dug wells in this formation ranges from less than 500 LPH to about 10,000 LPH with pumping duration ranging from less than 1 to 4 hours in a day.

The hard rocks (crystalline) cover the entire district with thin deposits of alluvium and valley fills over it as mentioned above. Groundwater occurs under phreatic condition in weathered crystallines. Semi confined to confined condition exists in deep fracture system, which forms potential aquifers and is developed by bore wells. The depth of wells and water levels in the weathered crystallines varies with respect to the parent rock formation as depicted in the hydrogeological maps. The weathered granite and granitic gneisses in Kalpetta and Sulthan Bathery Blocks form potential phreatic aquifers along valleys and topographic lows. The depth of dug wells in this formation generally varies in the range of 6 to 9m with water levels ranging from 4 to 8 mbgl during pre monsoon and from 3 to 5 mbgl during post monsoon.

The weathered charnockites seen in Kalpetta block and along the hill ranges of the Western Ghats form poor aquifer and can sustain only domestic wells. The depth of wells in this formation generally varies in the range of 7 to 10 m with water levels ranging from 4 to 9 mbgl during pre monsoon and from 3 to 7 m during post monsoon.

The weathered migmatite and gneiss seen along the central portion of the district form moderately potential aquifers and cover a major area of all the three blocks. The depth of dug wells in this formation generally varies from 14 to 20 m with water levels ranging from 10 to 15 mbgl during pre monsoon and from 8 to 11 m during post monsoon.

The weathered gabbro and diorite rocks seen in the northern portion of Mananthawady block form moderately potential aquifers. The depth of wells in this formation generally varies from 8 to 12 m with water levels ranging from 5 to 7 mbgl during pre monsoon and from 3 to 4.5 mbgl during post monsoon. The yield of dug wells in the crystallines varies in general from less than 500 LPH to 6000 LPH and can sustain pumping for a period of from less than 1 to 3 hours in a day.

Deeper aquifers in the crystallines with secondary intergranular porosity and fractures are feasible locations for bore wells. High yielding wells can be located along fracture zones identified by proper hydrogeological and geophysical studies. The depth of bore wells in the district generally varies from 10 to 100m with yield in the range of 250 LPH to 22,000 LPH. Out of 300 bore well data analysed only 6% of the wells are yielding more than 10,000 LPH and about 20% of wells are yielding 5000 to 10,000 LPH. The yield of bore wells in charnockites varies between 280 and 2900 LPH and that in diorite and gabbro formations varies between 400 and 22,000 LPH. Diorite and gabbro formations yield more compared to other formations in the district. Exploratory drillings by CGWB revealed deep potential fractures between 122 and 140 m along lineaments. The maximum discharge observed from these wells is around 40,000 LPH.

The casing depth of bore wells varies from 3 to 53 mbgl. The over burden thickness is maximum in gneisses in central and eastern parts of the district and is generally in the range of 20-35 m. While, on western and northern part of the district covered by charnockites, dolerite and gabbro it is generally in the range of 15-25m.

Seasonal fluctuation of the water table is due to variation in the rainfall, evapotranspiration, withdrawals for irrigation and other purposes, base flow, seepage from surface water bodies etc. The water table fluctuation with respect to pre monsoon (April 2006) and post monsoon (November 2006) water levels is shown Fig.6. The annual water level fluctuation is in the range of 0.72 to 2.60 m in alluvium and valley fills and that in weathered crystalline it ranges from 1.02 to 8.5 m. Both rise and fall in water level trends can be seen at various locations but, any significant change in trend for concern is not observed.

The State Ground Water Department has identified about 60 stations in this district and water sampling and analyses were done for 4 seasons in 2008 and 2009. It was observed that pH values are generally less than 7 which represent the acidic nature of water. Majority of the tested parameters were under permissible limits except for few stations. Higher values of EC

were observed for Thakarappadi (1470 $\mu\text{S}/\text{cm}$) and Sulthanbatheri (1030 $\mu\text{S}/\text{cm}$). Thakarapadi also showed a large value of Magnesium, 109.84 mg/l and Pulpally recording 45.87 mg/l. Potassium concentration was high at Sulthanbatheri (29.8 mg/l), Ambalavayal (24.2 mg/l) and Pozhuthana (21.8 mg/l). Many regions showed high Iron concentration; Thirunelli (9.27 mg/l), Vythiri (8.55 mg/l), Kalpetta (4.27 mg/l), Korom (2.89 mg/l).

As there were limited set of data during 2008, only analysis of 2010 was carried out for pre-monsoon season. An attempt was also made to compare the past data available with the Kerala State Groundwater Department. It was found that there is a gradual decline in water quality over the years in the district. This is quite pronounced in some of the locations particularly in and around Sulthan Bathery and Kalpetta town. Factor analysis were carried out for pre-monsoon 2010 and based on this four groups were identified which were having eigen values more than 1. The first group was dominated by Turbidity, EC, TH, TDS, HCO_3 , Cl, SO_4 , Mg and Na and the second group comprises of pH, Alk, TDS, CO_3 , HCO_3 , Ca and Sodium. The third group represents temperature, sulphate, potassium and fluoride and the fourth group is dominated by the presence of nitrates. The percentage of variance varies between 9.014 and 35.611.

Table 1: Factor Analysis results of Wayanad district

Sl No.	Parameter	Factor 1	Factor 2	Factor 3	Factor 4
1	Turb	0.921	0.301	-0.068	0.169
2	Temp	0.097	0.195	0.540	-0.125
3	pH	0.044	0.869	0.141	-0.219
4	EC	0.849	0.494	0.093	0.158
5	TH	0.935	0.309	0.103	0.073
6	Alk	0.318	0.936	0.047	-0.007
7	TDS	0.849	0.94	0.093	0.158
8	CO_3	0.344	0.926	0.036	0.035
9	HCO_3	0.915	0.931	0.057	0.034
10	Cl	0.774	0.327	-0.234	0.398
11	SO_4	0.763	-0.216	0.522	-0.137
12	NO_3	0.279	0.123	-0.350	0.652
13	Ca	0.633	0.602	-0.134	0.360
14	Mg	0.924	0.176	0.223	-0.111
15	Na	0.520	0.582	0.204	0.298
16	K	0.366	0.474	0.510	0.263
17	F	-0.007	-0.016	0.801	0.063
18	Fe	0.000	0.141	-0.135	-0.754
Eigen value		9.728	2.327	1.939	1.082
% of variance		35.611	28.962	10.162	9.014
Cumulative % of variance		35.611	64.573	74.735	83.749

Groundwater Classification

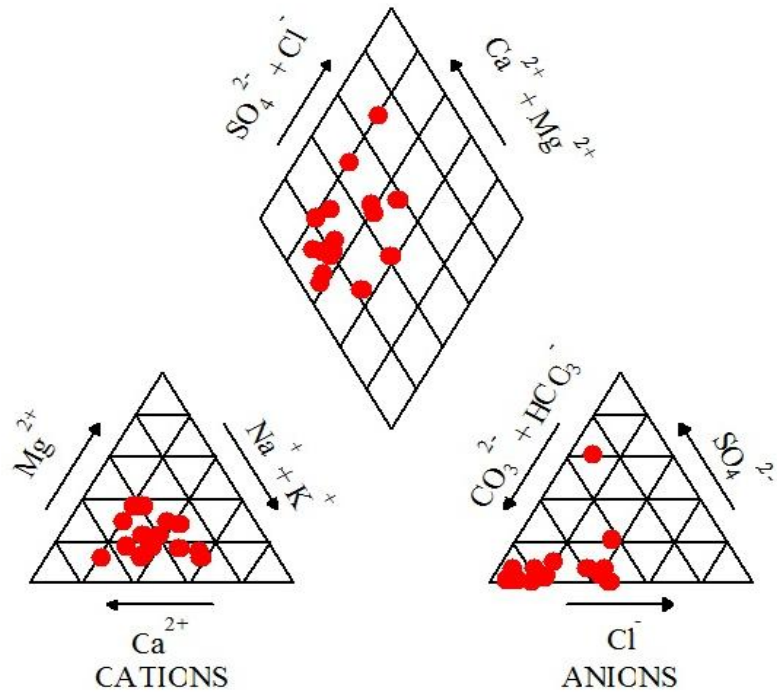


Figure 3a: Piper's classification of Ground water of wayanad district (Pre-monsoon 2010)

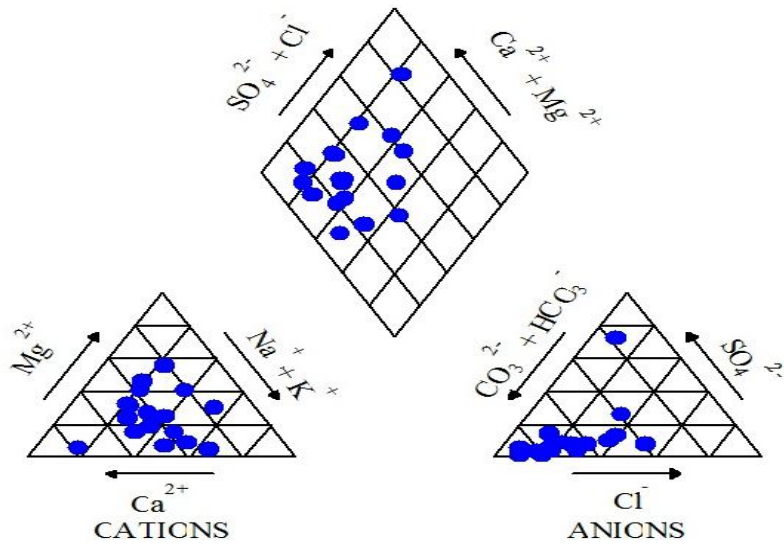


Figure 3b: Piper's classification of Ground water of wayanad district (Post-monsoon 2010)

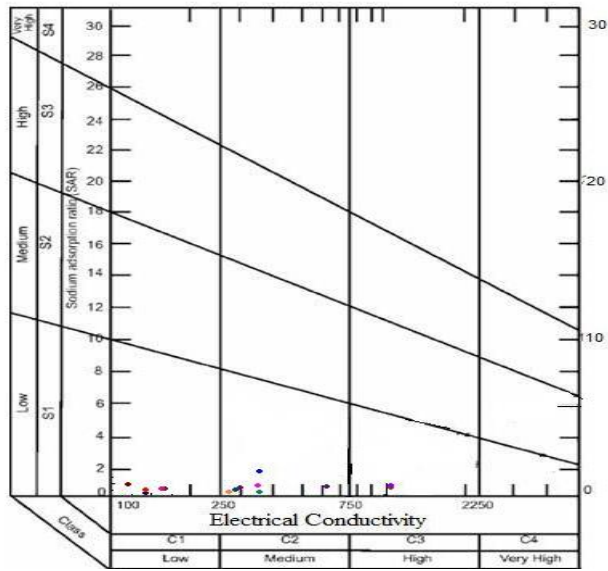


Figure 3c: USSL Irrigation classification of Groundwater of wayanad district (Pre-monsoon 2010)

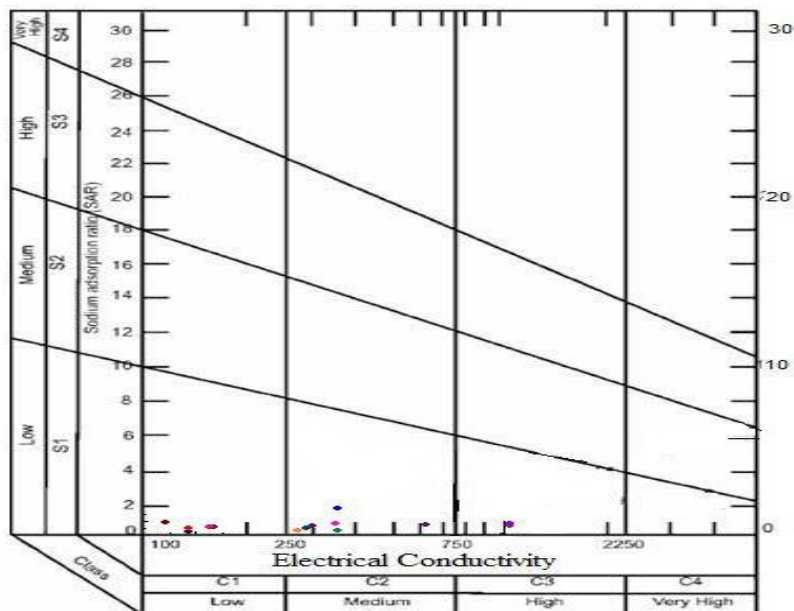


Figure 3d: USSL Irrigation classification of Groundwater of wayanad district (Post-monsoon 2010)

Heavy Metals in Groundwater of Wayanad District

It is observed that in Wayanad district there is severe degradation of groundwater quality in some of the localities. Eight samples from selected wells have been subjected to heavy metal analysis and found that majority of the observed wells there are heavy metals like Arsenic, copper, lead, nickel and zinc. Cadmium was absent in all observed wells. Table 2 shows the distribution of heavy metals in Wayanad district.

Table 2: Heavy metal distribution in groundwater of Wayanad district

Well No	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Nickel	Zinc
WYDPDSQ10	0	0.098	0	0	0	0.0117	0.06
WYDPDSQ10	0.02	0	0	0.0098	0.06	0	0.0117
WYDPDSQ13	0	0.0095	0	0	0	0.0279	0.0486
WYDPDSQ13	0.29	0	0	0.0095	0.0486	0	0.0279
WYDPDSQ14	0	0.0137	0	0	0	0.428	0.043
WYDPDSQ14	0.02	0	0	0.0137	0.043	0	0.428
WYDPDSQ9	0	0.0102	0	0	0	0.025	0.0556
WYDPDSQ9	0.011	0	0	0.02	0.0556	0	0.025

4.0 Groundwater Quality of Kozhikode district

The composition of the natural water is influenced by the environmental conditions effecting its characteristics. An investigation on the water quality of domestic water sources with reference to solid waste disposal in the areas of Kozhikode district is very important from the point of view of identifying the contamination and suggesting treatment procedures to bring the quality of the drinking water to the desired levels.

4.1 Study area and geographical features of Kozhikode district

Kozhikode, is situated in the northern part of Kerala at a latitude of 11°20'N and a longitude of 75°52'E. The district of Kozhikode has a total area of 2344 km² and a population of 26.2 lakhs which is about 9% of the total population of the Kerala state. The different physiographic units in the district are lowland - 362.8 km², midland - 1344.7 km², and highland - 625.8 km². The Kozhikode City Corporation has a population of 4,37,831 in an area of 82.68 km². The population density is 5,078 per km² (Raghu,2000). The major rivers flowing through this district are Korappuzha, Chaliyar and the Kallai River and their tributaries. The three rivers join the Arabian Sea. Most of the people depend on homestead open wells for domestic purposes. The density of open wells in the district is 258 per km². It is estimated that more than 50% of the population of the city depend on wells (KARMA, 2000). The wells in the coastal area have an average diameter of 1.68 m and an average depth of 3.32m. In the midland and highland, the wells are found to be deeper.

The soil in this area is very deep, well drained, gravelly clayey soil on gently sloping coastal laterites with moderate erosion, associated with moderate gravels. There are a number of large and medium scale industries flourishing along the banks of rivers and near the coastline of Kozhikode. These include besides textiles, detergent manufacturing industries, plywood industries, tile and rayon factories. The focus of the present study is on and around Njheliyanparamba, where Calicut Corporation dumps the collected waste.

Results and Discussion

The pH values of the samples collected from Kozhikode district, varied from 4.6 to 7.80 during pre-monsoon and 6.6 to 8.4 during post-monsoon in the year 2008. Water was found to be quite acidic in the northern and south-eastern part of the district. In order to understand the impact of seawater, sampling was done from the region close to the southern and coastal part of the district. The study shows that, in the coastal zone water is alkaline in nature and indicated the influence of sea water in the shallow aquifers. However, in the eastern part of the district, it is noticed that there are large scale erosion from acidic rocks which resulted in low pH of well waters. The acidic nature of the water can be attributed to carbon dioxide that is incorporated into the ground water by bacterial oxidation (Mathews and Pekdeger, 1981). The seasonal variation of pH in waters during 2008 and 2010 are given in Fig 4a and 4b..

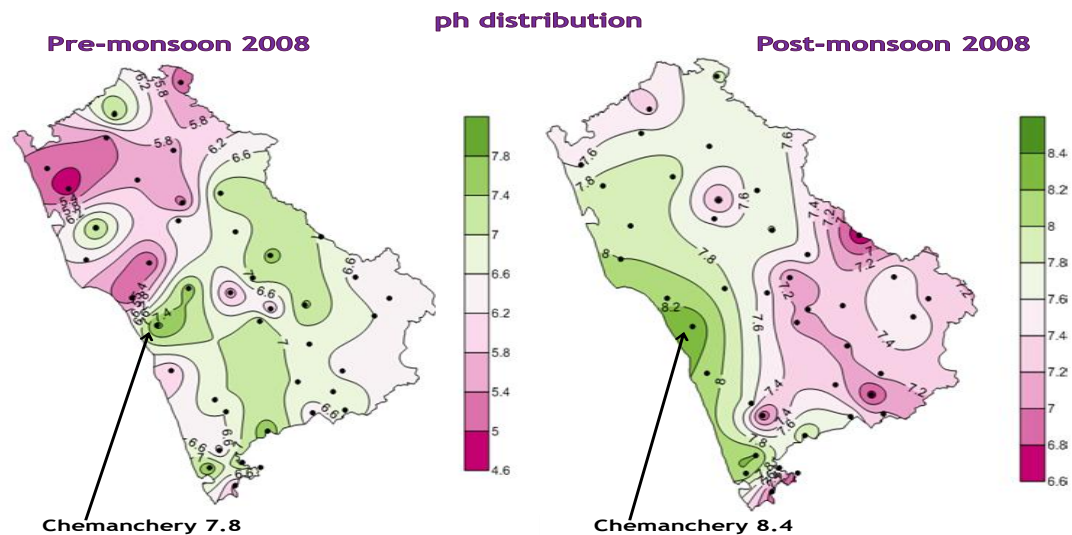


Figure 4a: Spatial variation of Iron in Groundwater of Kozhikode district (Year:2008)

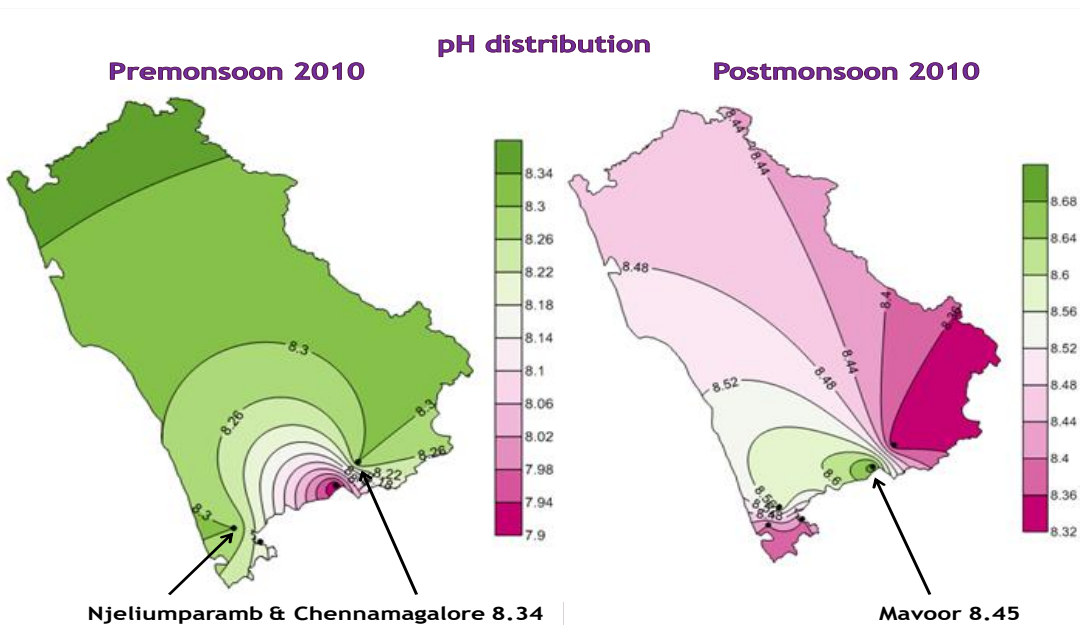


Figure 4b: Spatial variation of Iron in Groundwater of Kozhikode district (Year:2008)

Electrical conductivity

Electrical conductivity of the samples varied from 260.0 micro-siemens/cm to 1800 micro-siemens/cm during pre-monsoon, 118.50 to 1100 during the post-monsoon of 2008. Analysis carried out during 2009 and 2010 showed a gradual increase of Electrical conductivity at Njheliyaparamba. The value during 2010 increased to a maximum of 2600 micro-siemens/cm and 1540 microsiemen/cm during post-monsoon. The dissolution of ionic substances from the dumping site of Njheliyanparamba could be contributing to high electrical conductivity.

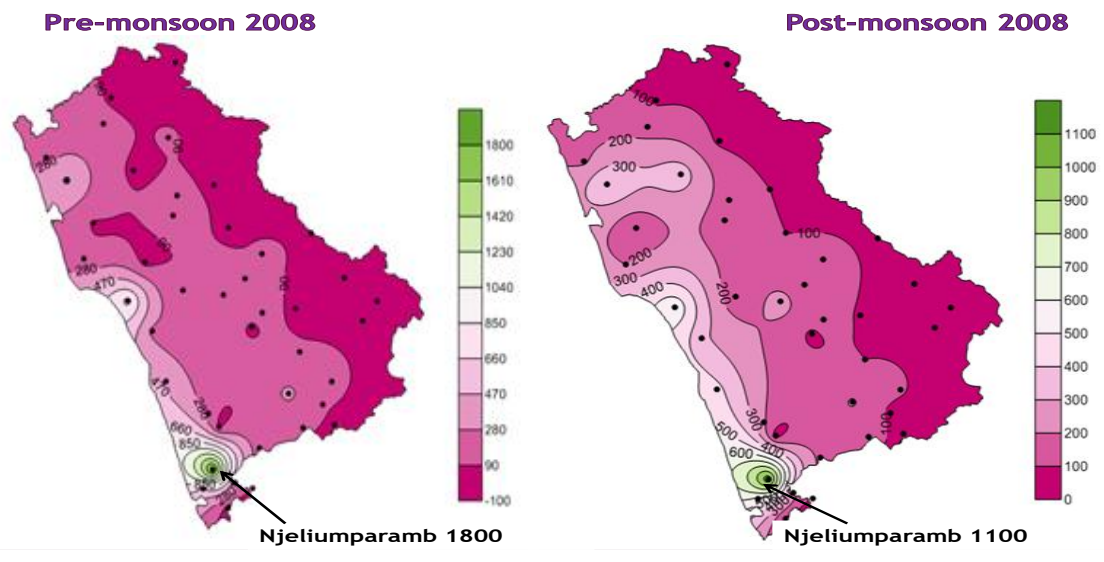


Figure 4c: Spatial distribution of Electrical conductivity during 2008.

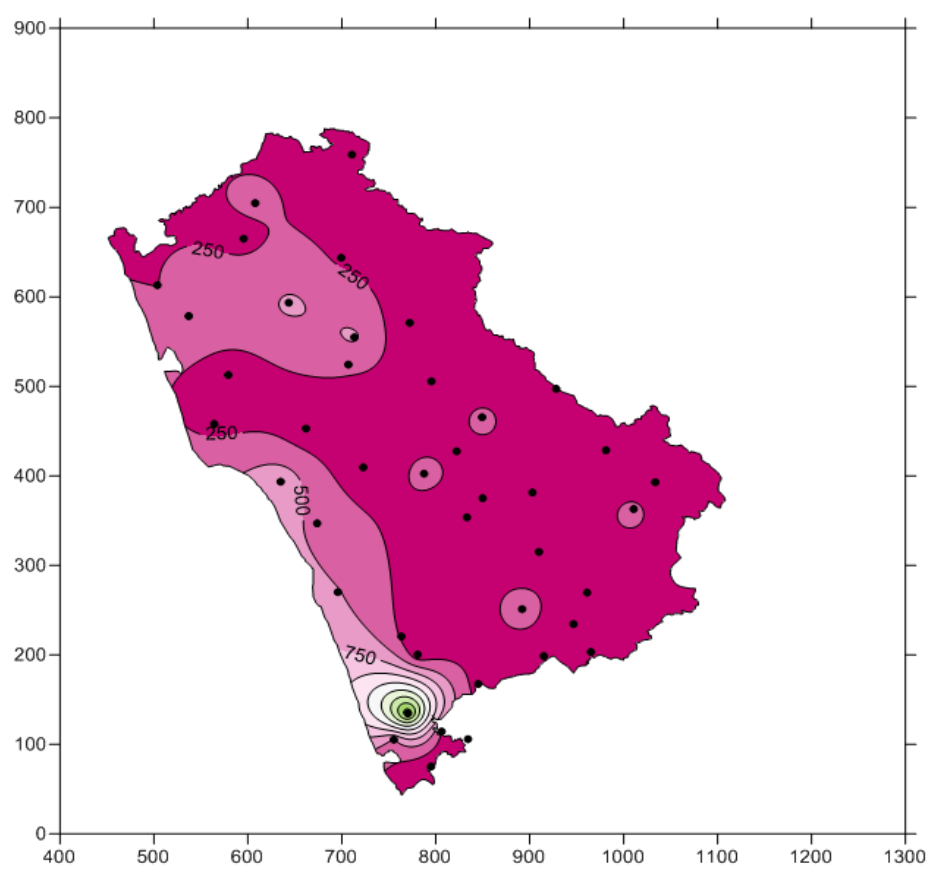


Figure 4d: Spatial Distribution of EC during post- monsoon 2009

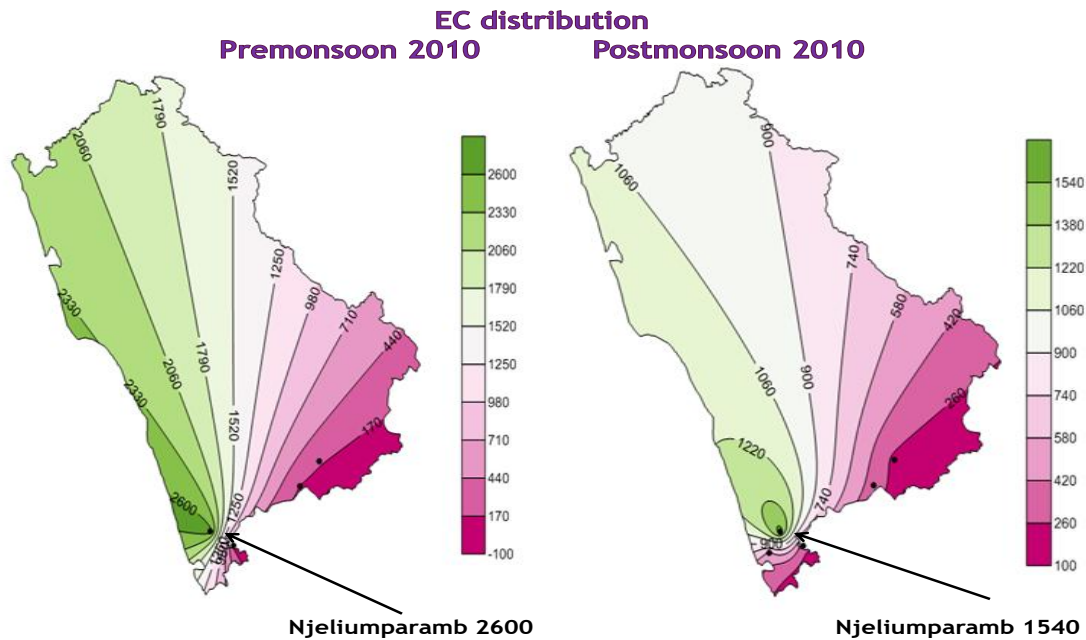


Figure 4e: Spatial Distribution of EC in Groundwater of Kozhikode district (Year:2010)

Total Dissolved Solids

Drinking water quality is affected by the presence of soluble salts. Total dissolved solids indicate in general, the nature of water quality. Therefore the level of total dissolved solids is one of the characteristics which decides quality of drinking water. When total dissolved solids in water is more than 500 mg/l, palatability decreases and may cause gastrointestinal irritation (Park and Park, 1998). The Total Dissolved Solids exceeded 1600 mg/l during pre-monsoon 2010 to 950 mg/l in the post-monsoon of 2010. The seasonal variation of TDS in water samples of Njheliyanparamba is depicted in figure 4f.

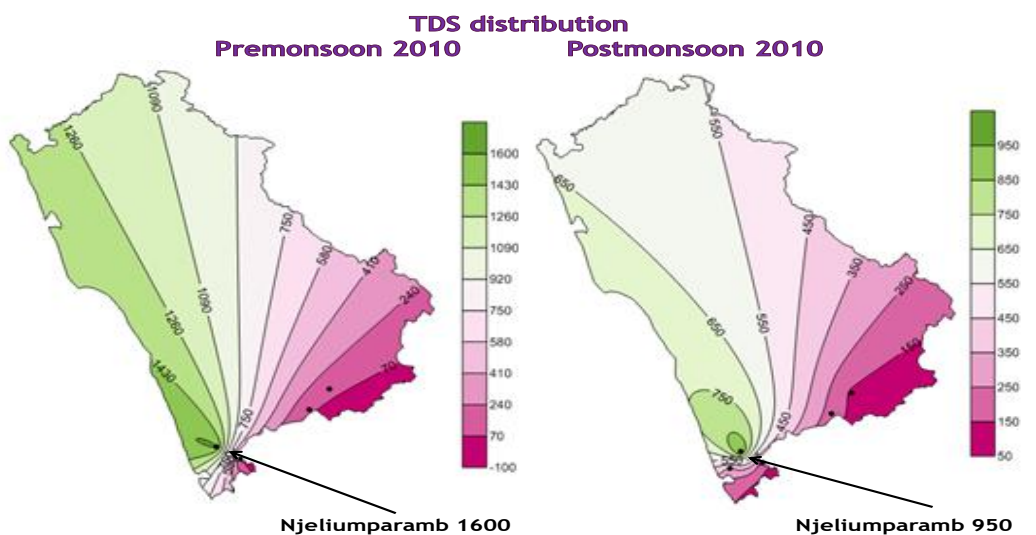


Figure 4f: Spatial Distribution of EC during post- monsoon 2010

Chlorides

The maximum chloride content in the water samples varied from 5 mg/l to 95 mg/l during 2008 pre-monsoon, 10 mg/l to 220 mg/l during post-monsoon 2010. Further observation taken during 2009 showed an increase of chloride concentration above 400 mg/l and during 2010 pre-monsoon it raised to 720 mg/l and post-monsoon it was 260 mg/l. This clearly indicates the impact of dumping sites on groundwater quality adjoining areas. Figures 4g, 4h and 4i show the variation of chloride during 2008, 2009 and 2010.

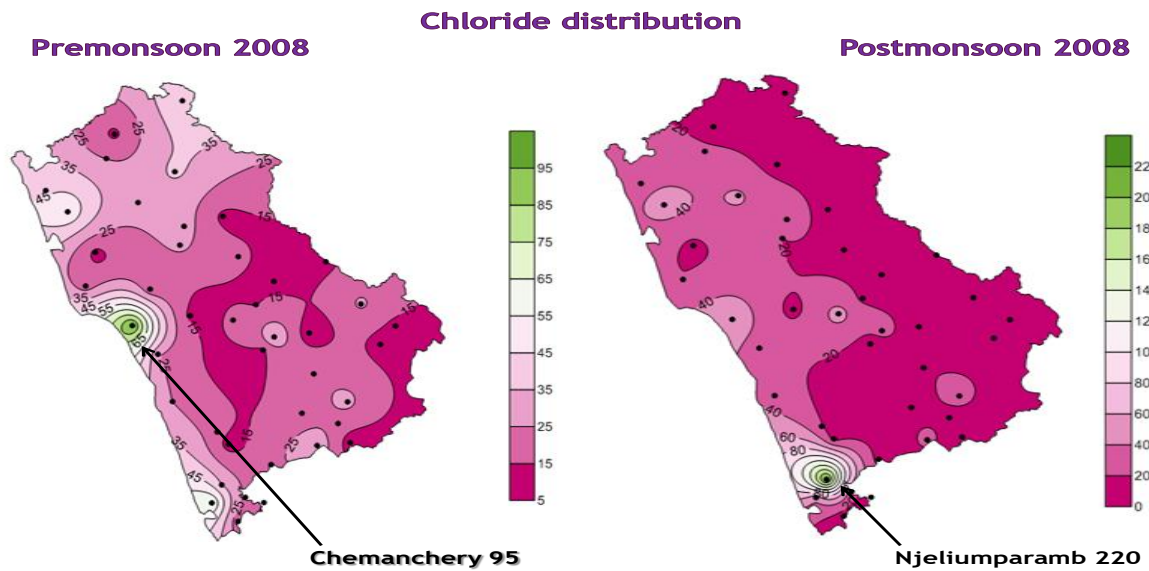


Figure 4g: Spatial Distribution of Chloride in Groundwater of Kozhikode district during 2008

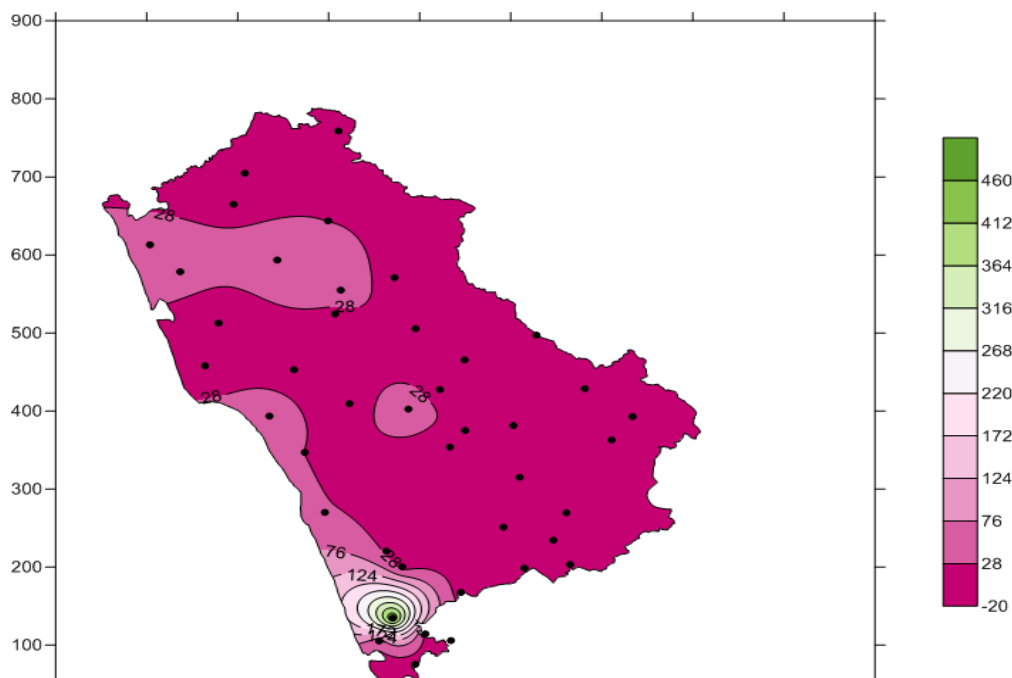


Figure 4h: Spatial Distribution of Chloride in Groundwater of Kozhikode district during 2009 (pre-monsoon)

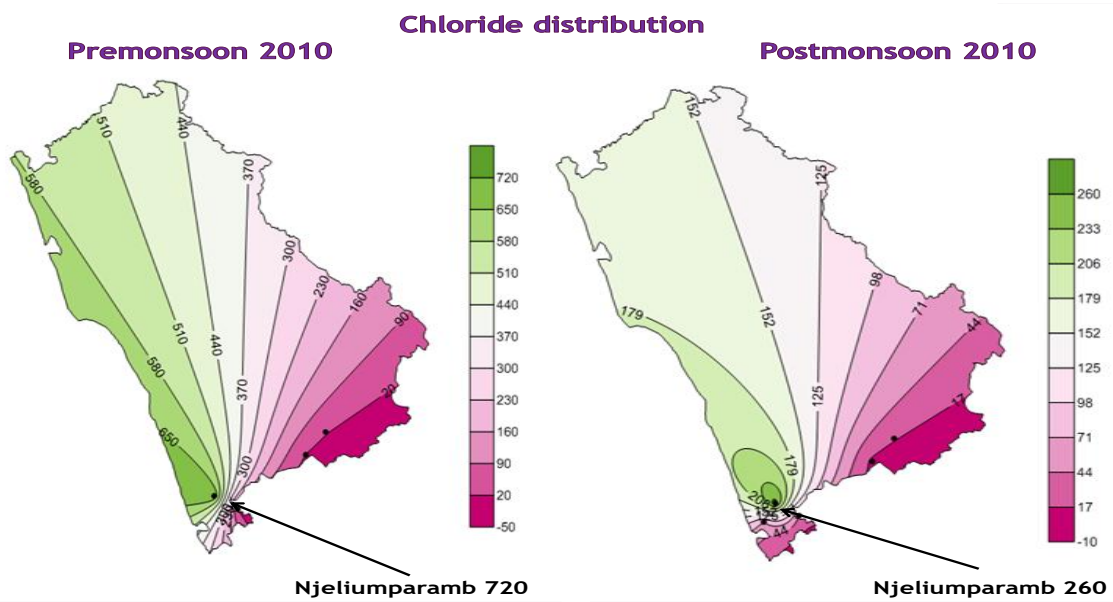


Figure 4i: Spatial Distribution of Chloride in Groundwater of Kozhikode district during 2010

Total Alkalinity

In the study area, it is found that there is a presence of carbonates in considerable quantity of carbonates (10 mg/l and 6 mg/l) both during pre-monsoon and post-monsoon seasons of 2010. Bicarbonate concentration was 145 mg/l and 147 mg/l during pre-monsoon and post-monsoon seasons of 2010. The variations of bicarbonates were quite minimal and needs further evaluation. The total alkalinity of the water samples were found to be within the permissible limit for all the samples as per BIS (1991).

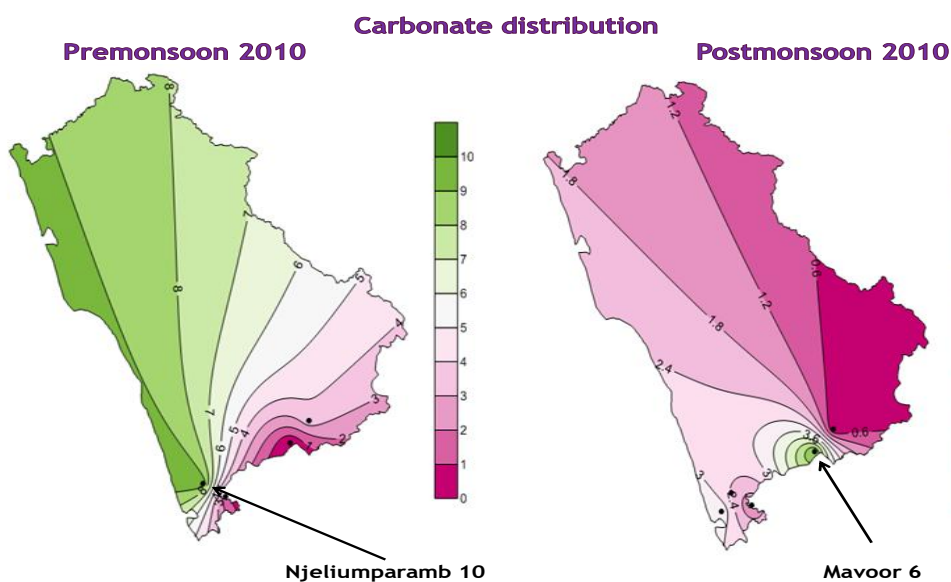


Figure 4j: Spatial Distribution of Carbonates in Groundwater of Kozhikode district during 2010

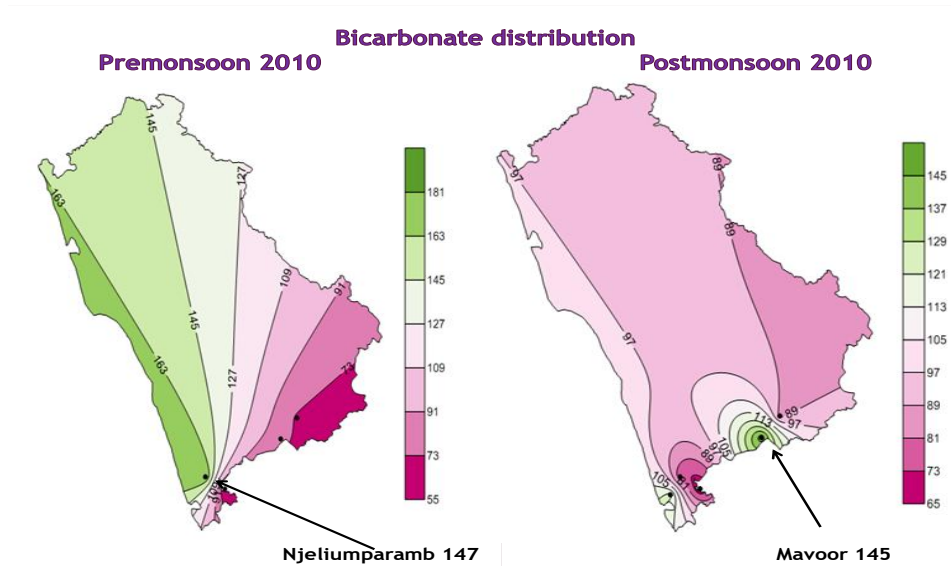


Figure 4k: Spatial Distribution of Bicarbonates in Groundwater of Kozhikode district during 2010

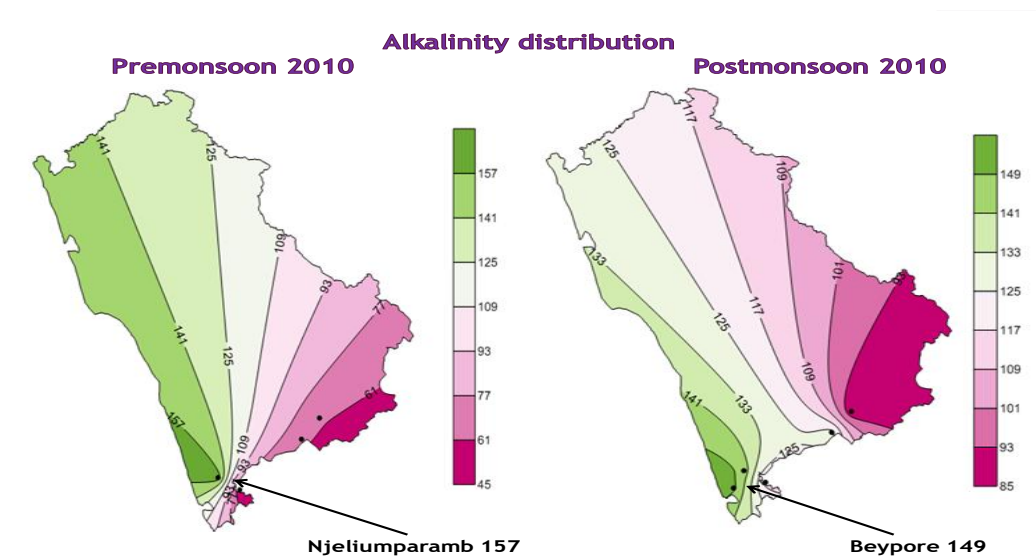


Figure 4l: Spatial Distribution of Total Alkalinity in Groundwater of Kozhikode district during 2010

Total Hardness

Total hardness of the water samples varied from less than 20 mg/l to 280 mg/l during pre-monsoon and a maximum of 250 mg/l was noticed in the post-monsoon 2008 and similar observation was reported during 2009. In the year 2010, Total hardness showed a considerable increase during pre-monsoon (344 mg/l) and it reduced to 149 mg/l in the post-monsoon of 2010. The seasonal variation of total hardness is represented in Figure 4m, 4n and 4o. Total hardness showed a very high positive correlation with magnesium suggesting a magnesium contributed hardness.

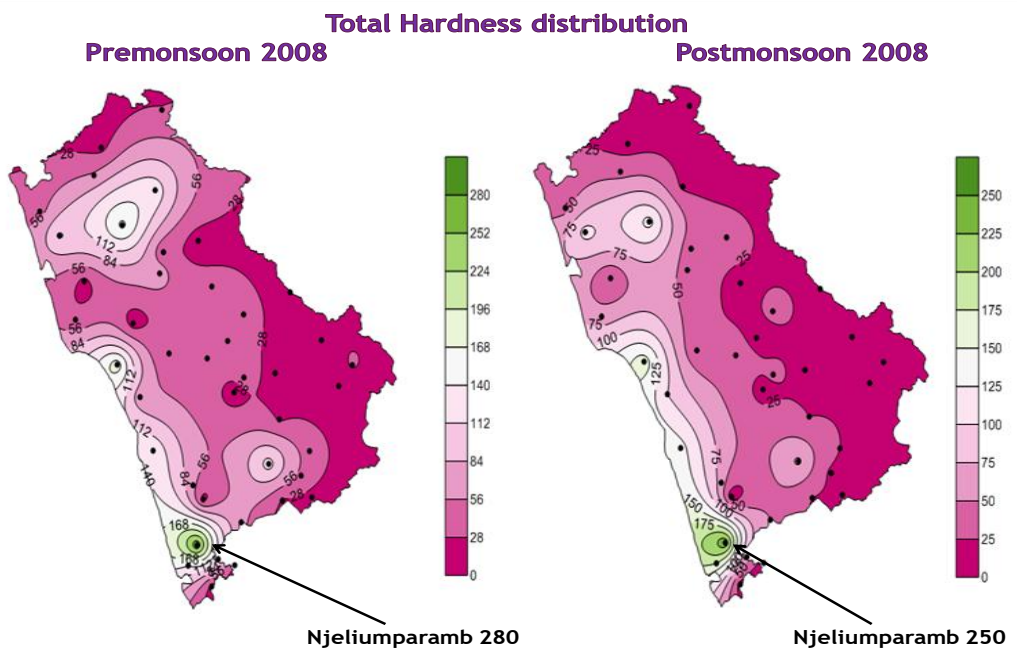


Figure 4m: Spatial Distribution of Total Hardness in Groundwater of Kozhikode district (2008)

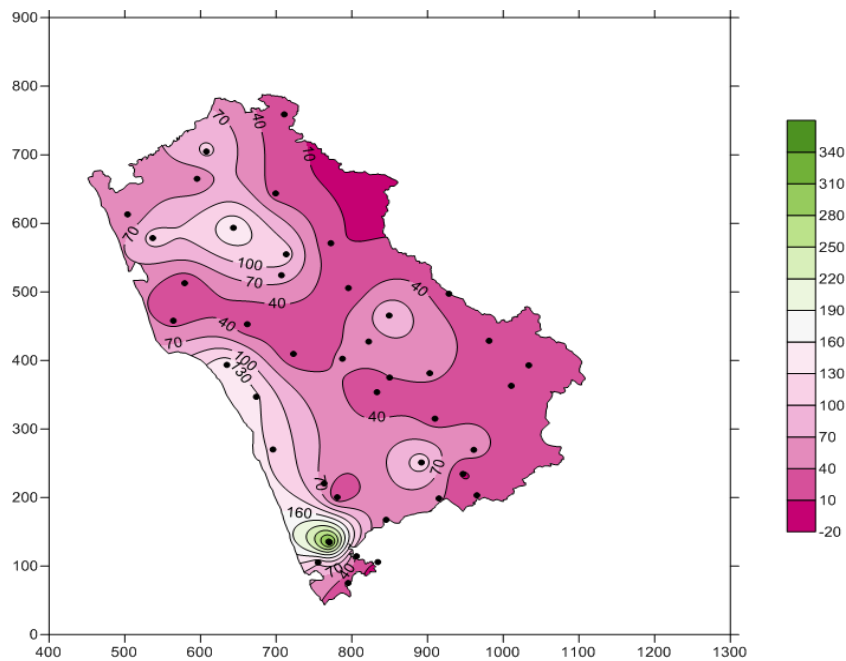


Figure 4n: Spatial Distribution of Total Hardness in Groundwater of Kozhikode district (pre-monsoon, 2009)

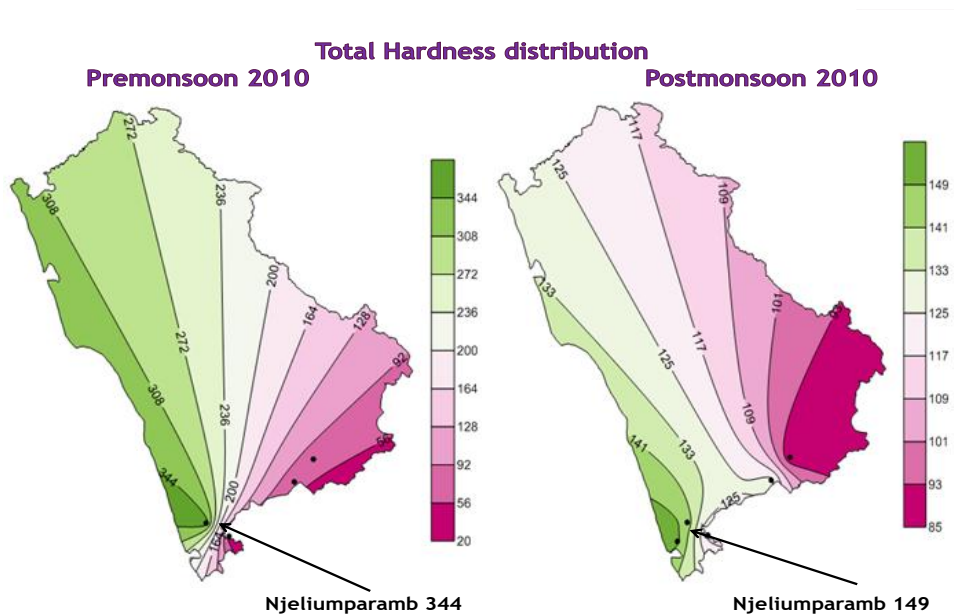


Figure 4o: Spatial Distribution of Total Hardness in Groundwater of Kozhikode district (2010)

Sulphates

The sulphate concentration ranged from 5.0 mg/l to 55 mg/l during pre-monsoon to 160 mg/l in the post-monsoon during 2010. From the existing literature it is stated that there is a significant change in the concentration of various ions in the adjoining areas of dumping site.

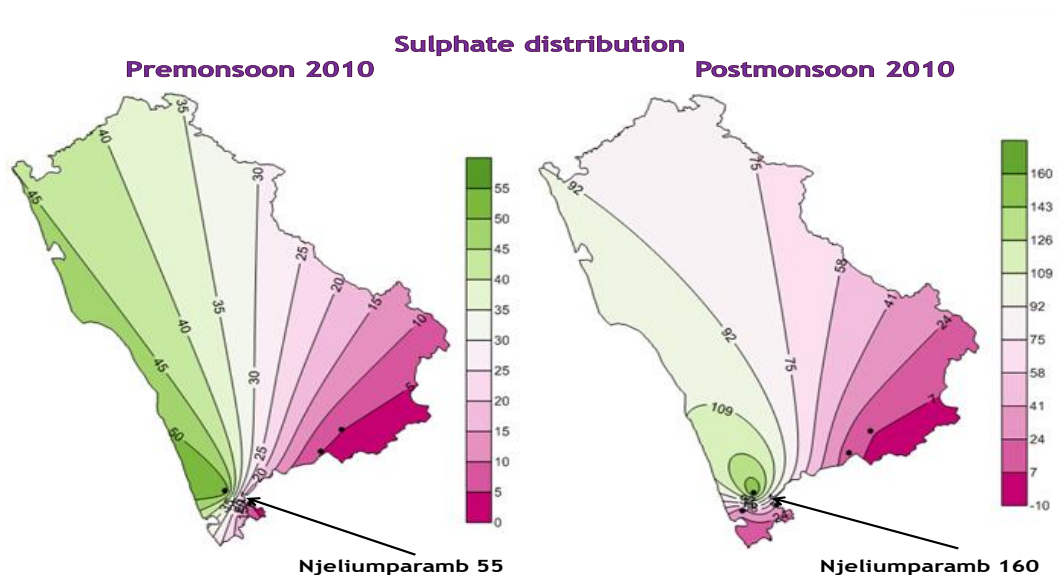


Figure 4p: Spatial Distribution of Total Hardness in Groundwater of Kozhikode district (2010)

Nitrates

The seasonal distribution of Nitrates in the study area seems to be quite negligible. The highest value observed was only 2.9 mg/l, i.e. at Beypore. However, with respect to dumping site

located in the city area, it is necessary to study in detail the movement of nitrates into the groundwater.

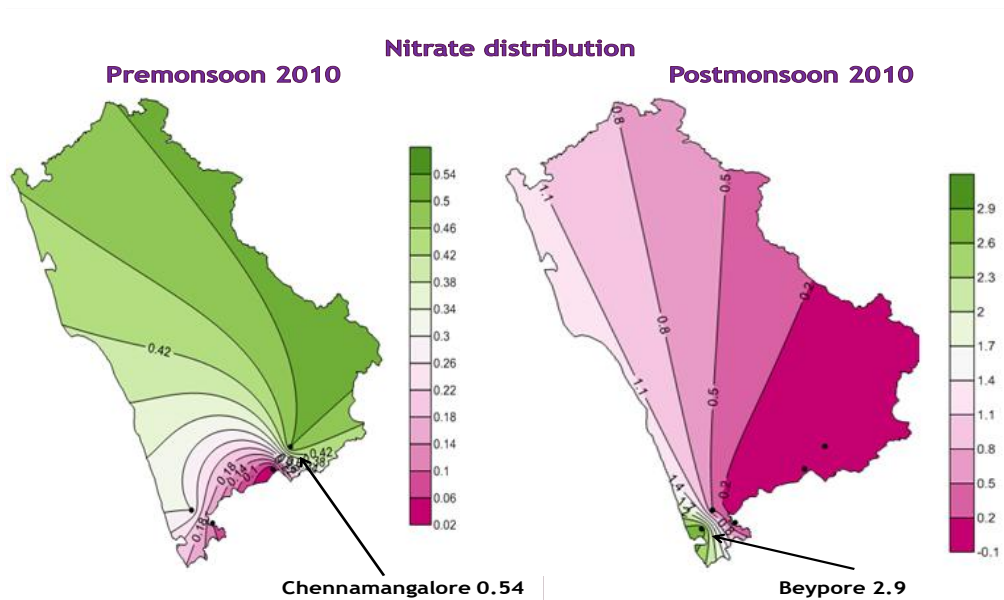


Figure 4q: Spatial Distribution of Chloride in Groundwater of Kozhikode district during 2009

Fluoride

The maximum concentration of fluoride observed was 0.87 mg/l during pre-monsoon and 0.97 mg/l during post-monsoon 2010. Fluoride concentration was found to be within the permissible limit during all the seasons. In the present study an attempt was also made to correlate fluoride with other anions and cations. In the present study a significant positive correlation was noted between fluoride and Electrical conductivity, Total hardness, Alkalinity, Total dissolved Solids, Chloride and Sulphate.

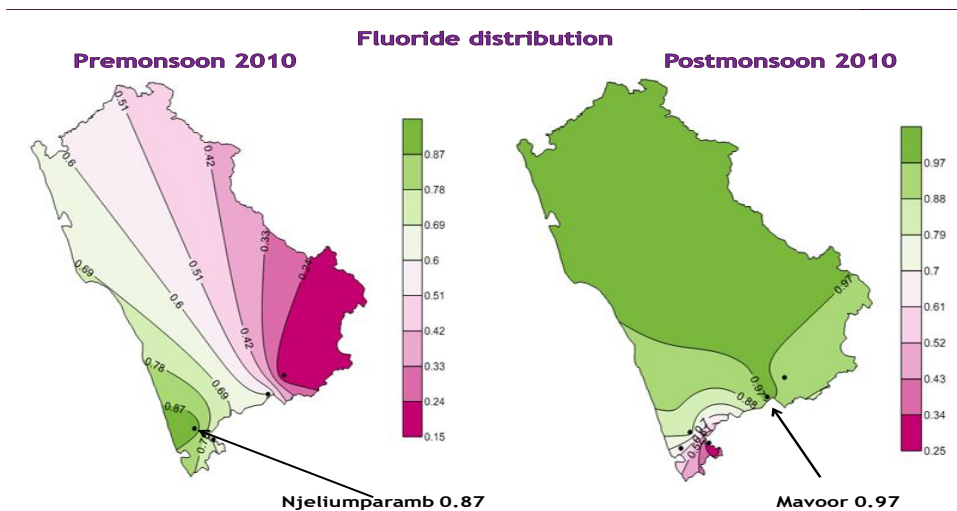


Figure 4r: Spatial Distribution of Flouride in Groundwater of Kozhikode district (2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figure 4s and 4t). It is observed that both calcium and magnesium concentrations are much below the permissible limit. The concentrations of calcium vary between 6 mg/l and 46 mg/l during pre-monsoon and in the post monsoon it varies from 18 mg/l to 43 mg/l. The concentration of magnesium varies from 2 mg/l to 56 mg/l during pre-monsoon of 2010 and 18 mg/l to 43 mg/l in the post-monsoon 2010. It is also noticed that the proportion of magnesium concentration is relatively higher than calcium, which could be due to the presence of saline water incursion through canals connected to estuarine areas.

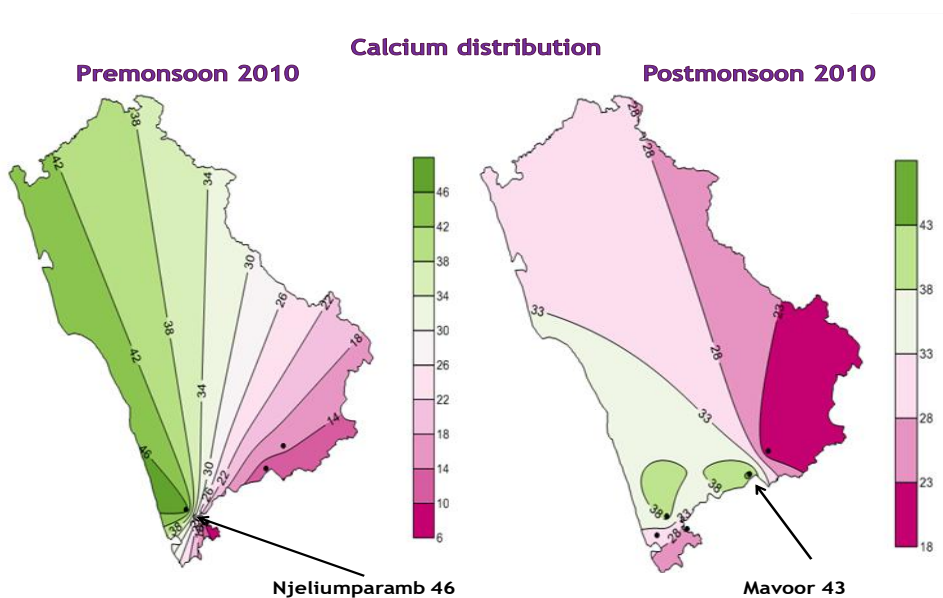


Figure 4s: Spatial Distribution of Calcium in Groundwater of Kozhikode district during 2009

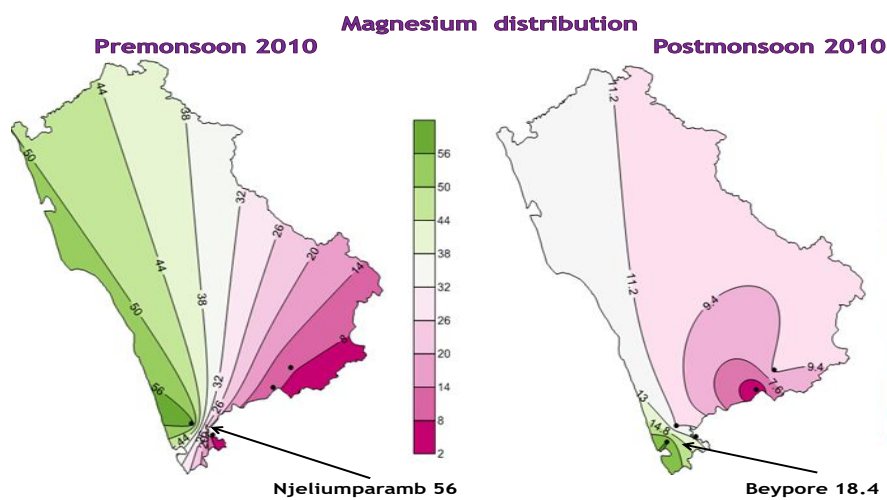


Figure 4t: Spatial Distribution of Magnesium in Groundwater of Kozhikode district (2010)

Sodium and Potassium

Sodium concentration of the samples was found to be in the range of 6.0 mg/l to 60 mg/l, during pre-monsoon and 11 mg/l to 110 mg/l during post-monsoon of 2008. Analysis of 2010 water showed a significant increase in the sodium concentration it increased to a maximum of 400 mg/l during pre-monsoon and 200 mg/l in the post-monsoon. The high range of sodium could be attributed to the leaching of solid waste containing sodium salts. The variation of sodium content in water samples is represented in Figures 4t & 4u in 2008 and 2010.

The potassium level of the Njheliyanparamba samples varied from 1.5 mg/l to 11.5 mg/l during the pre-monsoon of and 4.0 mg/l to 51.0 mg/l during post-monsoon 2010. The seasonal variation of potassium concentration is represented in figure 4v.

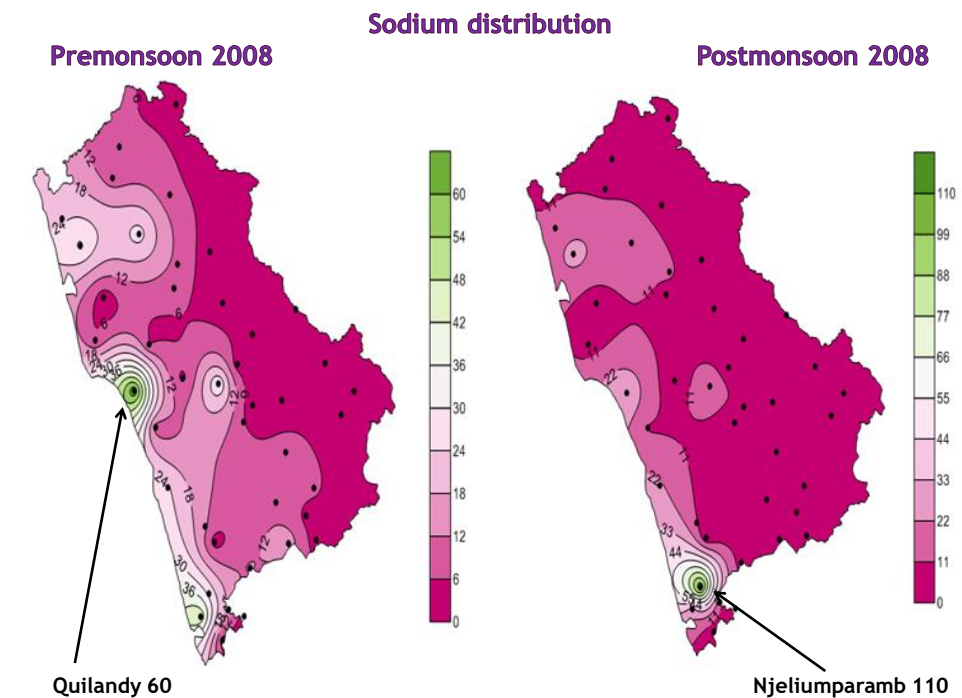


Figure 4t: Spatial Distribution of Sodium in Groundwater of Kozhikode district(2008)

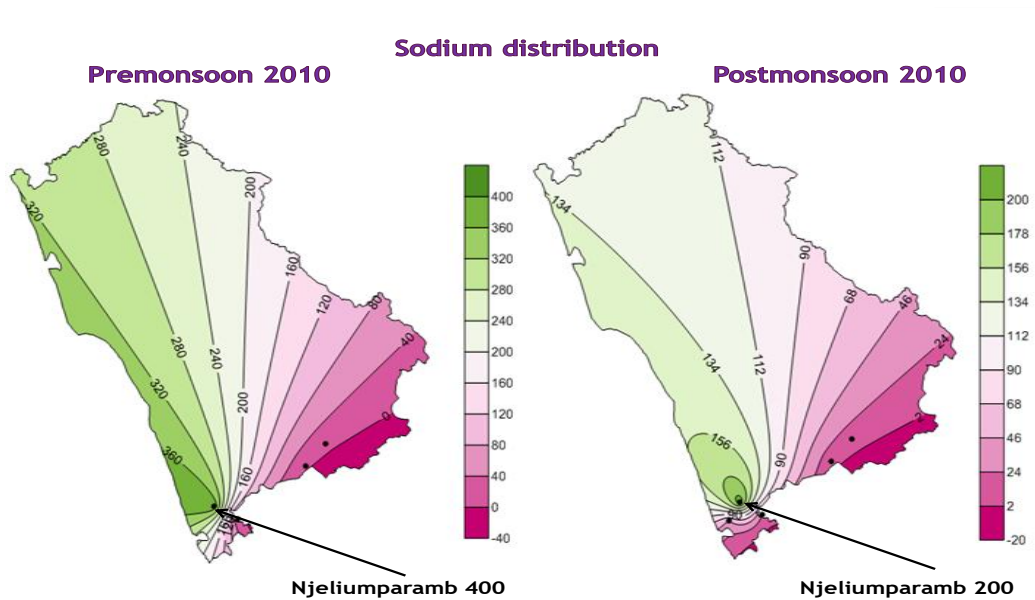


Figure 4u: Spatial Distribution of Sodium in Groundwater of Kozhikode district(2010)

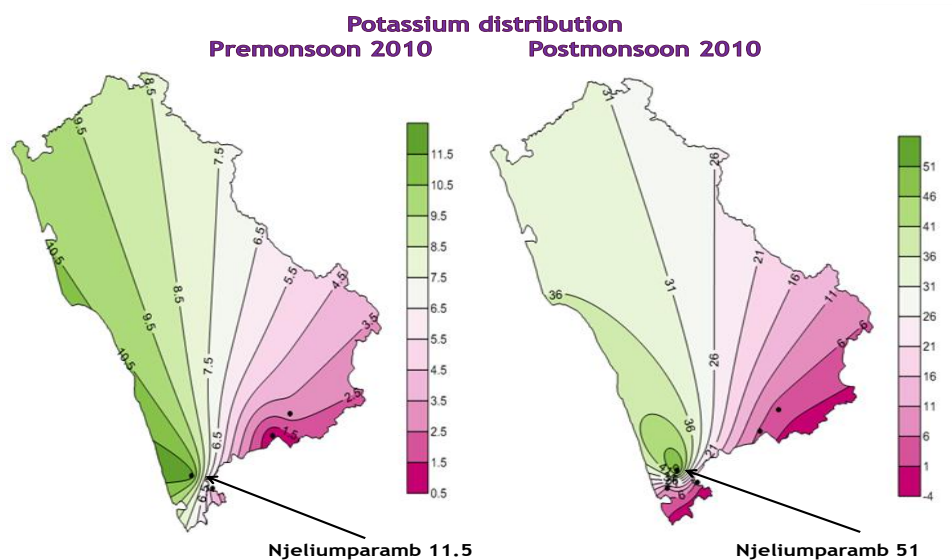


Figure 4v: Spatial Distribution of Potassium in Groundwater of Kozhikode district(2010)

Iron

The excess iron is one of the most common ion which is present in excess in ground water of Kerala. The maximum concentration of iron in the study area during 2008 is found to vary from 0.04 mg/l to 1.03 mg/l in the pre-monsoon and 0.08 mg/l to 1.04 mg/l during post-monsoon. However, analysis of 2009 pre-monsoon samples showed a very high concentration of iron (8.5 mg/l) which could be attributed to high intensity rainfall occurred in isolated patches. In the year 2010, concentration showed variation between 0.2 mg/l and 2.8 mg/l during pre-monsoon and 0.3 mg/l to 2.4 mg/l in the post-monsoon. Iron is comparatively lesser than some of the northern and eastern districts.

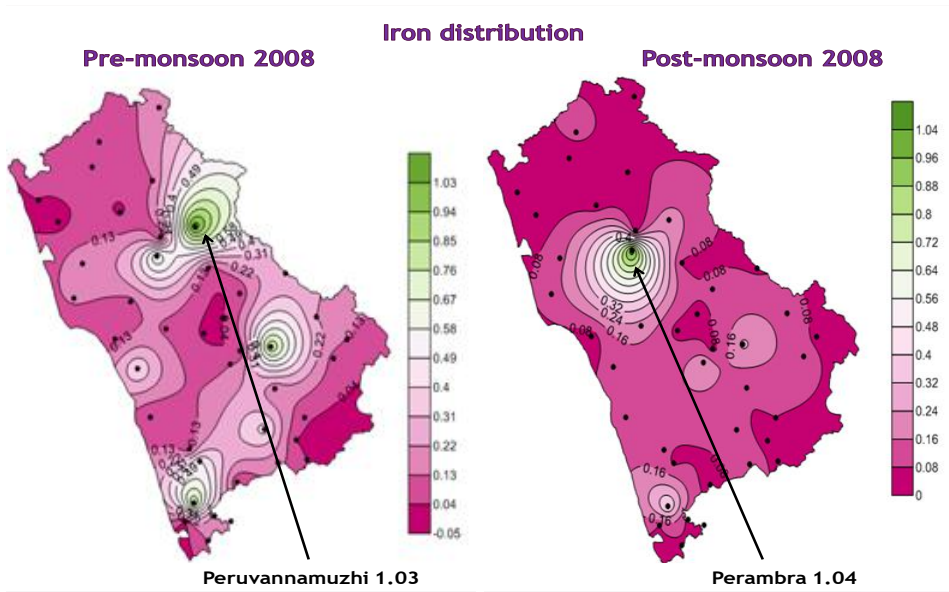


Figure 4w: Spatial Distribution of Iron in Groundwater of Kozhikode district(2008)

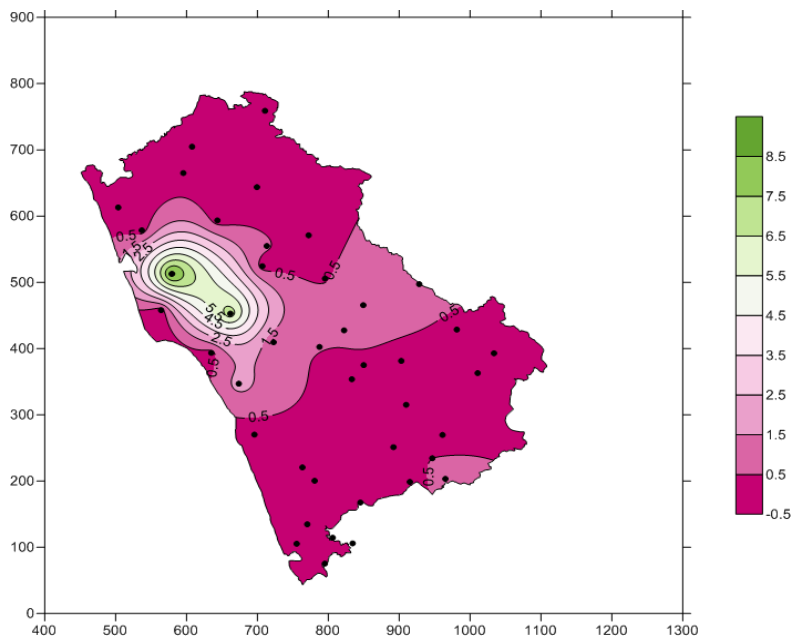


Figure 4x: Spatial Distribution of Iron in Groundwater of Kozhikode district(2010)

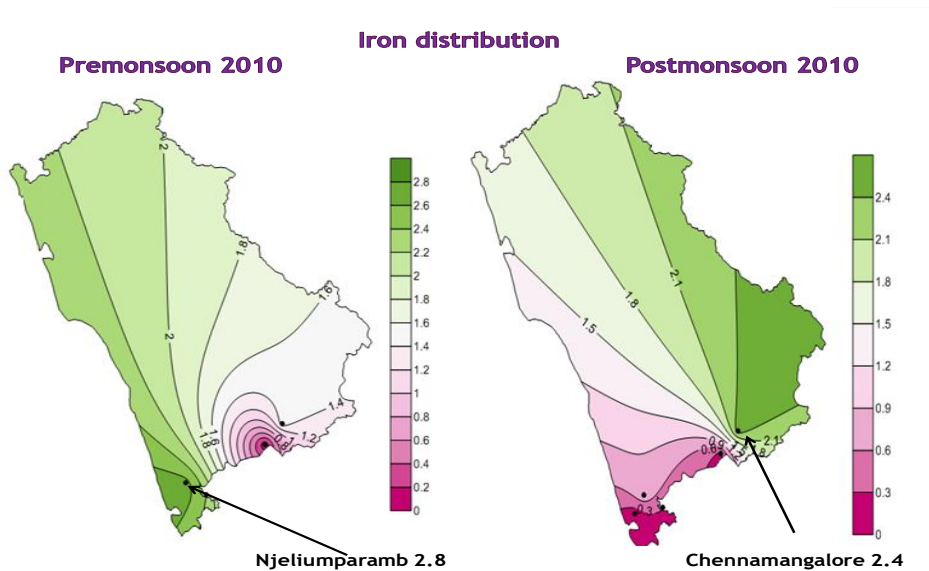


Figure 4y: Spatial Distribution of Iron in Groundwater of Kozhikode district(2010)

Statistical Analysis

Statistical analyses were carried out to understand the relationship between various anions and cations. A moderate to high positive correlation were observed between EC & TDS, Total Hardness. Chloride shows high positive correlation sodium, Both sodium and chloride showed a moderate correlation with Electrical conductivity

Table 4a: Correlation between parameters during pre-monsoon 2008

Kozhikode Premonsoon 2008 Correlation						
	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	-0.15	1.00				
Total Hardness	-0.22	0.83	1.00			
Cl	-0.45	0.52	0.58	1.00		
Na	-0.32	0.65	0.72	0.83	1.00	
Fe	0.25	0.25	0.11	-0.20	-0.17	1.00

Table 4b: Correlation between parameters during post-monsoon 2008

Kozhikode Postmonsoon 2008 Correlation						
	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	0.58	1.00				
Total Hardness	0.63	0.97	1.00			
Cl	0.38	0.90	0.79	1.00		
Na	0.43	0.95	0.85	0.99	1.00	
Fe	0.11	0.15	0.11	0.21	0.19	1.00

Table 4c: Correlation between parameters during pre-monsoon 2010

Kozhikode Premonsoon 2010													
	pH	EC	Total Hardness	Alkalinity	Total Dissolved Solids	CO ₃	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na
pH	1.00												
EC	0.44	1.00											
Total Hardness	0.42	1.00	1.00										
Alkalinity	0.38	0.99	1.00	1.00									
Total Dissolved Solids	0.44	1.00	1.00	0.99	1.00								
CO ₃	0.69	0.94	0.94	0.93	0.94	1.00							
HCO ₃	0.33	0.99	0.99	1.00	0.99	0.91	1.00						
Cl	0.45	1.00	1.00	0.99	1.00	0.94	0.98	1.00					
SO ₄	0.44	1.00	1.00	0.99	1.00	0.94	0.99	1.00	1.00				
NO ₃	0.79	0.24	0.26	0.25	0.24	0.54	0.21	0.23	0.22	1.00			
Ca	0.46	0.99	1.00	1.00	0.99	0.96	0.99	0.99	0.99	0.33	1.00		
Mg	0.41	1.00	1.00	1.00	1.00	0.93	1.00	1.00	1.00	0.23	0.99	1.00	
Na	0.45	1.00	0.99	0.99	1.00	0.94	0.98	1.00	1.00	0.23	0.99	1.00	
K	0.65	0.96	0.94	0.92	0.96	0.96	0.90	0.96	0.96	0.33	0.94	0.94	
F	-0.07	0.67	0.64	0.63	0.67	0.43	0.65	0.68	0.69	-0.52	0.58	0.66	
Fe	0.84	0.57	0.51	0.46	0.57	0.67	0.43	0.57	0.57	0.34	0.51	0.51	

Table 4d: Correlation between parameters during post-monsoon 2010

Kozhikode Postmonsoon 2010 Correlation																
	pH	EC	Total Hardness	Alkalinity	Total Dissolved Solids	CO ₃	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1.00															
EC	0.42	1.00														
Total Hardness	0.47	0.61	1.00													
Alkalinity	0.54	-0.26	0.34	1.00												
Total Dissolved Solids	0.42	1.00	0.61	-0.26	1.00											
CO ₃	0.80	0.03	0.58	0.89	0.03	1.00										
HCO ₃	0.49	-0.30	0.30	1.00	-0.30	0.86	1.00									
Cl	0.31	0.99	0.56	-0.38	0.99	-0.09	-0.41	1.00								
SO ₄	0.36	0.98	0.52	-0.42	0.98	-0.09	-0.46	0.99	1.00							
NO ₃	-0.26	0.10	0.65	0.28	0.10	0.19	0.29	0.10	-0.03	1.00						
Ca	0.97	0.51	0.67	0.57	0.51	0.85	0.52	0.40	0.43	-0.02	1.00					
Mg	-0.63	0.12	0.40	-0.30	0.12	-0.34	-0.29	0.20	0.10	0.82	-0.42	1.00				
Na	0.34	0.99	0.54	-0.36	0.99	-0.07	-0.39	1.00	0.99	0.07	0.42	0.15	1.00			
K	0.40	1.00	0.54	-0.30	1.00	-0.02	-0.33	0.99	0.98	0.03	0.47	0.07	1.00	1.00		
F	0.47	0.13	-0.06	0.54	0.13	0.38	0.55	0.04	-0.01	-0.16	0.40	-0.58	0.09	0.17	1.00	
Fe	-0.46	-0.14	-0.77	-0.40	-0.14	-0.68	-0.36	-0.09	-0.12	-0.40	-0.59	-0.21	-0.07	-0.05	0.39	1.00

Figure 4z, 4aa & 4bb shows the clustering between the ions indicating their mutual relationship during the years 2008 and 2010.

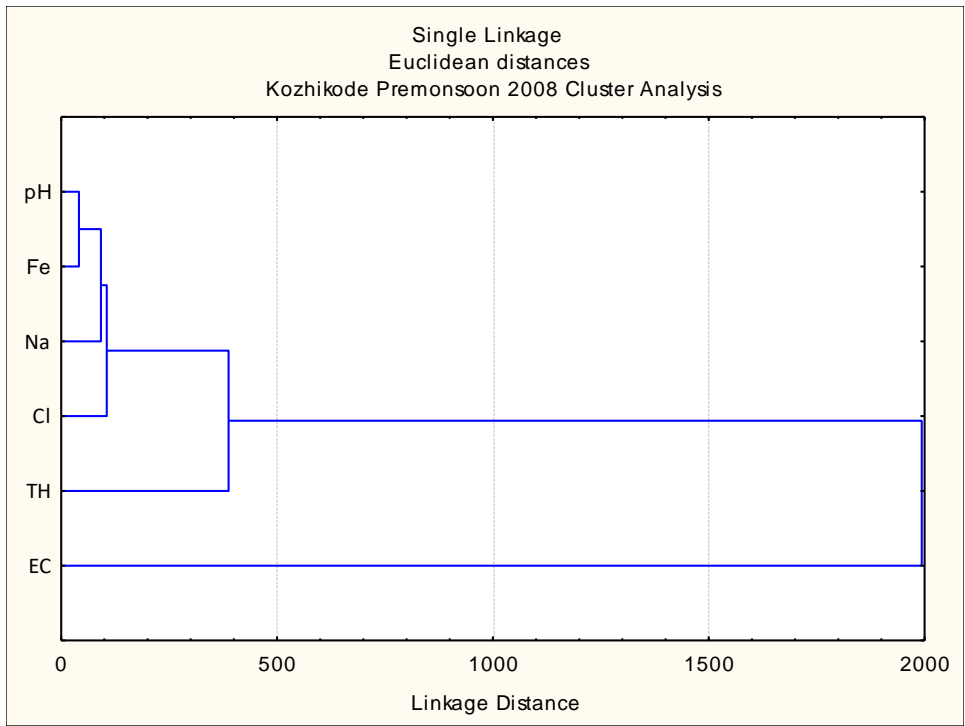


Figure 4z: Dendrogram showing the relationship between ions in Groundwater of Kozhikode district (pre-monsoon, 2008)

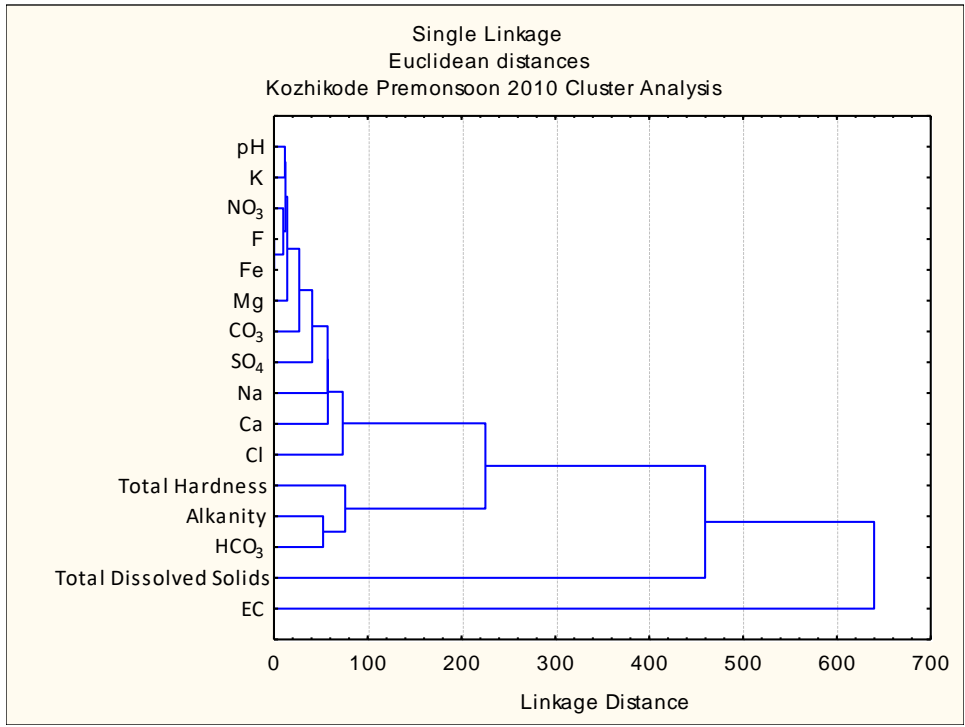


Figure 4z: Dendrogram showing the relationship between ions in Groundwater of Kozhikode district (pre-monsoon, 2010)

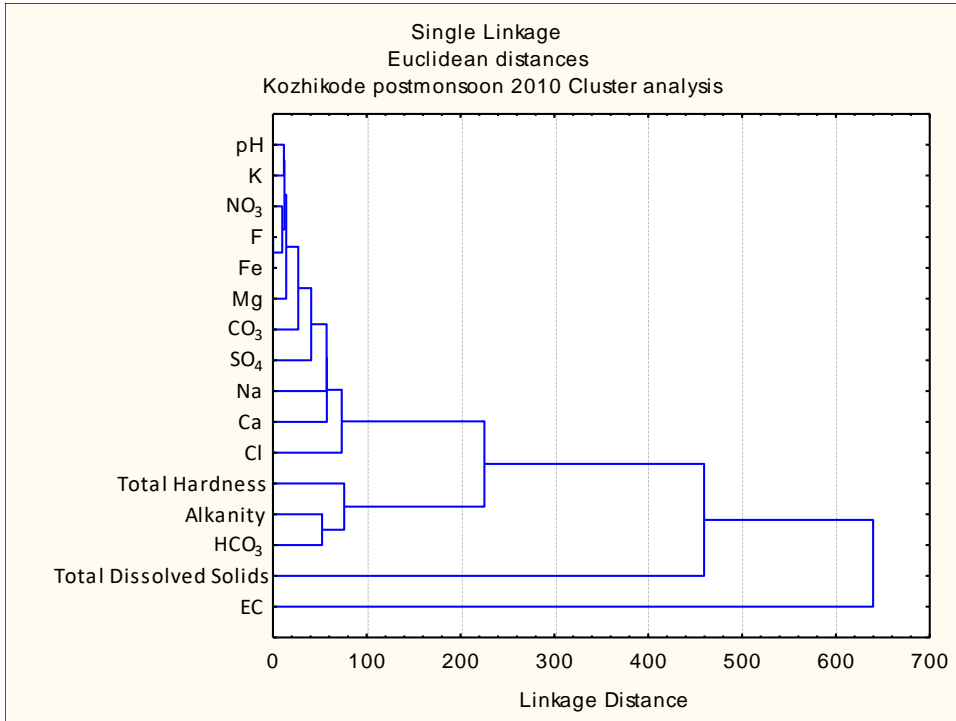


Figure 4bb: Dendrogram showing the relationship between ions in Groundwater of Kozhikode district (post-monsoon, 2010)

Groundwater Classification

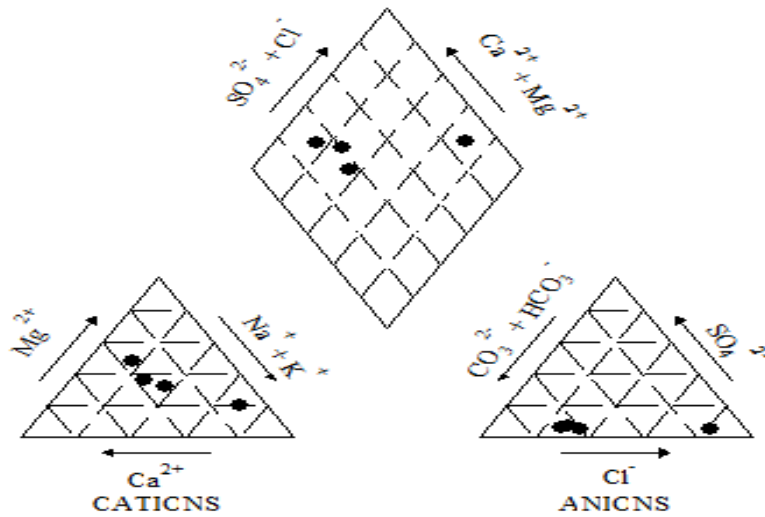


Figure 4cc: Piper's diagram for Groundwater classification (pre-monsoon 2010)

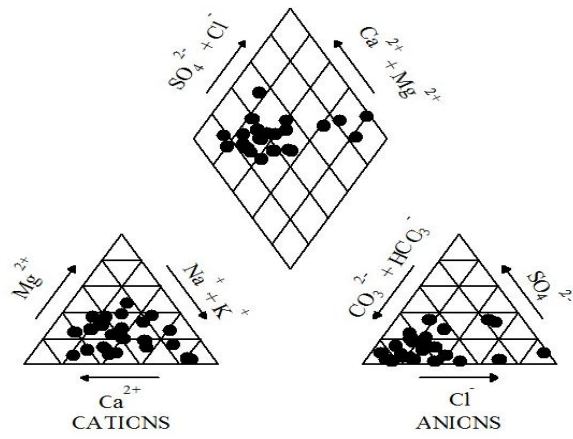


Figure 4dd: Piper's diagram for Groundwater classification (post-monsoon 2010)

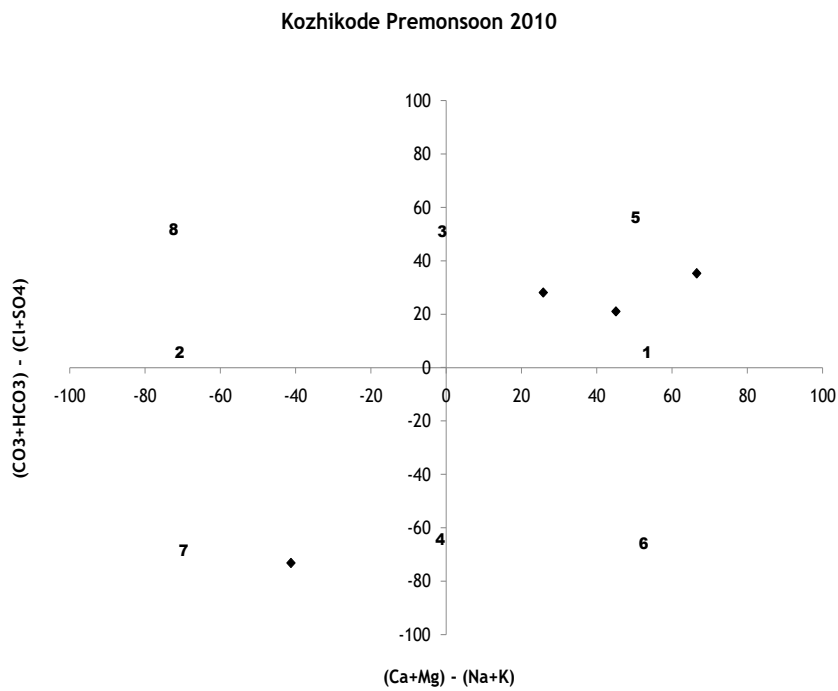


Figure 4ee: Piper's diagram for Groundwater classification (post-monsoon 2010)

Kozhikode Postmonsoon 2010

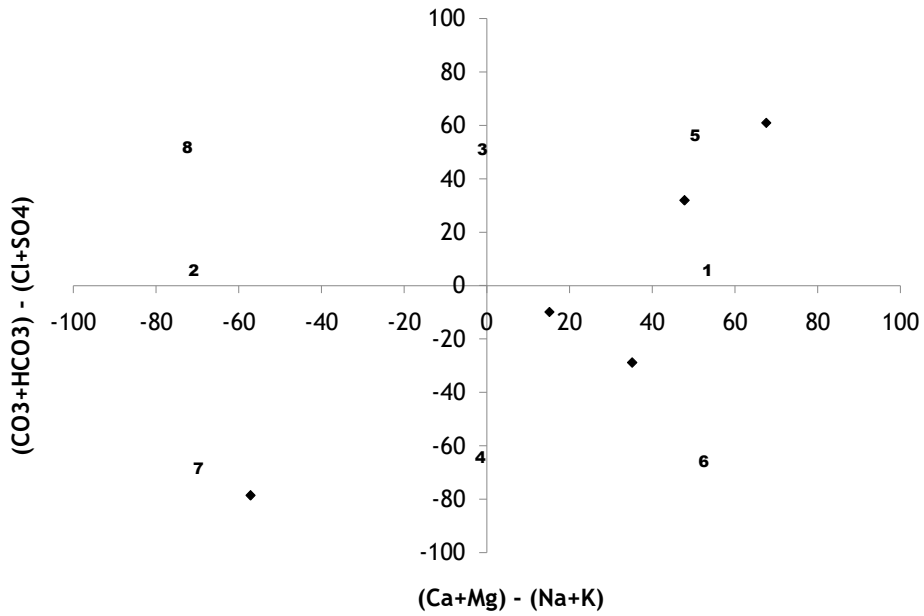


Figure 4ff: Piper's diagram for Groundwater classification (post-monsoon 2010)

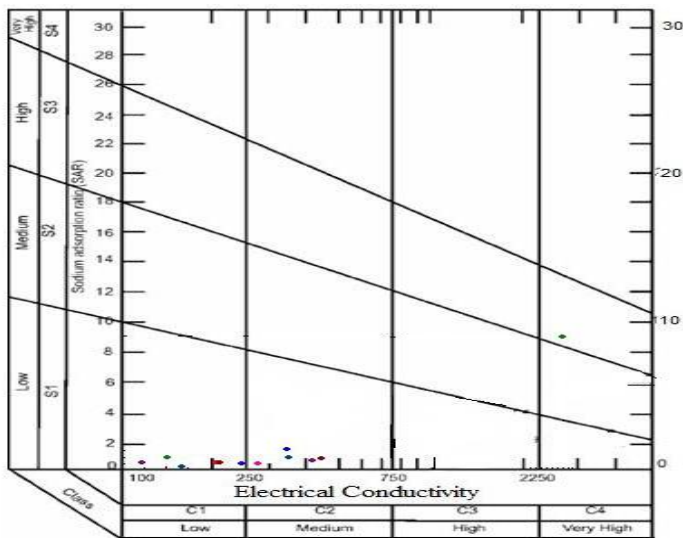


Figure 4gg: USSL classification of Ground water of Kozhikode district (Pre-monsoon 2010)

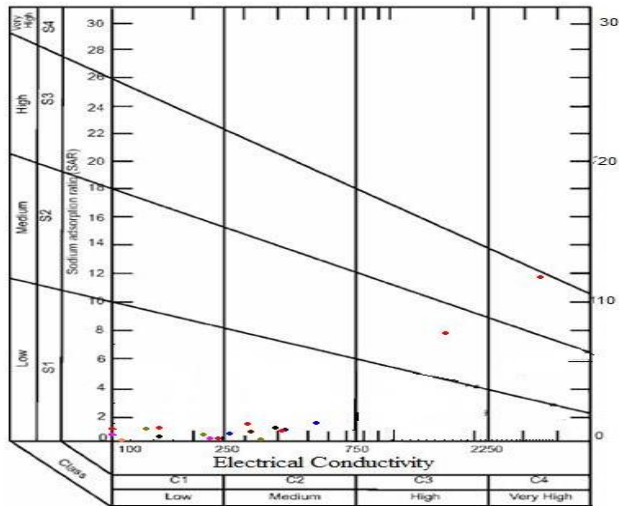


Figure 4hh: USSL classification of Ground water of Kozhikode district (Post-monsoon 2010)

From the above study it is found that one of the major issue with regard to management of municipal solid waste. In recent years it is brought to the notice that groundwater pollution through leachate is matter of serious concern. The movement of leachate from a waste-disposal site is governed by the physical environment (William, 1972). When the wastes are above the water table, both chemical and biological contaminants in the leachate move vertically through the zone of aeration at a rate partly dependent on the properties of the soils. The chemical contaminants, being in solution, generally tend to travel faster than biological contaminants. Sandy or silty soils in general retard particulate biological contaminants and often filter them from the percolating leachate. The chemical contaminants, however, may be carried by the leachate water to the water table where they enter the ground-water flow system and move according to the hydraulics of that system. The analysis results show that there are possibilities of leaching of contaminants to groundwater due to the unplanned dumping site. Therefore, it is necessary to have a detailed study on the movement of the chemical contaminants to groundwater.

Heavy Metals in Groundwater of Kozhikode District

The heavy metals were determined for selected wells in Kozhikode district. Sixteen wells have been identified based on field investigations which are most prone to heavy metal contamination. Analysis shows that in majority of the wells there are indications of contamination. The present observations show that the concentrations are below the permissible limits. However, it is very important to note that there is a need of immediate attention for controlling the sources of such pollution.

Table 4e : Heavy metal concentrations in Selected wells of Kozhikode district								
well No	Ortho Phosphate	Zinc	Cadmium	Lead	Copper	Mercury	Arsenic	Nickel
PDSKKD 01	0	0.119	0	0.008	0.008	0	0	0
PDSKKD 02	0.01	0.169	0	0	0	0	0	0
PDSKKD 03	0.01	0.947	0	0.003	0.009	0	0	0
PDSKKD 04	0.02	0.09	0	0.09	0.09	0	0	0
PDSKKD 05	0.08	0.116	0	0.004	0.004	0	0	0
PDSKKD 06	0.01	0.294	0.005	0	0	0	0	0
PDSKKD 09	0.06	2.527	0.1006	0.019	0.019	0	0	0
PDSKKD 10	0.16	0.366	0	0.012	0.012	0	0	0
PDSKKD 12	0.03	0.082	0	0	0	0	0	0.001
PDSKKD 13	0	0.082	0	0	0	0	0	0
PDSKKD 14	0	0.153	0.003	0.012	0.012	0	0	0.0021
PDSKKD 14		0.153	0.003	0.012	0.012			0.0021
PDSKKD 18	0.05	1.034	0.006	0	0.012	0.012	0	0
PDSKKD 18	0.05	1.034	0.006		0.012	0.012		
PDSKKD 19	0.02	1.95	0.01	0	0	0	0	0.0093
PDSKKD 19	0.02	1.95	0.01					0.0093

5.0 GROUNDWATER QUALITY OF MALAPPURAM DISTRICT

5.1 General features and Characteristics of the District

Malappuram literally means an elevated place on the top of hills. The district has a unique importance in the geological history. Laterite was first identified in the area near Angadippuram Railway Station by Francis Buchanan. This is the type area of Laterite. The district lies between North latitudes 10° 40' and 11° 32' and East longitude 75° 50' and 76° 36'. The Nilgiris of Tamil Nadu in the east and Lakshadweep Sea in the west provide natural boundaries. In the north it is bounded by Kozhikode and Wayanad and in the south by Palakkad and Trichur districts. The district has a geographical area of 3550 sq.km, which is 9.13 % of the total area of the State.

According to 2001 census, the district has a population of 3629640, which is about 12 % of the total population of the State. Of the total population 1759479 are males and 1870161 are females. The district has recorded a population growth rate of 17 % during 2001 which is the highest in the State. Malappuram ranks 3rd in the area and first in the population of the State. There are 6 taluks namely Ernad, Perinthalmanna, Tirur, Ponnani, Nilambur and Tirurangadi 14 blocks, 100 panchayats and 135 villages. There are five municipalities namely Malappuram, Manjeri, Tirur, Ponnani and Nilambur.

Drainage

Malappuram district is mainly drained by the Kadalundi river, Chaliyar and Bharathapuzha. Of these rivers, only Chaliyar and Bharathapuzha are perennial and all others get dried up in summer and hence Malappuram district is highly drought prone. The Kadalundi river is formed by the confluence of its two main tributaries viz; the Olipuzha and the Veliyar. The Olipuzha takes its origin from 'the Cherakkobban Mala' (1160 m amsl) and the Veliyar originates from the forest of the 'Erattakomban Mala' (1190 m amsl). The Kadalundi river is 130 km long with a drainage area of 1274 sq. km. The river joins the Lakshadweep Sea at about 5 km south of the Chaliyar river mouth.

The Chaliyar river, one of the major rivers of the State, originates from the Ilambalari Hills in Nilgiri district of Tamilnadu (2066 m amsl). The river flows along the northern boundary of Malappuram district through Nilambur, Mambad, Edavanna, Areakode and Feroke. It joins the Lakshadweep Sea near Beypore. The river is 169 km long with a drainage area of 2535 sq. km in Kerala State.

The Bharathapuzha or the Ponnani river is the second longest river of Kerala, originating from the Anamalai Hills (1964 m amsl) in the Western Ghats. The river below the confluence of Bharathapuzha and Gayathripuzha is called the Ponnani river. It flows through the districts of Palakkad, Malappuram and Trichur and drains into the Lakshadweep Sea near Ponnani town in Malappuram district. The drainage pattern of the three rivers in the district is generally dendritic. Tidal effects are experienced in places such as Vallikkunnu and Tirurangadi, which are 6 to 8 km away from the coast.

Analysis of the drainage characteristics of the two basins reveals that Kadalundi river is a fourth order stream, the Ponnani river is fifth order stream and the Chaliyar river is a seventh order stream.

Land use

The Kerala State Land Use Board has computed the area under various uses. The following Table 5a represents the land under various categories.

Table 5a: Land use types present in Malappuram district

Sl.No	Category	Area in hectares	% of total area
1	Geographical area	355000	100
2	Built up land	2322	0.65
3	Agriculture land	266890	75.18
4	Forest land	75699	21.32
5	Water bodies	4994	1.41
6	Waste land	5094	1.44

Rainfall & Climate

The district has more or less the same climatic conditions prevalent elsewhere in the State viz. dry season from December to February and hot season from March to May, the South-West monsoon from June to September and the North East monsoon from October to December. The normal rainfall

Table 2.: Rainfall distribution in the district during 2001-2006(source: CGWB, District report). of the district is 2793.3 mm. Out of this, major rainfall contribution is from SW monsoon followed by the NE. The South West monsoon is usually very heavy and nearly 73.5% of the rainfall is received during this season. NE monsoon contributes nearly 16.4% and March to May summer rain contributes nearly 9.9% and the balance 0.2% is accounted for January and February months. The monthly rainfall for the Malappuram district during the period 2001 – 06 is tabulated in Table 5b.

Table 5b: Monthly rainfall of Malappuram district during 2001-2006

Month	2001-02	2002-03	2003-04	2004-05	2005-06
April	269	73	165	99	116
May	229	306	70	598	106
June	709	461	669	708	550
July	553	257	525	271	887
August	294	460	279	404	125
September	150	48	52	156	369

Geomorphologically the district can be divided into three viz. coastal plain (less than 7.5 m amsl) mid land (7.5 – 75 m amsl) and highland (above 75 m amsl). The coastal plains extend as a narrow stretch of land lying along the coast from Kadalundi Nagaram in the north to Ponnani in the south. It becomes very narrow towards north of Tirur and the maximum width is seen along Chauravallam - Tirurangadi area. The area lying between the coastal plain in the west and the high ranges in the east is occupied by midlands. This is the most prominent physiographic unit of the district. This is characterised by flat topped hillock with steep 'U' shaped valleys and ridges. The valley forms potential area for agriculture including paddy, arecanut, vegetable, banana and coconut. The hill tops are generally barren and covered by thick and compact laterite. The eastern parts of the district are characterised by steep hills, gorges and escarpments. The elevation of the hill ranges goes upto 1127 m amsl. Most of the high lands are occupied by forests.

The soils of the district can be broadly divided into the following categories

(i) Alluvial soils

Those are mainly seen along the coastal plains and valleys. The soils range from exclusively drained to moderately/well drained sand to sandy clay in nature.

(ii) Lateritic soil

These are mostly lateritic soil, and is seen along the mid land portion of the district. These are deep to very deep, well drained gravelley to clayey.

Hydrogeology

The aquifer system in the district can be broadly divided into Crystalline aquifers, Laterite aquifers and Alluvial aquifers. Crystalline and Laterite aquifers constitute major part of the district. In the crystalline rocks of the area viz. Charnockite, Biotite gneiss and Migmatite, the occurrence and movement of ground water are dominantly controlled by the nature and extent of weathering and the presence of structural features like fractures, joints and shear zones which generally varies from place to place. Ground water occurs in the secondary intergranular pores and voids, under unconfined conditions in the shallow weathered and fractured rocks and under semi-confined to confined conditions in the deeper fractured zones. Weathered rock forms potential aquifers and the thickness of weathered rock ranges from 4 to 12 mtrs below ground level. Along valley portions in the area ground water is developed mostly by means of dug wells. The wells piercing the weathered zone vary from 15 to 20 m and ranges in diameter from 2 to 5 m. Their depth varies from 3.5 to 21.2 m bgl. The yields of those wells are of the order of 6 to 12 m³/hrs. The wells located in the hornblende biotite gneiss vary in depth from 6 to 15 m bgl. The yield of these wells ranges from 4 to 5 m³/hrs. They can sustain pumping for only few hours and recuperation rate is very poor.

The wells tapping deep crystalline aquifers range in depth from 90 to 300 m bgl. The yield of these wells ranges from 0 to 920 lpm. The depth of over burden varies from 3 to 35 mts. The water bearing fractured zone were encountered at depth ranges of 20 to 30, 40 to 60, 70 to 80, 90 to 120 and 150 to 160 m bgl.

Lateritic Aquifers, is the most commonly occurring aquifer system in the district and occupies the midland region. The laterite constitutes the potential aquifer because of the porous and highly permeable nature. Ground water occurs under water table conditions. Due to this porosity,

the stored water escapes as sub-surface run-off from the elevated hills and slopes once the rain recedes. The laterites are derived from both the Tertiary formation and also from the crystallines. The laterites mainly occupy the hill top areas as laterite capping. Also occupy in low land areas where thickness is very meager.

The thickness of laterite and overlying charnockites varies from 1 to 3 m and from 15 to 20 m in hornblende gneiss. Majority of well tapping laterites dry up during summer months. The bottom part the wells are mainly of lithomargic clay and becomes low yielding during peak summer periods. Subsequent rains contribute little to the aquifer system and escapes as rejected recharge. However in the lower attitudes especially in valley portions the water table is shallow and appreciable thickness of saturated zone is available for ground water development. Yield ranges from 8 to 10 m³ per hour.

The coastal alluvium is essentially composed of sand, silt and clay. The ground water occurs under water table conditions. Large number of dug wells and filter point wells tap this aquifer to meet the domestic and agricultural needs. The coastal alluvium can sustain medium to heavy duty pumping. Filter point wells are feasible along the coast wherever the saturated sand thickness exceeds 5 m. Such potential areas are seen around Ponnani, Chamravattom, Mangalam, B.P Angadi, Tirur, Tanur, Parappanagadi and Kadalundi. Riverine alluvium of considerable thickness is seen in and around Thirunavaya, Kuttipuram area along the northern side of Bharatapuzha (Ponnani) river. Open dug wells and shallow tube wells are feasible in the stretch.

5.2 Ground water Quality of Malappuram District

Water quality monitoring was conducted for pre and post monsoon seasons of 2008, and 2009 for 70 stations within this district. Presence of Iron was emerged as the major water quality problem. Few stations recorded higher levels of EC, TH, Cl and Na. Low pH values (< 7) were observed at Thirur (4.57), Pandikadu (4.85), Kalachal (4.90) and Parannekad (4.98). High value of Electrical Conductivity was observed at Puduponnani (40000 µS/cm) and the values of Total Hardness (5300 mg/l) Chlorine (18130 mg/l) and Sodium (8650 mg/l) were high for the water sample from the same location.

It was also observed that the Iron concentration at many of the places is in excess of the desirable limit. Higher values were recorded at Poroor (10.24 mg/l), Paloor (8.77 mg/l), Melmuri (8.80 mg/l), Kadavanad (7.37 mg/l), Kuttipuram (5.74 mg/l), Edavanna (4.38 mg/l) etc.

pH

The pH values of the samples collected from selected locations of Malappuram district varied from 5.60 to 8 during pre-monsoon and 4.4 to 8.4 during post-monsoon in the year 2008. Water was found to be acidic in certain patches of the north-western and central part of the district. In order to understand the overall changes based on land use/land cover changes, analysis were also carried out during the year 2010. The study also shows that part of south-western part and eastern areas are found to be alkaline in nature. This could be attributed to the influence of seawater in the western region and agriculture activities in the eastern region. The seasonal variation of pH in waters during 2008 and 2010 are given in figures 5a and 5b.

Pre-monsoon pH 2008

Post-monsoon pH 2008

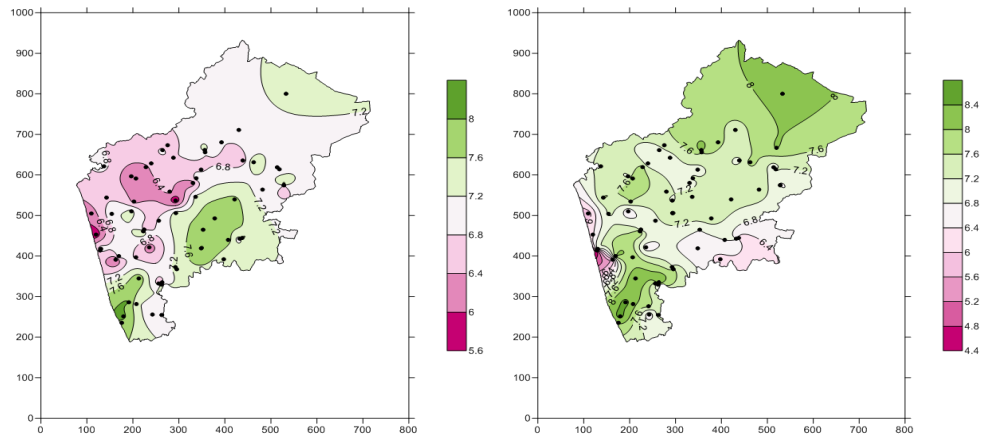


Figure 5a : Distribution of pH in Malappuram district during Pre and post monsoon of 2008

Pre-monsoon pH (2010)

Post-monsoon pH (2010)

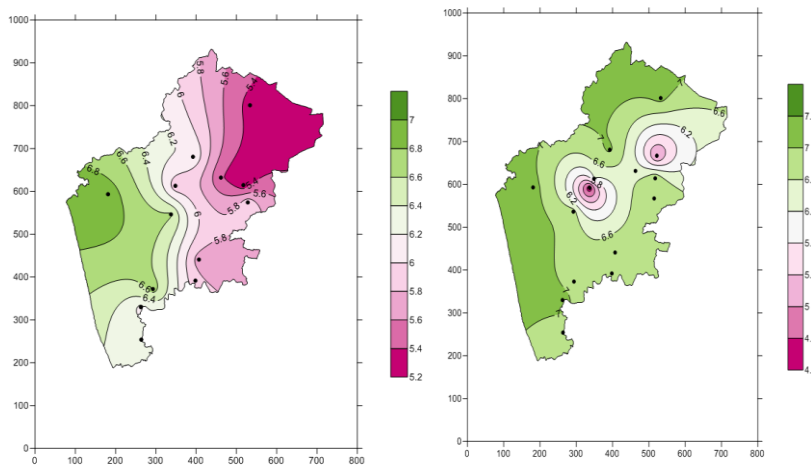


Figure 5b: Spatial distribution of pH in Malappuram district during Pre and post monsoon of 2010

Electrical conductivity

Electrical conductivity of the samples varied from 400.0 micro-siemens/cm to 11500 micro-siemens/cm during pre-monsoon of 2008. However, the highest value of 11500 micro-siemens/cm was observed only at one point near the coastal region. In the post-monsoon season of 2008, highest EC noticed was slightly higher than 1100 micro-siemens/cm. In the year 2010, the analysis results showed that EC was much lower than 1000 micro-siemens/cm. This is one of the clear indications that the water is suitable for all purposes including drinking

as per BIS specifications except in few isolated patches where there is an influence of seawater and estuarine waters. Figures 5c & 5d shows the variation of Electrical conductivity during 2008 and 2010.

Pre-monsoon 2008 (EC)

Post-monsoon 2008(EC)

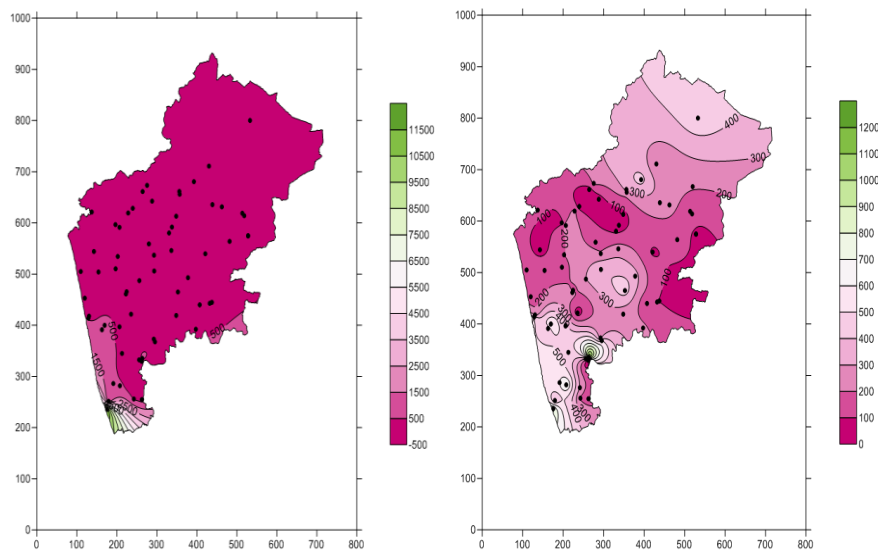


Figure 5c: Spatial distribution of pH in Malappuram district during 2008

Pre-monsoon EC (2010)

Post-monsoon EC (2010)

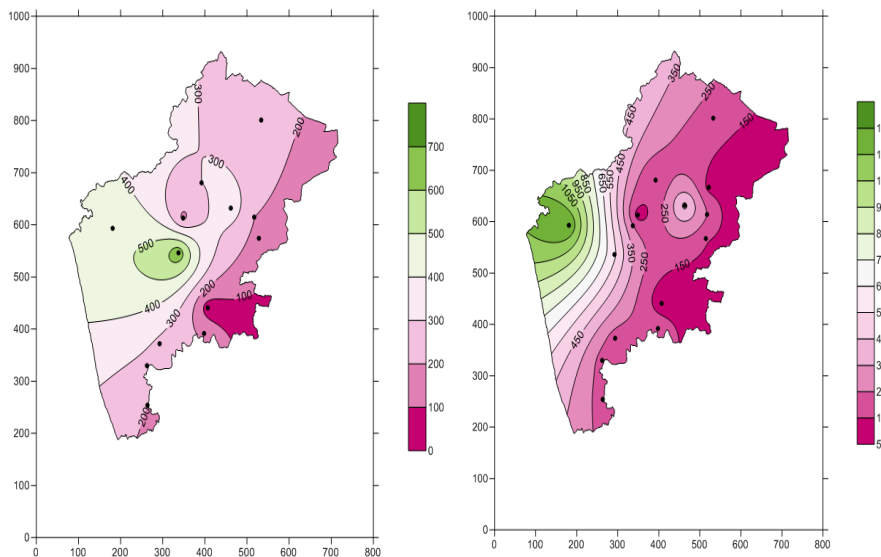


Figure 5d: Distribution of pH in Malappuram district during 2010

Total Dissolved Solids

The concentration of TDS during 2008 and 2010 were analysed and found that the values are much below the desired limits. Total Dissolved Solids exceeded 500 mg/l in an isolated patch in the north-western part of the district during post-monsoon of 2010. The seasonal variation of TDS during 2010 is depicted in figure 5e.

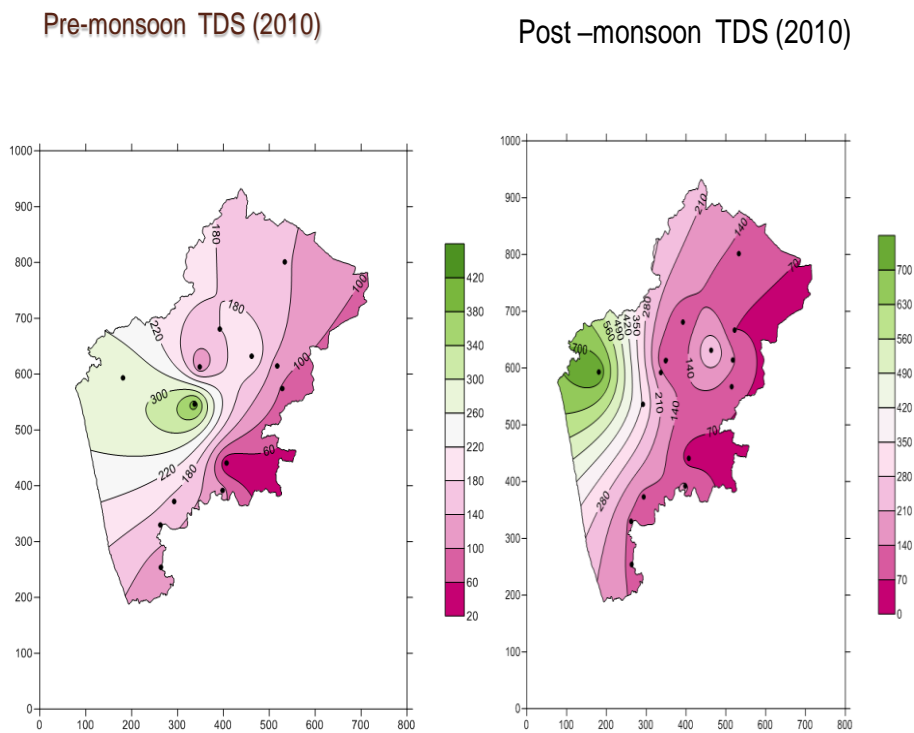


Figure 5e: Distribution of Total Hardness in Malappuram district during 2010

Total Hardness

Total hardness of the water samples varied from less than 20 mg/l to more than 600 mg/l during pre-monsoon (one well showed a sign of sea water intrusion during the pre-monsoon and Total hardness found to be more than 1000 mg/l). A maximum of 250 mg/l was noticed in the post-monsoon 2008 and similar observation was reported during 2009. In the year 2010, Total hardness showed a considerable increase during pre-monsoon (344 mg/l) and it reduced to 149 mg/l in the post-monsoon of 2010. The seasonal variation of total hardness is represented in figure 5f. Total hardness showed a very high positive correlation with magnesium suggesting a magnesium contributed hardness.

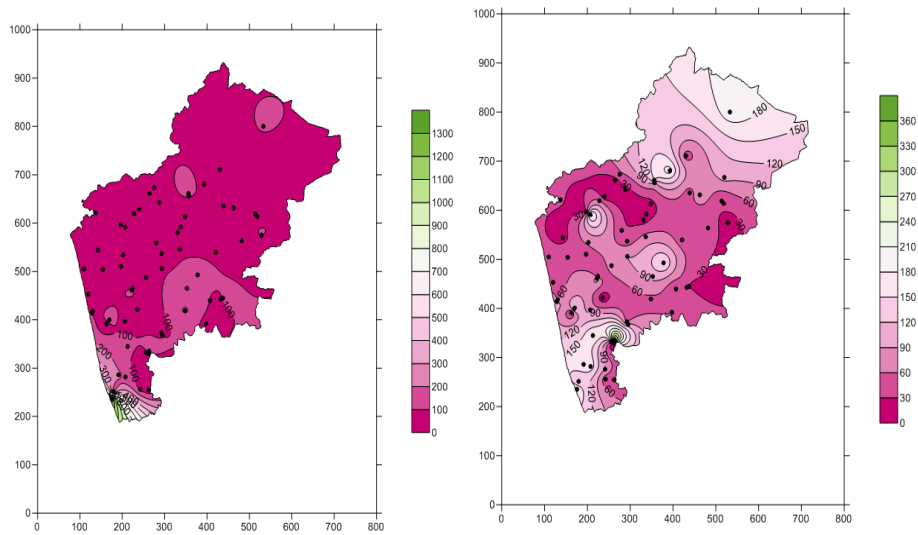


Figure 5f: Distribution of Total Hardness in Malappuram district during 2008

Pre-monsoon 2010 (TH)

Post-monsoon 2010 (TH)

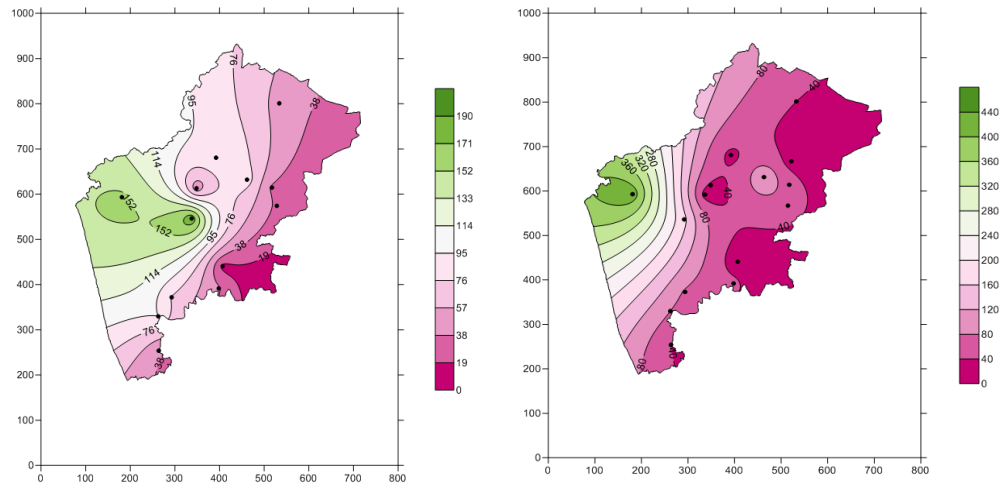


Figure 5g: Distribution of Total Hardness in Malappuram district during 2010

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 5 mg/l to slightly more than 130 mg/l during the pre-monsoon of 2010. In the post-monsoon, it increased to a minimum of 30 mg/l to a maximum 270 mg/l. More than 95% of the wells showed the absence of carbonates. The variations of bicarbonates were quite minimal and needs further evaluation. The total alkalinity of the water samples were found to be within the permissible limit for all the samples as per BIS (1991). Figure 5h shows the variation of Total alkalinity in Malappuram district.

Pre-monsoon Alkalinity (2010)

Post-monsoon Alkalinity (2010)

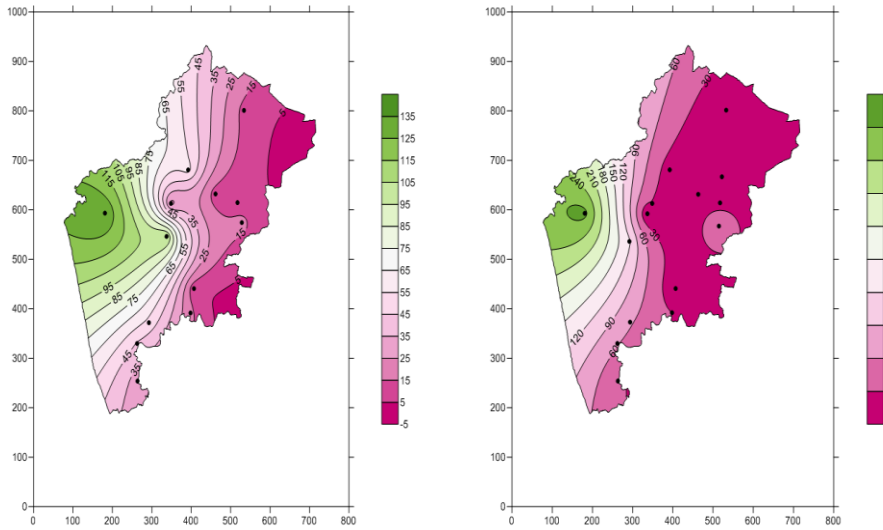


Figure 5h: Distribution of Total Alkalinity in Malappuram district during 2010

Chlorides

In majority of the locations, the maximum chloride content in the water samples varied from less than 200 mg/l to a maximum of 3000 mg/l during 2008 pre-monsoon. The excess chloride was found only in a well close to the coastal zone. However, during the post-monsoon, it was reduced to less than 30 mg/l to 275 mg/l. The observations made during the year 2010, in a limited number of wells showed that the chloride content is less than 100 mg/l during pre-monsoon and increased to 220 mg/l during post-monsoon 2010. The reason could be the runoff conditions which might have brought comparatively higher sediments there by increasing the chloride concentration. Figures 5i & 5j shows the spatial distribution of chloride during 2010.

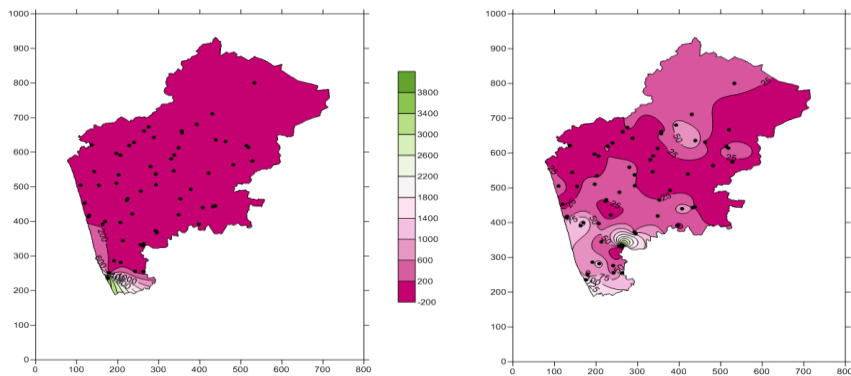


Figure 5i: Distribution of Chlorides in Malappuram district during 2008

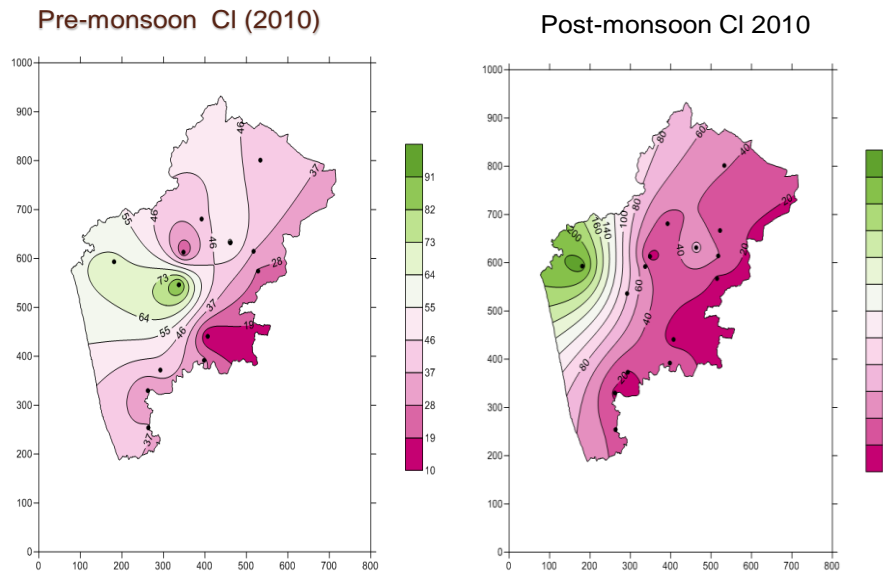


Figure 5j: Distribution of Chlorides in Malappuram district during 2010

Sulphates

The sulphate concentration ranged from 2.0 mg/l to 110 mg/l during pre-monsoon and in the post-monsoon, concentration showed a decline. The maximum observed was less than 50 mg/l. The comparatively higher rainfall occurred in the year 2010 may be the reason for reduction in sulphate concentration. Figure 5k represents the spatial variation of sulphates in Malappuram district.

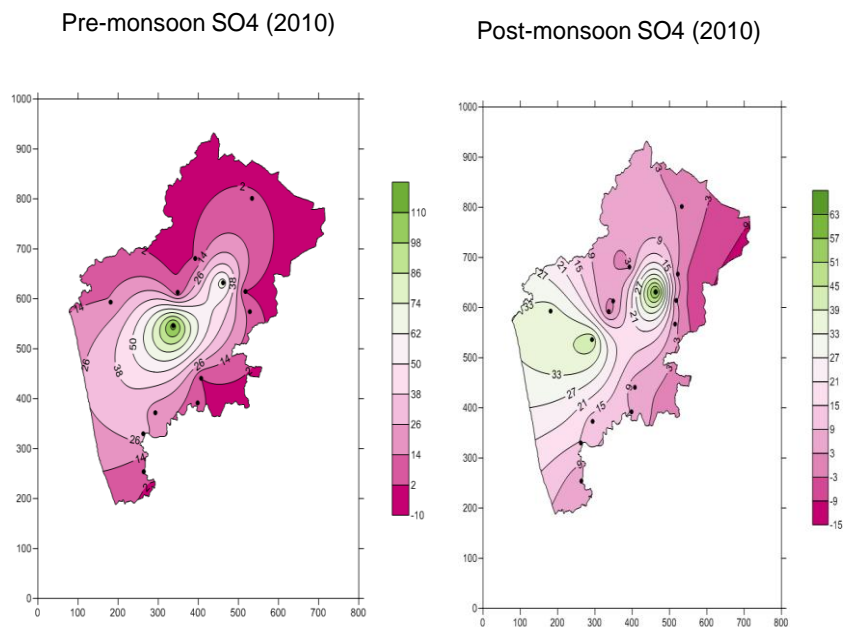


Figure 5k: Spatial distribution of Sulphates in Malappuram district during 2010

Fluoride

The maximum concentration of fluoride observed was 0.75 mg/l during pre-monsoon and 0.38 mg/l during post-monsoon 2010. Fluoride concentration was found to be within the permissible limit during all the seasons. In the present study an attempt was also made to correlate fluoride with other anions and cations. In the present study a significant positive correlation was noted between fluoride and Electrical conductivity, Total hardness, Alkalinity, Total dissolved Solids, Chloride and Sulphate. Figure 5l shows the distribution of fluoride in Malappuram district.

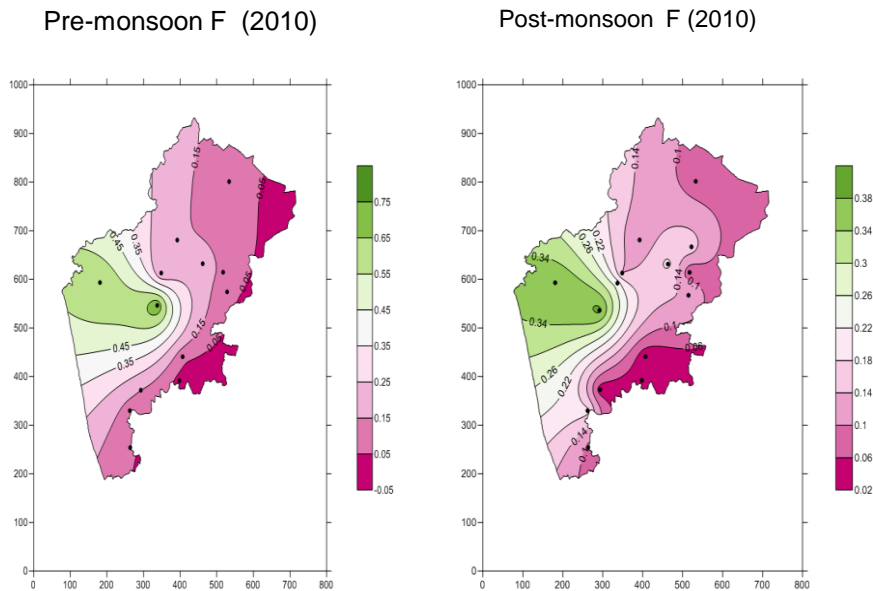


Figure 5l: Spatial distribution of Fluorides in Malappuram district during 2010

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figure 5m & 5n). It is observed that both calcium and magnesium concentrations are much below the permissible limit. However, there is an increase during post-monsoon period during north western part of the district. Further, it is also noticed that magnesium concentration is relatively higher than the expected values in comparison to calcium.

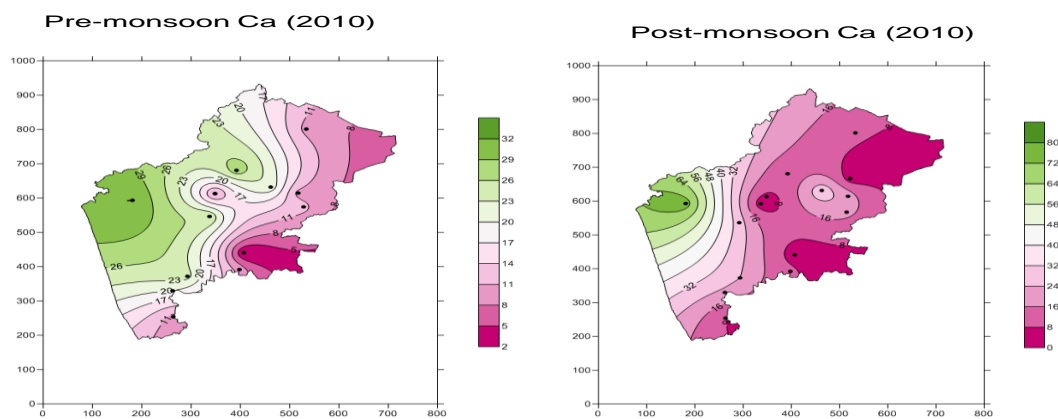


Figure 5m: Distribution of Calcium in Malappuram district during 2010

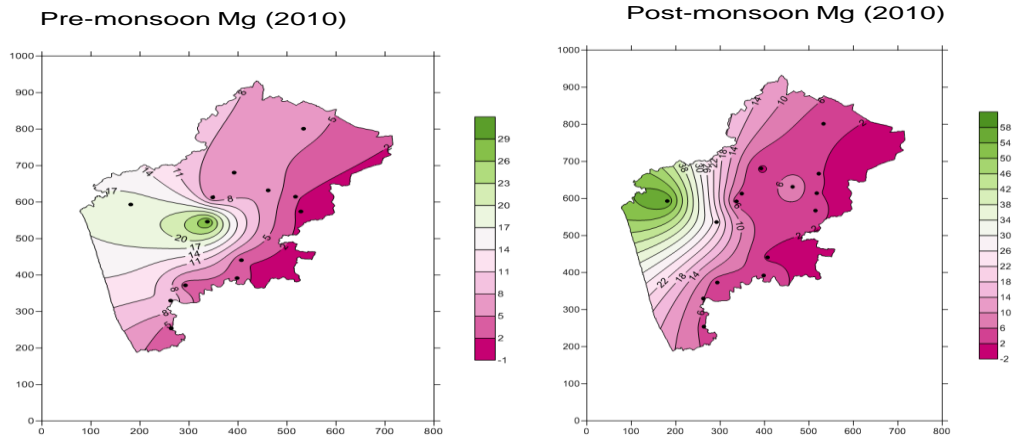


Figure 5n: Spatial distribution of Magnesium in Malappuram district during 2010

Sodium and Potassium

Analysis of sodium concentration in the ground water samples from 2008 to 2010, shows that there is no significant change in the concentration during the study period. The observed concentration was below the permissible ranges. Similar observation was found in the case of potassium. The concentration of sodium varies between 6.0 mg/l to 68 mg/l, during pre-monsoon and 11 mg/l to 85 mg/l during post-monsoon of 2010. The potassium concentration varied from 1 mg/l to 21 mg/l during the pre-monsoon of and 2.0 mg/l to 18.0 mg/l during post-monsoon 2010. The seasonal variation of sodium and potassium concentration is represented in figures 5o and 5p.

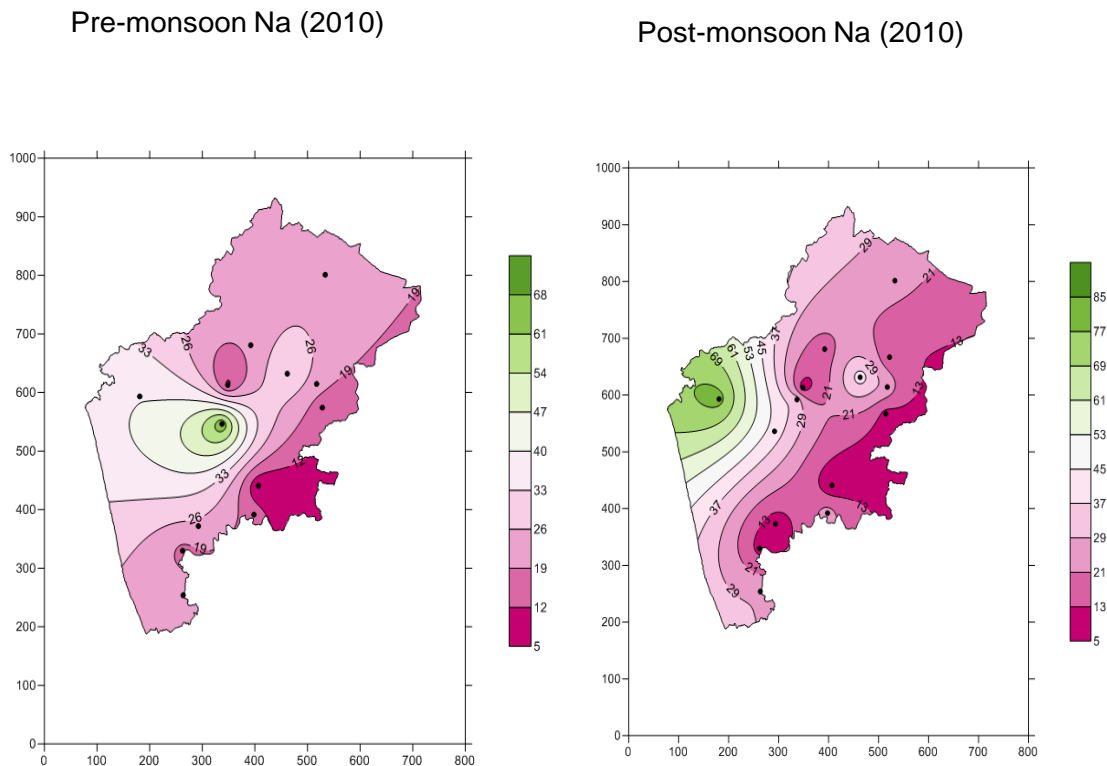


Figure 5o: Spatial distribution of Sodium in Malappuram district during 2010

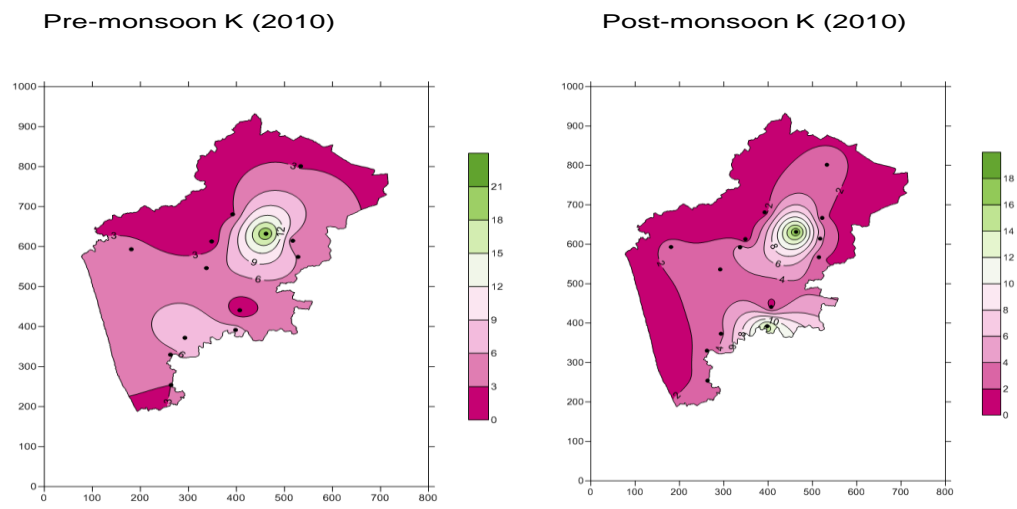


Figure 5p: Distribution of potassium in Malappuram district during 2010

Iron

The maximum concentration of iron in the study area during 2010 is found to be less than 0.3 mg/l to a maximum of 6.7 mg/l in the pre-monsoon that is much higher than the permissible limit of 0.3 mg/l. The highest concentration was found on the western part of the study area during the pre-monsoon season. In the post-monsoon of 2010 it was found to be negligible in concentration and the highest observed was 2.7 mg/l. This wide spread occurrence of iron in this part of the state is quite common as the rocks are acidic and iron rich in concentration.

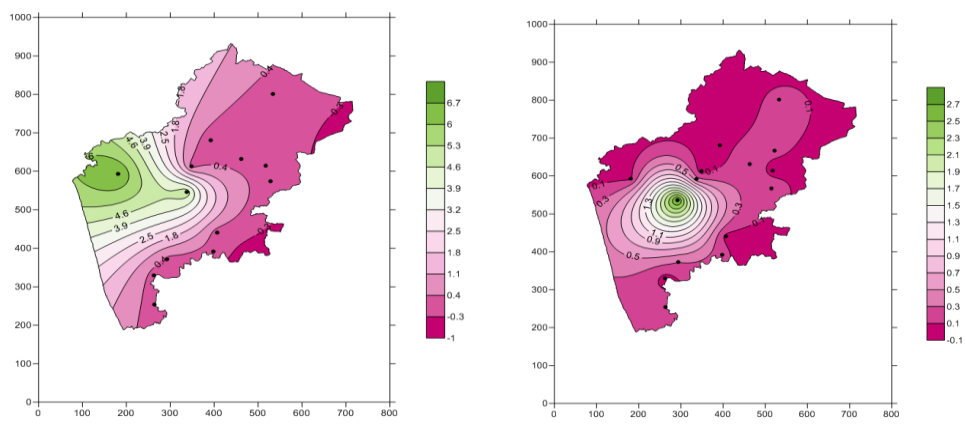


Figure 5q: Distribution of Iron in Malappuram district during 2010

Statistical Analysis

Statistical analyses were carried out using SYSTAT/SPSS software. The correlation coefficient between the observed parameters were determined and shown in table . Cluster diagram was also developed to understand the relationship and mutual cause of occurrence (figure)

Table 5c: Correlation between parameters observed during 2008

Malappuram Premonsoon 2008 Correlation						
	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	0.26	1.00				
Total Hardness	0.42	0.97	1.00			
Cl	0.21	1.00	0.95	1.00		
Na	0.21	1.00	0.95	1.00	1.00	
Fe	0.14	0.00	0.06	-0.02	-0.02	1.00

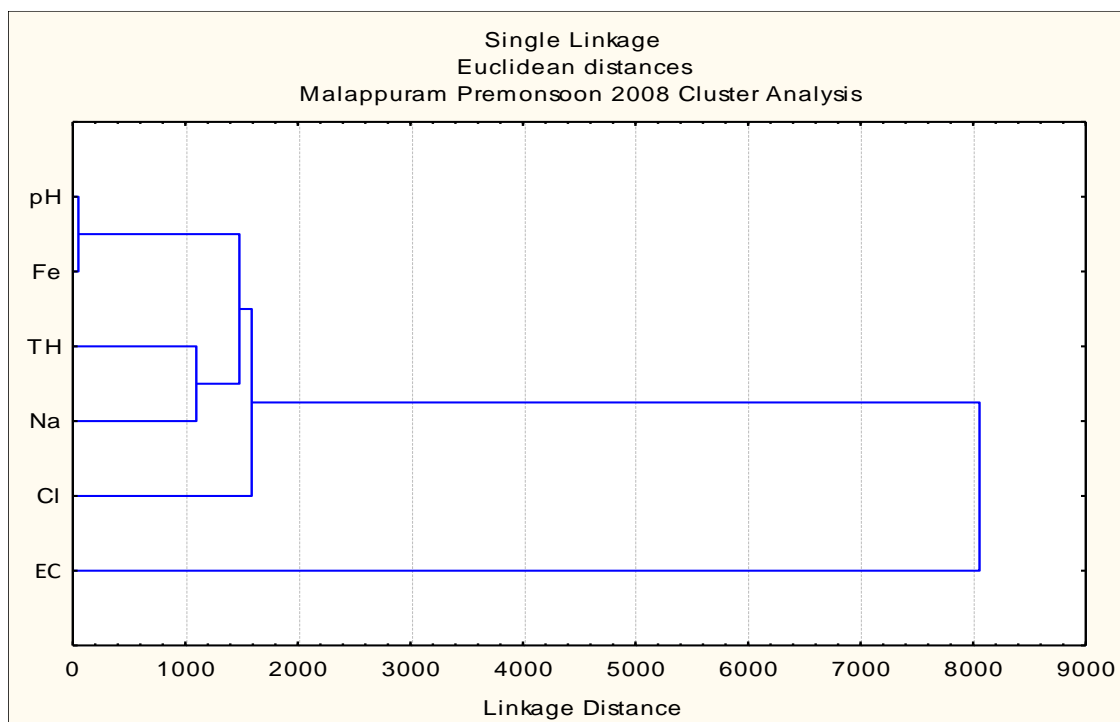


Figure 5r: Cluster Diagram for the year 2008 (Pre-monsoon)

Table 5d: Correlation matrix for the post-monsoon season

	pH	EC	Total Hardness	Cl	Na	Fe
pH	1.00					
EC	0.42	1.00				
Total Hardness	0.57	0.88	1.00			
Cl	0.19	0.83	0.63	1.00		
Na	0.28	0.93	0.68	0.85	1.00	
Fe	0.23	0.12	0.13	0.03	0.08	1.00

After screening the data for the study period, 2010 (pre-monsoon) data was selected for factor analysis. The cluster analysis showed the grouping of various ions during the study period and (figure). Data was further subjected to factor analysis based on the eigen values obtained for understanding the proportion of variance. Table shows the results of the analysis below

Table 5e: Correlation matrix of Pre-monsoon 2010 samples of Malappuram district

Malappuram Premonsoon 2010 Correlation															
Parameters	pH	EC	Total Hardness	Alkanity	Total Dissolved Solids	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1.00														
EC	0.55	1.00													
Total Hardness	0.66	0.97	1.00												
Alkanity	0.85	0.81	0.90	1.00											
Total Dissolved Solids	0.55	1.00	0.97	0.81	1.00										
HCO ₃	0.85	0.81	0.90	1.00	0.81	1.00									
Cl	0.44	0.96	0.88	0.72	0.96	0.72	1.00								
SO ₄	0.25	0.81	0.73	0.42	0.81	0.42	0.77	1.00							
NO ₃	-0.68	-0.29	-0.34	-0.56	-0.29	-0.56	-0.27	-0.22	1.00						
Ca	0.66	0.80	0.87	0.81	0.80	0.81	0.72	0.48	-0.17	1.00					
Mg	0.55	0.93	0.94	0.82	0.93	0.82	0.85	0.79	-0.42	0.64	1.00				
Na	0.44	0.96	0.87	0.71	0.96	0.71	0.99	0.83	-0.31	0.65	0.89	1.00			
K	-0.17	0.23	0.13	-0.15	0.23	-0.15	0.28	0.46	0.24	0.29	0.00	0.24	1.00		
F	0.60	0.90	0.91	0.88	0.90	0.88	0.85	0.67	-0.53	0.68	0.93	0.87	-0.01	1.00	
Fe	0.64	0.80	0.83	0.91	0.80	0.91	0.75	0.47	-0.59	0.62	0.85	0.76	-0.10	0.95	1.00

Table 5f: Correlation matrix of Post-monsoon 2010 samples of Malappuram district

Parameters	pH	EC	Total Hardness	Alkalinity	Total Dissolved Solids	HCO ₃	Cl	SO ₄	NO ₃	Ca	Mg	Na	K	F	Fe
pH	1.00														
EC	0.20	1.00													
Total Hardness	0.30	0.98	1.00												
Alkalinity	0.34	0.91	0.96	1.00											
Total Dissolved Solids	0.20	1.00	0.98	0.91	1.00										
HCO ₃	0.34	0.91	0.96	1.00	0.91	1.00									
Cl	0.15	0.98	0.95	0.88	0.98	0.88	1.00								
SO ₄	0.20	0.66	0.62	0.48	0.66	0.48	0.55	1.00							
NO ₃	-0.58	-0.21	-0.36	-0.48	-0.21	-0.48	-0.15	-0.25	1.00						
Ca	0.38	0.94	0.97	0.92	0.94	0.92	0.90	0.64	-0.34	1.00					
Mg	0.22	0.97	0.98	0.96	0.97	0.96	0.96	0.57	-0.36	0.92	1.00				
Na	0.05	0.94	0.86	0.75	0.94	0.75	0.95	0.61	0.05	0.80	0.88	1.00			
K	-0.07	0.12	0.01	-0.17	0.12	-0.17	0.07	0.52	0.28	0.08	-0.04	0.23	1.00		
F	-0.15	0.74	0.71	0.69	0.74	0.69	0.70	0.60	-0.18	0.62	0.76	0.71	-0.09	1.00	

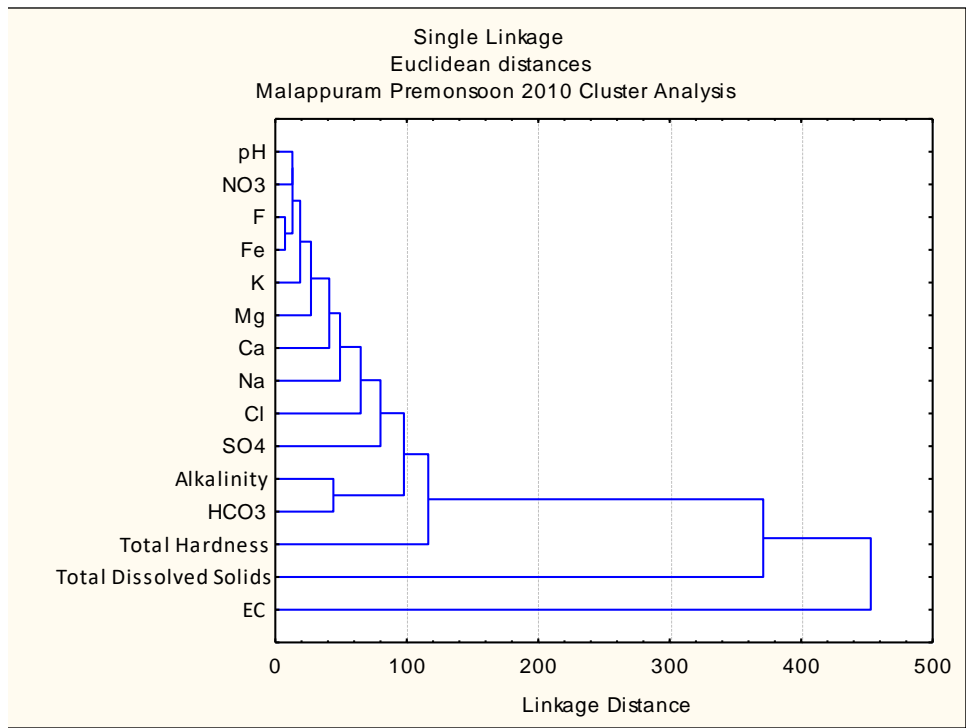


Figure 5s: Cluster Analysis of Groundwater Quality data (Pre-monsoon 2010)

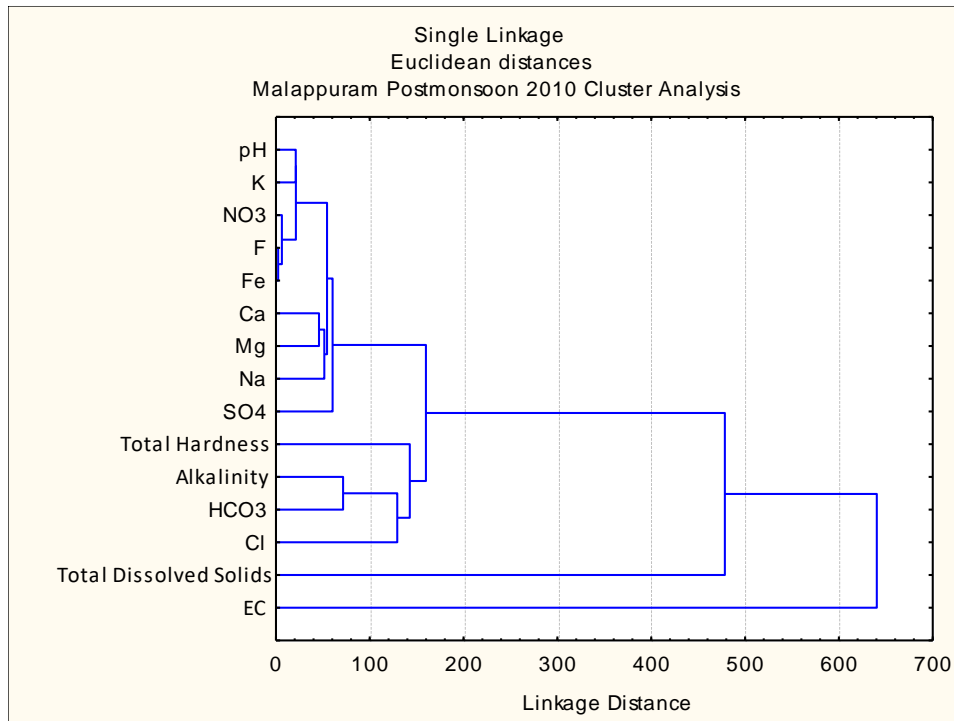


Figure 5t: Cluster analysis of Groundwater Quality data (Post-monsoon 2010)

Table 5g: Results of factor Analysis of Pre-monsoon 2010 samples

	Factor 1	Factor 2
pH	0.338886	0.804196
EC	0.950935	0.291375
Total Hardness	0.877544	0.434686
Alkanity	0.619279	0.762157
Total Dissolved Solids	0.950935	0.291375
HCO ₃	0.618627	0.762483
Cl	0.938217	0.201608
SO ₄	0.887419	-0.083093
NO ₃	-0.113048	-0.752688
Ca	0.744398	0.331492
Mg	0.832891	0.438762
Na	0.933413	0.216626
K	0.487713	-0.633588
F	0.787326	0.548168
Fe	0.640450	0.676594
Eigenvalue	10.69214	2.125977
% Total	71.28091	14.17318
Cumulative Eigenvalue	10.69214	12.81811

Table 5h: Results of factor Analysis of Post-monsoon 2010 samples

	Factor 1	Factor 2	Factor 3	Factor 4
pH	0.135737	0.885162	0.092045	-0.158887
EC	0.974108	0.069510	0.153434	0.145089
Total Hardness	0.964661	0.219384	0.053589	0.120399
Alkanity	0.911283	0.311812	-0.146698	0.165248
Total Dissolved Solids	0.974108	0.069510	0.153434	0.145089
HCO ₃	0.911413	0.311874	-0.146414	0.164753
Cl	0.985142	-0.003775	0.084192	0.049562
SO ₄	0.490945	0.206253	0.652043	0.467167
NO ₃	-0.156334	-0.852774	0.203874	-0.229832
Ca	0.920847	0.287797	0.140320	0.032040
Mg	0.962802	0.158513	-0.014568	0.184269
Na	0.914687	-0.161187	0.245577	0.131129
K	-0.002415	-0.136312	0.957827	-0.071594
F	0.695392	-0.139672	-0.057979	0.638709
Fe	0.090603	0.053481	0.026471	0.940281
Eigenvalue	9.655397278	1.91	1.323439548	1.276732973

Ground water Classification based on Piper's and Chaddha's methods: Ground water quality data of 2010 pre-monsoon and post-monsoon were classified based on Piper's method and Chaddha's methods (Figures)

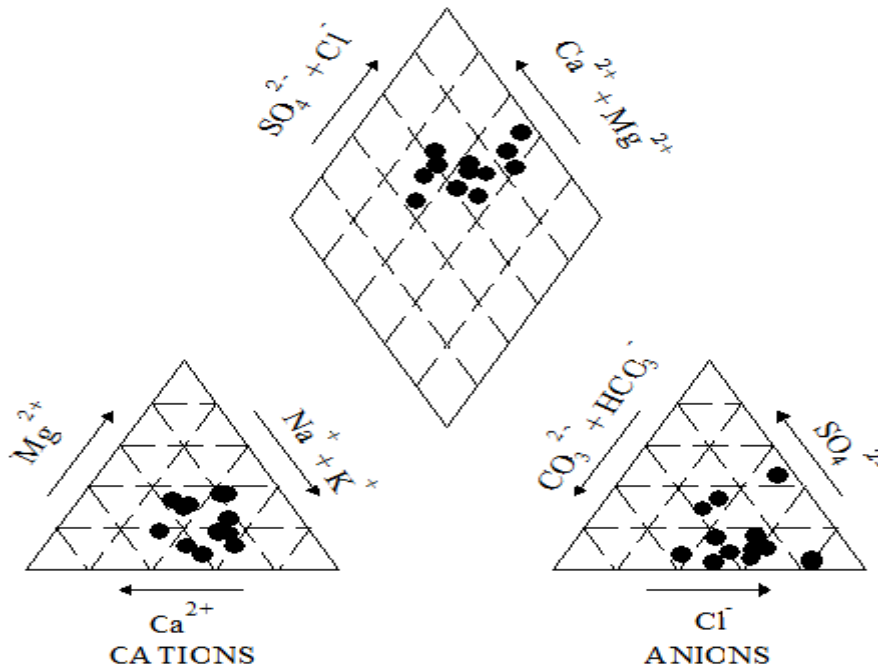


Figure 5t: Piper's Classification of Ground water (Pre-monsoon 2010)

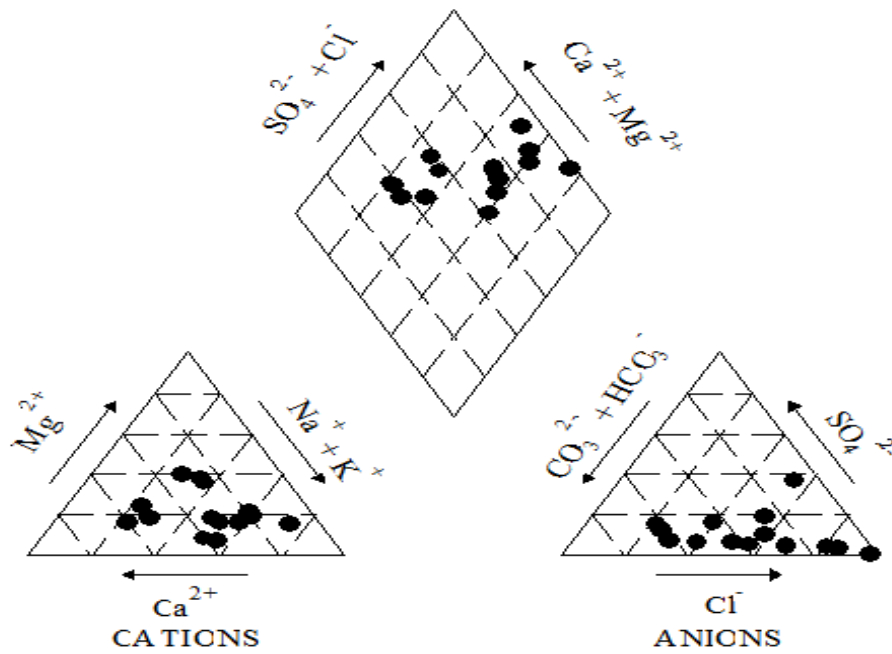


Figure 5u: Piper's Classification of Ground water (Post-monsoon 2010)

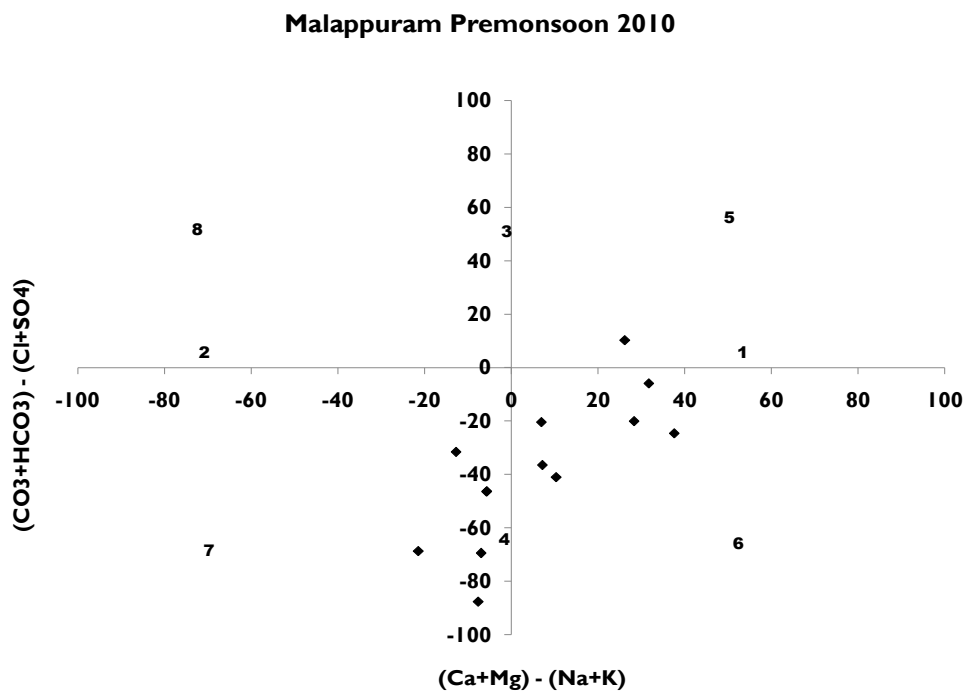


Figure 5u : Chadha's Classification of Ground water (Pre-monsoon 2010)

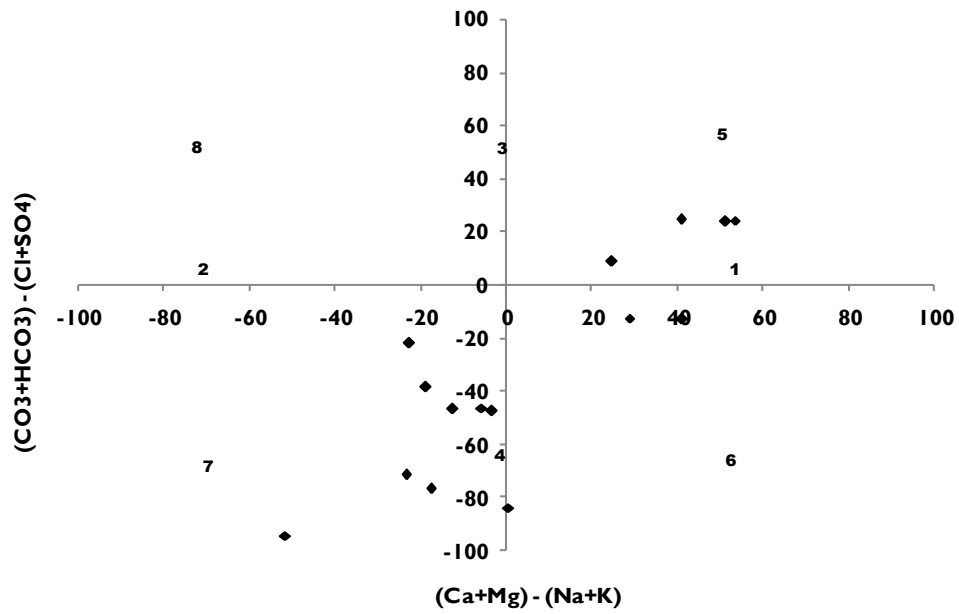


Figure 5v: Chadha's Classification of Ground water (Post-monsoon 2010)

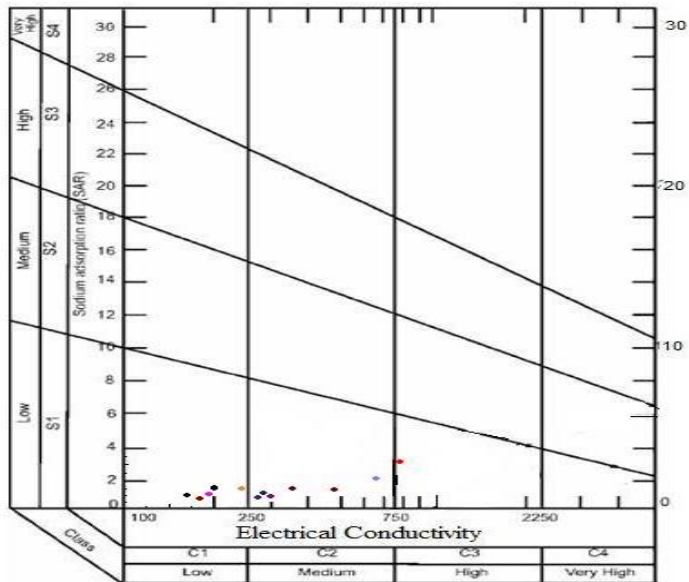


Figure 5w: USSL Irrigation Classification of Ground water (pre-monsoon 2010)

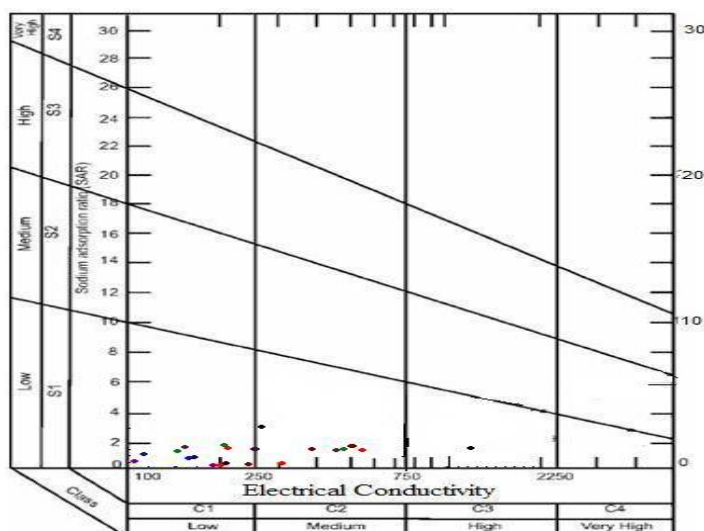


Figure 5x: USSS Irrigation Classification of Ground water (Post-monsoon 2010)

Heavy Metals in Groundwater of Malappuram District

It is observed that in Malappuram district, though the heavy metals showed the presence in some of the selected wells, no immediate threat is found due to contamination. Five samples from selected wells have been subjected to heavy metal analysis and found that majority of the observed wells there are heavy metals like copper, lead, nickel and zinc. Cadmium was absent in all observed wells except in one of the wells. Table 5i shows the distribution of heavy metals in Malappuram district.

Table 5i: Heavy metal distribution in groundwater of Malappuram district

Well No	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Nickel	Zinc	Mercury
MPM PDS OW-11	0.022	0	0	0	0.024	0	2.46	0
MPM PDS OW-12	0.033	0	0	0.004	0	0	1.17	0
MPM PDS OW-19	0.213	0	0.009	0.017	0.014	0.004	3.8	0
MPM PDS OW-5	0.02							
MPM PDS OW-6	0.022	0	0	0.025	0.018	0	2.3	0

6.0 GROUND WATER QUALITY OF THRISSUR DISTRICT

Thrissur is one of the important historical cities of Kerala which is known as the cultural capital of Kerala. The district has an area of 3032 sq.km and is located in the central part of the State. Thrissur district lies between North latitudes $10^{\circ} 10' 22''$ and $10^{\circ} 46' 54''$ and East longitudes $75^{\circ} 57' 20''$ and $76^{\circ} 54' 23''$. The district has five taluks viz. Chavakkad, Talappilli, Thrissur, Kodungallur and Mukundapuram which comprises 17 blocks spread over a total of 97 panchayaths and 7 municipalities.

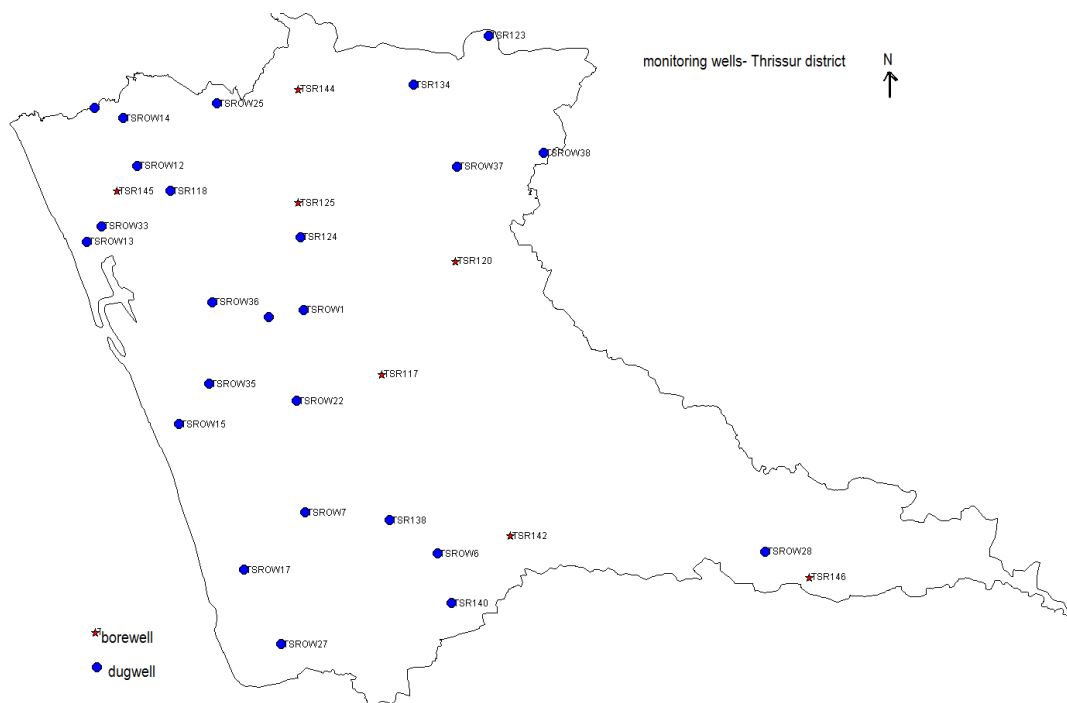


Figure A: Sampling locations in Thrissur district during the year 2008

Climate & Rainfall

The rainfall occurs more during southwest monsoon season during June to September and followed by northeast monsoon season during October to December. The average annual rainfall ranges between 2180.0 and 3484.0 mm in the district and mean annual rainfall for the district is 2924.4 mm. In general, the rainfall increases from south to north and west to east. The maximum rainfall occurs during the period June to September (SW monsoon) and nearly 73.7% of the total rainfall is received during the season. 16.8% of the total rainfall is received during North East monsoon between October and December, 9.0% of the total rainfall is received during March to May and the balance 0.5% is accounted for during January and February months.

Temperature

The maximum temperature ranges from 29.3 to 36.2⁰C where as the minimum temperature ranges from 22.1 to 24.9⁰C. The average annual maximum temperature is 32.30⁰C and the average annual minimum temperature is 23.3⁰C. Generally, March and April months are the hottest and November, December, January and February months are the coldest.

Relative Humidity

The humidity is higher during monsoon months from June to October and is around 93% during morning hours and 76% during evening hours.

Wind Velocity

The wind speed is more during December and January months and it is less during October.

Evaporation

It is high during the months of December to April because of more bright sunshine hours and less number of rainy days. It is less during the monsoon months from June to October. The maximum rate of 7.4 mm/day is recorded in the month of January and the minimum rate of 2.9 mm/day is recorded in the month of July.

Potential evapo-transpiration

The annual PET for Vellanikara is 1776.3 mm-based on Thornthwaite's method.

Aridity index

The ratio of potential evapotranspiration to rainfall is known as aridity index and it is around 0.6 for Vellanikara.

Geomorphology and Soil Types

There are three well marked geomorphological features are seen in this district i) Coastal plain ii) mid lands and iii) high lands. The coastal plain with an average width of 7 km have elevation ranging from 1m below mean sea level to as much as 7.6 m above mean sea level. This coastal belt consists of number of beach ridges. The Kole land, which has elevations in the range of 1-2m below, mean sea level and water-logged for 5-6 months in a year due to tidal effects. Two geomorphic zones mark the midland region. These are the flat-topped landform covered by a thick blanket of laterite, which is immediately to the east of coastal plain and rises up to 20 m above mean sea level. The hill ranges along the eastern part constitute the rugged terrains of Western Ghats. Pappattaparamudi (elevation 1160 m amsl) and Mangattukumban are the high peaks in the area. The eastern high lands exhibit a typical topography with a steep hills dissected by deep 'V' shaped valleys drained by youthful rivers.

Soils

The soils in Thrissur district have been classified in the following types, based on the morphological features and physiochemical properties. The predominant soil type observed is the lateritic soil, which covers almost the entire midland areas of the district. These soils are in general well drained, low in essential plant nutrients and organic matter. They exhibit very low cation exchange capacity and are generally acidic. The second prominent soil type is the

brown hydromorphic soil. These are confined to the valleys between undulating topography in the midlands and in the low lying areas of the coastal strip in the district.

Ground Water Quality Analyses

Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystalline, where as in the deeper fractured crystalline the groundwater occurs under semi confined to confined conditions.

The State Department has selected 78 stations for water quality monitoring. The major parameters observed during the year 2008 (pre-monsoon) were within the limits in majority of stations except pH and Iron concentration. pH values were less than 7 in most of the stations; minimum values was observed as 5.1 at Muringur of Mukundapuram taluk. The maximum was noticed in Vadanapalli (8.09) of Chavakkad taluk. The data available for the regular monitoring wells of State Ground water department showed even lower values than reported during the pre-monsoon 2008. Some of the locations are Cherpu (4.62), Koratty (4.64), Ollur (4.66), Puthukad (4.68) and Aalur (5.12). High concentration of Iron was noticed at Mulamkunnathukavu (9.98 mg/l), Kondazhy (9.23 mg/l), Kunnamkulam (9.32 mg/l), Elanad (9.07 mg/l), Tholur (6.78 mg/l), etc.

The minimum EC (40 μ S/cm) was noticed at Muringur of Mukundapuram taluk. Chittilappally recorded a value of 1100 μ S/cm for Electrical Conductivity and Chavakkad recorded 940 μ S/cm. Chittilappally also showed high values of Total Hardness (320 mg/l) and Chloride (300 mg/l). High concentration of Sodium was observed at Chavakkad (109 mg/l).

Table 6a: Statistical analysis of Pre-monsoon 2008

parameters	No.	minimum	maximum	mean	St. Deviation
	78	5.1	8.09	6.63	0.73
	78	40	1100	242.17	212.63
	78	10	320	72.44	65.71
	78	6.9	299.9	31.85	44.34
	78	2.5	109	18.62	19.98
	78	0.02	9.98	0.75	1.80

Table 6c shows the ranges of various parameters during the post-monsoon of 2008. The pH has shown good improvement (increased from an average of 6.63 to 7.41) during the post-monsoon indicating the impact of rainfall at various places. Iron concentration also showed a comparative decline, i.e. it reduced from 9.98 to 6.78.

Table 6c: Statistical analysis of Post-monsoon 2008

Trissur postmonsoon 2008					
parameters	No.	minimum	maximum	mean	St. Deviation
pH	34	6.13	8.17	7.41	0.49
EC	34	50	640	216.15	155.91
TH	34	20	230	68.38	55.85

Cl	34	1.9	84.8	25.55	19.57
Na	34	4.5	65.4	17.14	13.61
Fe	34	0.02	6.78	0.77	1.36

PH

The pH values of the samples collected from selected locations of Thrissur district varied from 5.10 to 8.10 during pre-monsoon and 6.1 to 8.2 during post-monsoon of 2008. It is quite interesting to note that major part of the study area falls under acidic groups both during pre-monsoon and post-monsoon seasons. However, in the post-monsoon, situation improved much and only northern part of the district was having neutral to alkaline water and rest are acidic to neutral. In the year 2010, limited analysis were carried out based on investigations for pollution prone areas, however no significant variations were found during the year, therefore, the number of samples analysed were quite limited so that contour diagrams were not plotted. This clearly indicates that the modifications and runoff waters play a significant role in pH variation. The seasonal variation of pH in waters during 2008 is given in Figures 6a.

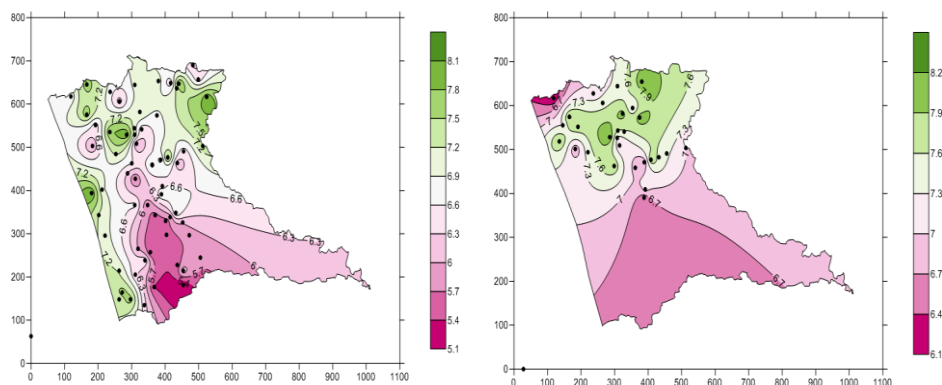


Figure 6a: Spatial Distribution of pH in Thrissur district during 2008

Electrical conductivity

Electrical conductivity of the samples varied from less than 50 micro-siemens/cm to 1100 micro-siemens/cm during pre-monsoon and less than 100 micro-siemens/cm to 600 micro-siemens/cm in the post-monsoon in the year 2008. However, it is noticed that highest EC was found in almost a central part of the district whereas in all other parts of the districts it is within the permissible limits. An observation taken during 2010 for limited number of wells showed a different picture. The EC values varied from 50 micro-siemens/cm to 1300

microsiemen/cm during pre-monsoon and 160 microsiemen/cm to 720 micro-siemen/cm during post-monsoon. However, the higher values observed are quite localized in nature. Figure 6b shows the variation of Electrical conductivity during 2008 & 2010.

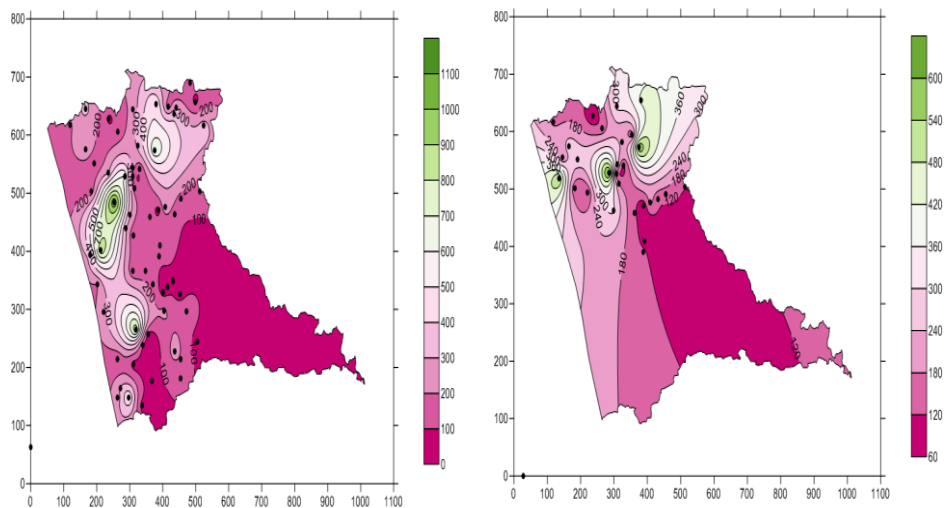


Figure 6b: Spatial Distribution of EC in Thrissur district during 2008

Chlorides

The chloride content in the water samples varied from less than 30 mg/l to a maximum of 300 mg/l during pre-monsoon and in the post-monsoon, it is between 5 mg/l and 85 mg/l. Highest concentration was found in north-central part of the district. The higher concentration above the permissible range is localized in nature. However, in major part of the district, it is within the permissible ranges. Figure 6c shows the spatial distribution of chloride in Thrissur district in the year 2008.

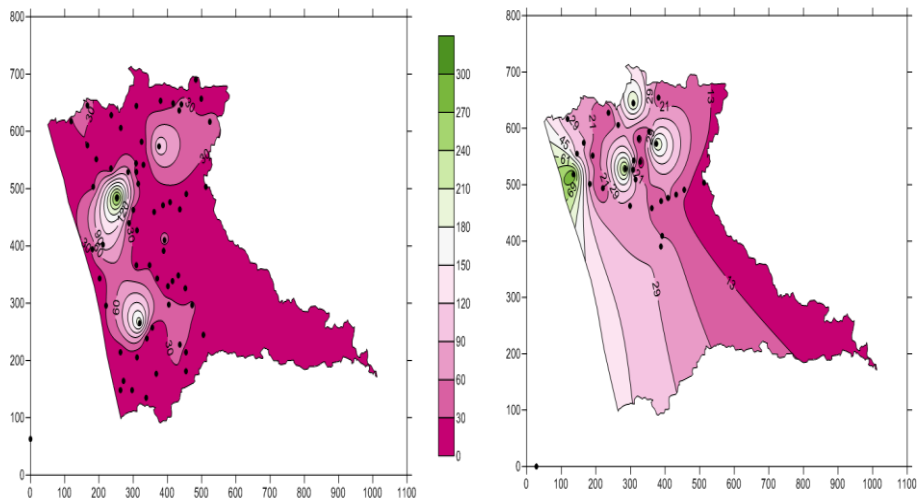


Figure 6c: Spatial Distribution of Chlorides in Thrissur district during 2008

Total Hardness

Total hardness of the water samples varied from less than 10 mg/l to 310 mg/l during pre-monsoon and in the post-monsoon, it varied between 10 mg/l to 230 mg/l in the year 2008. Total hardness showed a considerably higher concentration during pre-monsoon and in the post-monsoon it showed a decline. The seasonal variation of total hardness is represented in Figure 6d.

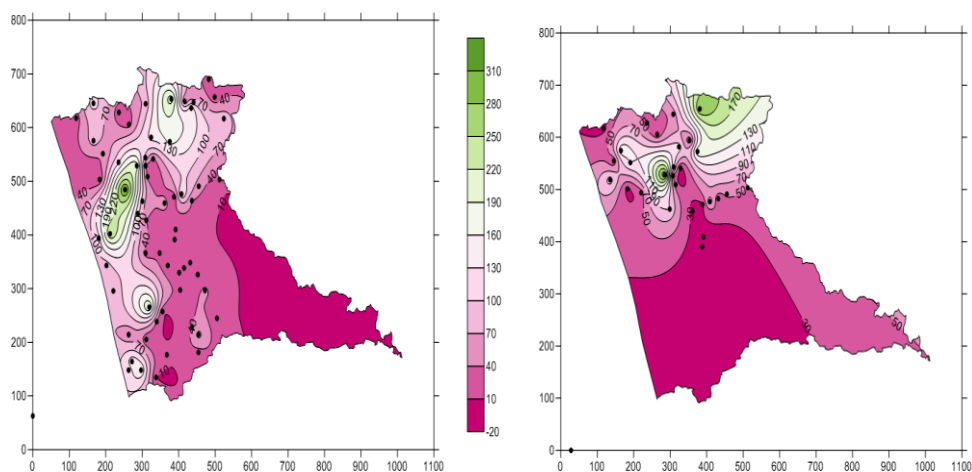


Figure 6d: Spatial Distribution of Total Hardness in Thrissur district during 2008

Sodium & Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2008 and for selected number of wells in the year 2010. The number of samples analysed were quite less due to various technical and logistic reasons. The result of 2008 is shown in figure 6e. The observed concentration of sodium varied from less than 9 mg/l to 90 mg/l during pre-monsoon and in the post-monsoon it ranges from 6 mg/l to 62 mg/l. Observations taken during 2010 showed that both the concentrations of sodium and potassium were well within the permissible limits.

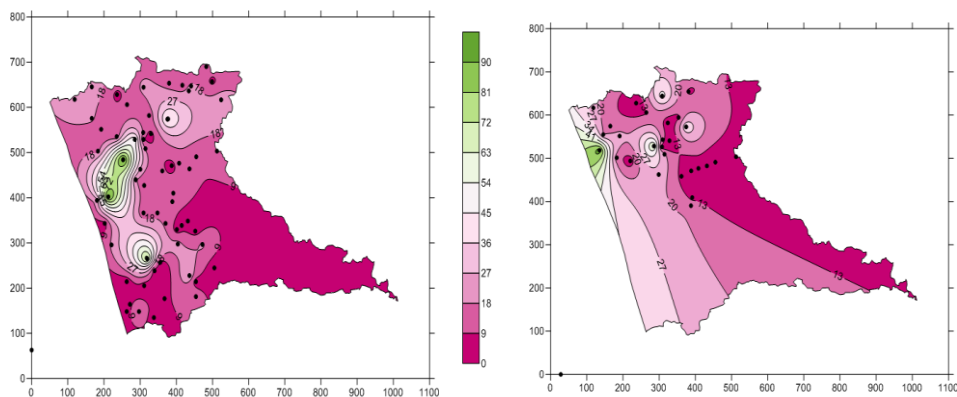


Figure 6e: Spatial Distribution of Sodium in Thrissur district during 2008

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2008 was found to be 9.5 mg/l which is much higher than the desirable ranges. The concentration varied between 0.3 mg/l to 9.5 mg/l during pre-monsoon and 0.1 mg/l to 6.7 mg/l in the post-monsoon. The figure 6f shows the variation of iron in the district. It is found that in majority of the locations iron concentration is much higher than the desirable ranges.

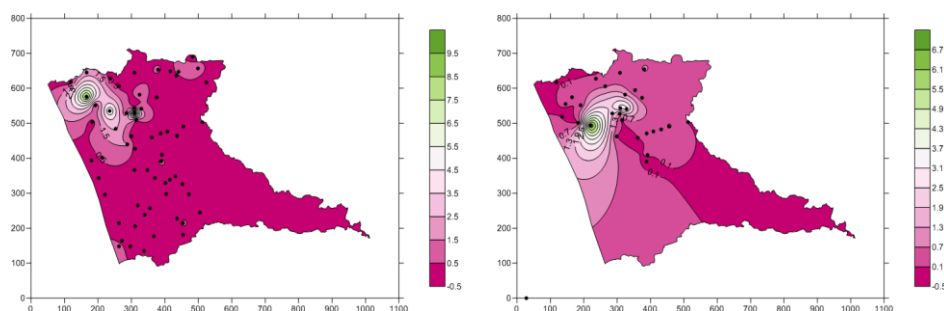


Figure 6f: Spatial Distribution of Iron in Thrissur district during 2008

Groundwater Classification

From the Piper's diagram (figures 6g,6h,6i & 6j) and Chadha's diagram (figure 6k & 6l) it is found that the groundwater samples collected from the coastal districts shows the enrichment of chlorides, followed by cations like calcium and magnesium. The majority of the samples show dual behavior fluctuating between pre-monsoon and post-monsoon season.

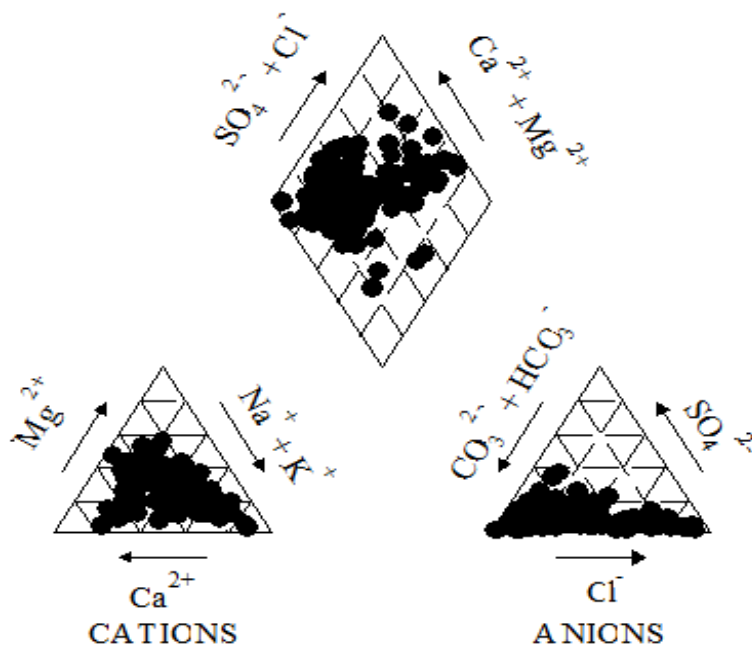


Figure 6g: Piper's classification of ground water of Thrissur district (Pre-monsoon, 2007)

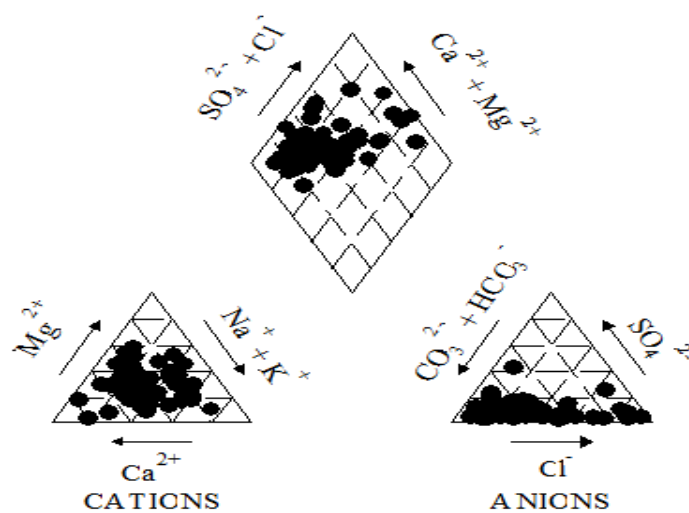


Figure 6h: Piper's classification of ground water of Thrissur district (Post-monsoon, 2007)

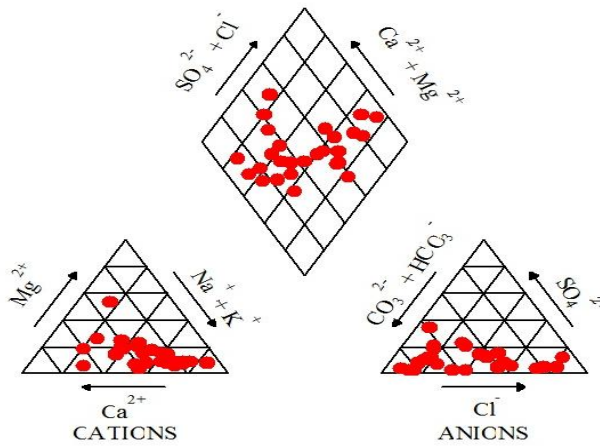


Figure 6i: Piper's classification of ground water of Thrissur district (Pre-monsoon, 2010)

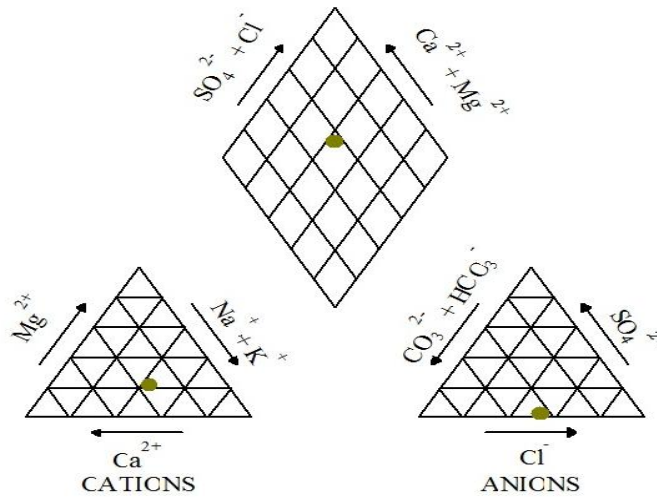


Figure 6j: Piper's classification of ground water of Thrissur district (Post-monsoon, 2010)

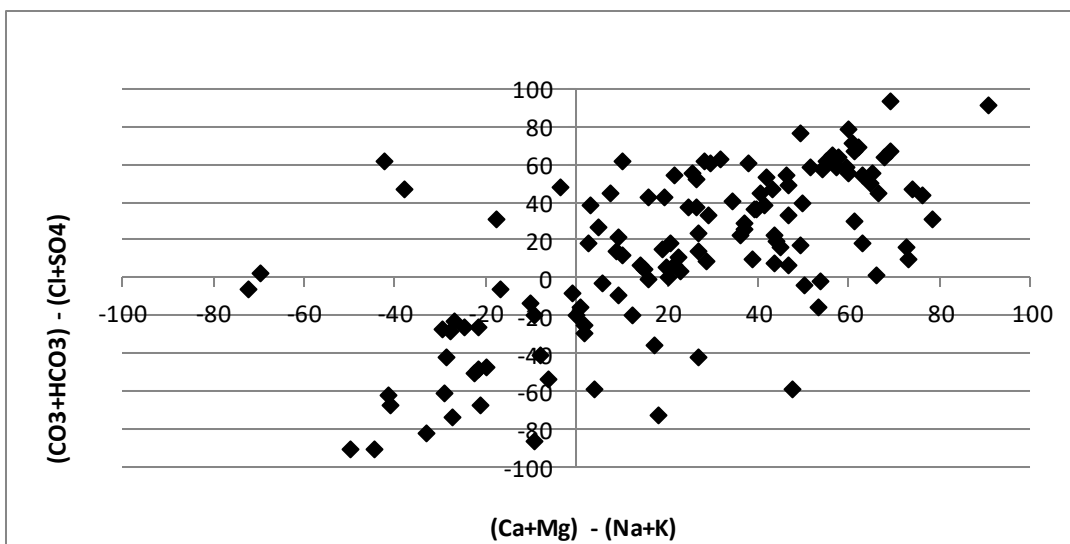


Figure 6k: Chadha's diagram of Thrissur district (Pre-monsoon, 2007)

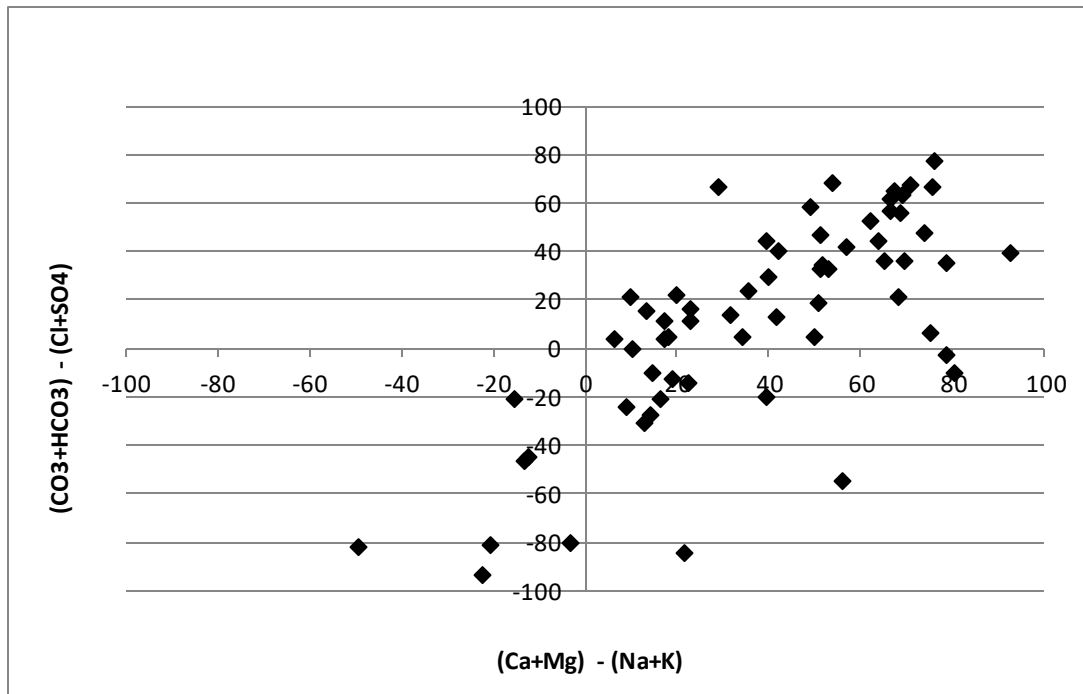


Figure 6l: Chadha's diagram of Thrissur district (Post-monsoon, 2007)

USSL Irrigation classification of groundwater shows that water is within the low sodium hazard zone.

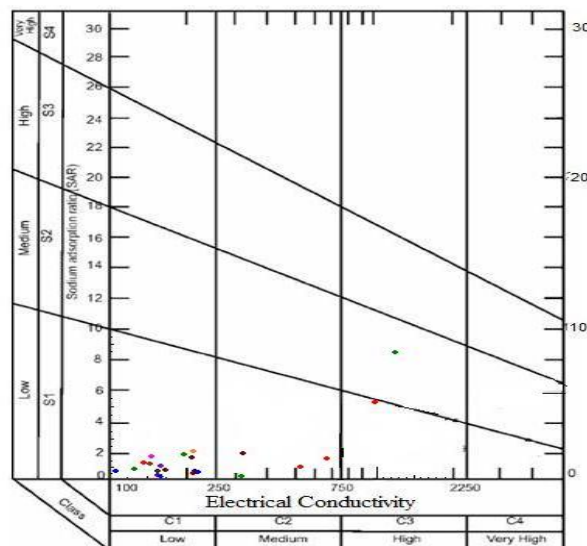


Figure 6i: Piper's classification of ground water of Thrissur district (Pre-monsoon, 2010)

Table 6d and 6e shows the correlation between various parameters during pre-monsoon and post-monsoon of 2008

Table 6d: Correlation between various ions during Pre-monsoon 2008

	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	0.386	1				
TH	0.525	0.925	1			
Cl	0.092	0.856	0.677	1		
Na	0.191	0.919	0.729	0.894	1	
Fe	0.261	0.057	0.106	0.028	0.018	1

Table 6e: Correlation between various ions during Post-monsoon 2008

	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	0.682	1				
TH	0.772	0.877	1			
Cl	0.288	0.774	0.449	1		
Na	0.358	0.837	0.546	0.911	1	
Fe	0.241	0.024	0.107	0.098	-0.094	1

Heavy Metals in Groundwater of Trissur District

It is observed that in Trissur district, though the heavy metals showed the presence in some of the selected wells, no immediate threat is found due to contamination. Five samples from selected wells have been subjected to heavy metal analysis and found that in majority of the observed wells there are heavy metals like cadmium and zinc Table 6g shows the distribution of heavy metals in Trissur district.

Table 6g: Heavy metal distribution in Trissur district

well No	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	Nickel
TSR125	0.04	0	0.025	0	0	0	4.348	0
TSROW13	1.1	0	0.009	0.025	0.009	0	4.5	0
TSROW15	0.06	0	0.004	0	0.008	0	6	0
TSROW17	0.09	0	0.01	0	0.014	0	3.9	0

TSROW27	0.03	0	0	0	0	0	5.9	0
TSROW33	0.06	0	0.013	0	0.03	0	5.6	0.0004

7.0 GROUND WATER QUALITY OF PALAKKAD DISTRICT

Palakkad (Palghat) is the land of Palmyrahs and Paddy fields. Palakkad is a major Paddy growing area of the State. It is often called as the “Gateway of Kerala”. There is considerable change in the land use and cropping pattern in the district for the last five years. Due to low income from paddy and coconut, farmers are changing the cropping pattern to cash crops like sugarcane, vegetables and flower cultivation. Over dependence on groundwater for domestic, irrigation and industrial purposes in the district has led to the lowering of water table and water scarcity especially along the eastern parts. In most of the areas especially in eastern part of the district decline of water levels necessitates deepening of existing dug wells and putting deep bore wells thereby increasing cost of pumping and quality deterioration. Local enquiry revealed that farmers have taken loan from the banks for putting bore wells and fitting pump sets for irrigation purposes. Figure 7 shows the distribution of monitoring stations in Palakkad district.

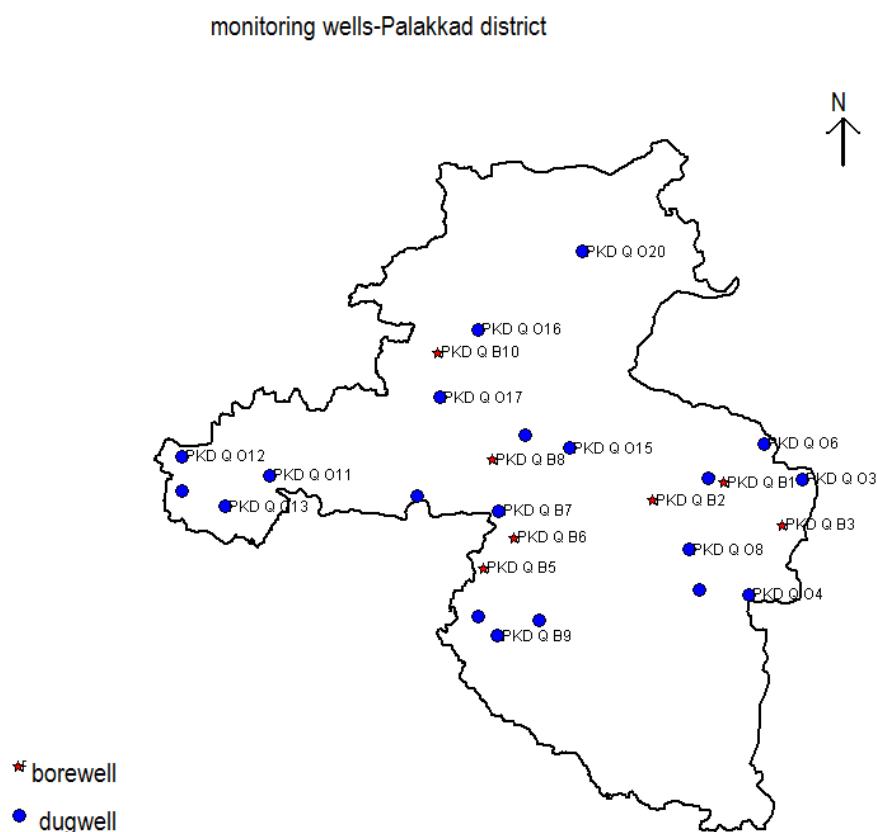


Figure 7. Location of Selected wells for monitoring during the study period

Climate & Rainfall

Based on Thornthwaite’s climatic classification, the district experiences humid type of climate. The district receives maximum rainfall during the south west monsoon followed by the north

east monsoon. The other months receive considerably less rainfall. The temperature is pleasant from December to February. The annual rainfall varies from 1757.6 to 2849.5 mm based on long term normal. The district receives on an average 2348 mm of rainfall annually. Major rainfall is received during June to September in the southwest monsoon (71%). The northeast monsoon contributes about 18%. The western part of the district around Mannarghat receives the maximum rainfall (2849 mm) whereas in the rain shadow area of Chittur in the eastern part receives the minimum rainfall (1758 mm). The last 10 years of data is presented below.

Soil types

There are four types of soil

- (1) Laterite soil
- (2) Virgin forest soil
- (3) Black cotton soil
- (4) Alluvial soil

Palakkad district is underlain by rocks of Archaean metamorphic complex. They include the granulite group, the gneisses and the schists above which laterite and alluvium are observed. Intrusives of pegmatites and quartz veins are also common in the northeastern parts of the district.

Groundwater occurs in all the geological formation from Archaean crystalline (hard rock) to Recent alluvium (soft rock). Groundwater occurs in phreatic condition in the laterite, alluvium and weathered crystallines. It is in semi confined to confined condition in the deep fractured rocks. The entire district can be divided into three units based on hydrogeological information.

- 1) Valley fills/Alluvium
- 2) Laterite terrain
- 3) Crystallines.

Valley fills are noticed along the valley portion and along the river terraces/banks (near Ottapalam, Pattambi area) and are shown in the hydrogeological map. These are mainly seen in Mannarghat, Ottapalam and Pattambi, Trithala blocks. The water level ranges from 2- 12 m bgl (premonsoon) and 1- 6 m bgl (post monsoon). The fluctuation is generally high up to 5 m.

The yield of dug well ranges from 5 to 20 m³ / day.

Ground Water Quality Analyses

During pre-monsoon season of 2008 only 33 samples were selected for the chemical analysis. Table 7a & 7b shows the statistical analysis and correlation between various parameters existing in the region. pH in the region varied between 6.59 and 8.12. The minimum was observed at Kongad in Palakkad taluk whereas the maximum was noticed at Mundur (Palakkad taluk). Electrical conductivity ranged between 90 and 1410 indicating salinity problems in some of the patches. Total hardness is found to be minimum 20mg/l Kadampzhipuram II in Ottapalam taluk and maximum (460 mg/l) was observed at Agali of Mannarkkad taluk. Major anions and cations like chloride and sodium were also found to be within the permissible limits except in few locations. One of the major water quality problem in the district is the presence of iron. It exceeds well above the permissible limits and a maximum of 41 ppm was reported from Kongad in Palakkad taluk.

Table 7a: Statistical Analysis of Pre-monsoon (2008)

parameters	No.	Minimum	maximum	mean	St. Deviation

pH	33	6.59	8.12	7.45	0.37
EC	33	90	1410	272.30	234.25
TH	33	10	460	79.09	78.89
Cl	33	5.9	235.2	31.95	41.00
Na	33	5.1	96	21.63	20.34
F	33	0.07	0.99	0.44	0.19
Fe	33	0.11	41	3.20	7.28

Table 7b: Correlation between various parameters (pre-monsoon, 2008)

Parameters	pH	EC	TH	Cl	Na	F	Fe
pH	1						
EC	0.355	1					
TH	0.347	0.884	1				
Cl	0.067	0.888	0.782	1			
Na	0.174	0.836	0.597	0.750	1		
F	0.410	0.577	0.610	0.438	0.364	1	
Fe	-0.369	-0.146	0.05	-0.114	-0.143	0.093	1

Table 7c: Statistical Analysis of Post-monsoon (2008)

parameters	No.	minimum	maximum	mean	St. Deviation
pH	77	6.57	8.53	7.81	0.42
EC	77	40	1390	491.97	357.08
TH	77	20	430	148.77	86.66
Cl	77	6.8	341	66.49	72.42
Na	77	2.7	237	49.22	51.38
F	77	0.07	2.9	1.25	0.57
Fe	77	0.11	11.25	1.88	2.70

Table 7d: Correlation between various parameters (post-monsoon 2008)

	pH	EC	TH	Cl	Na	F	Fe
pH	1						
EC	0.558	1					
TH	0.617	0.855	1				
Cl	0.273	0.840	0.697	1			
Na	0.250	0.624	0.483	0.527	1		
F	0.376	0.416	0.385	0.282	0.301	1	

Fe	-0.179	-0.253	-0.223	-0.147	-0.249	-0.062	1
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During post-monsoon it is found that the mean pH shown a sharp increase from 7.45 to 7.81 as compared to pre-monsoon. Similarly the electrical conductivity has shown drastic increase from a mean 272.3 $\mu\text{S/cm}$ to 491.97 $\mu\text{S/cm}$. This is because of the high increase in some of the locations. It is important to note that there is an increase in fluoride concentration during post-monsoon season. In Chittur taluk (Eruthempatty) 2.9 ppm of fluoride was noticed. There is an overall increase in the mean value of fluoride concentration which showed an increase from 0.44 ppm during pre-monsoon to 1.25 ppm during post-monsoon season.

An analysis of the regular monitoring wells of ground department showed that water quality is a major constraint in some of the pockets in the district. Various parameters such as Total Hardness, Chloride, Sodium, Fluoride, Iron, pH and Electrical Conductivity showed marked variations in various parts of the district.

The highest value of pH was observed at Ambalapara (8.90) and the lowest at Cherpulacherry (5.18). The Total Hardness value at Kannimari was observed as 1410 mg/l. Chloride concentration showed a maximum value of 1025 mg/l at Kannimari. Fluoride concentration was also found to be very high in villages like Nattukal (2.87 mg/l), Panangattiri (2.80 mg/l), Tharur (2.80 mg/l), Chempanthode (2.90 mg/l) etc. Ion content of 41 mg/l was noticed at Kongad village. Iron concentration was also high at Pudukode (11.25 mg/l), Cherpulacherry (9.62 mg/l), Vallapuzha (9.28 mg/l), Pattambi (9.27 mg/l), Ambalapara (9.75 mg/l), Pulapetta (9.38 mg/l), etc.

The variation of pH was between 5.2 (Ottappalam) and 8.5 at Chittur. Electrical Conductivity, the maximum observed was at Kannimari (3200 $\mu\text{S/cm}$). EC value recorded at Kozhinjampara was 1980 $\mu\text{S/cm}$, Chullinada (1570 $\mu\text{S/cm}$), Venthapalayam (1550 $\mu\text{S/cm}$) and Thavalam (1520 $\mu\text{S/cm}$). Higher values of Sodium were observed at Kodakad (636 mg/l), Mannarkad (237 mg/l), Venthapalayam (232 mg/l) and Chittur (207 mg/l).

PH

The pH values of the samples collected from selected locations of Palakkad district varied from 6.7 to 8.10 during pre-monsoon and 6.5 to 8.5 during post-monsoon of 2010. It is noticed that the pH is well within the permissible ranges for drinking and other purposes. The seasonal variation of pH in waters 2010 is given in Figures 7a.

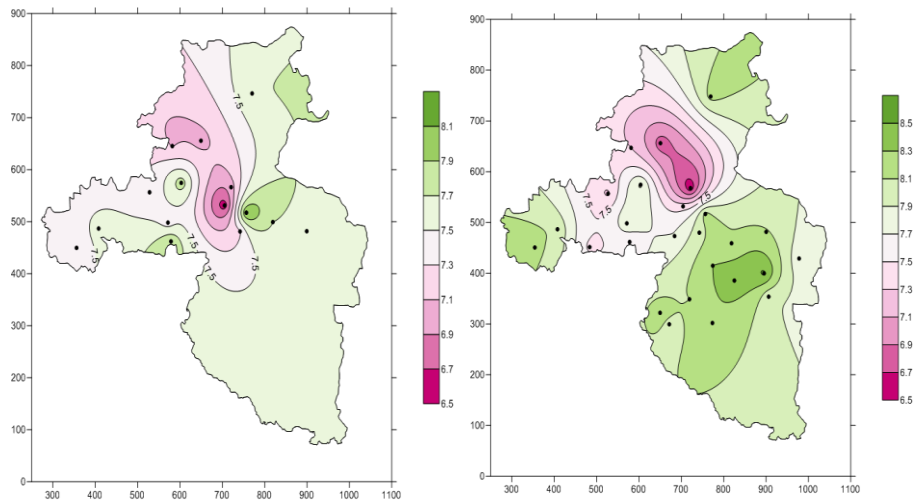


Figure 7a: Spatial Distribution of pH in Palakkad district (2008)

Electrical conductivity

Electrical conductivity of the samples varied from less than 100 micro-siemens/cm to 1400 micro-siemens/cm during pre-monsoon and post-monsoon in the year 2008. This clearly indicates that water is quite stable does not subject to other physical environmental variations. However, it is noticed that in the year 2010 highest EC was 2900 micro-siemen/cm. During the pre-monsoon varied from 100 micro-siemen/cm to 1400 mcirosiemen/cm and in the post-monsoon it varies from 100 micro-siemen/cm to 2900 microsiemen/cm. This could be due to agriculture and other wastes waters entering into the well during the post monsoon. It is found that north-eastern and eastern part of the district are affected much as compared to the western district. Figures 7b and 7c represents the seasonal variation of EC in Palakkad district.

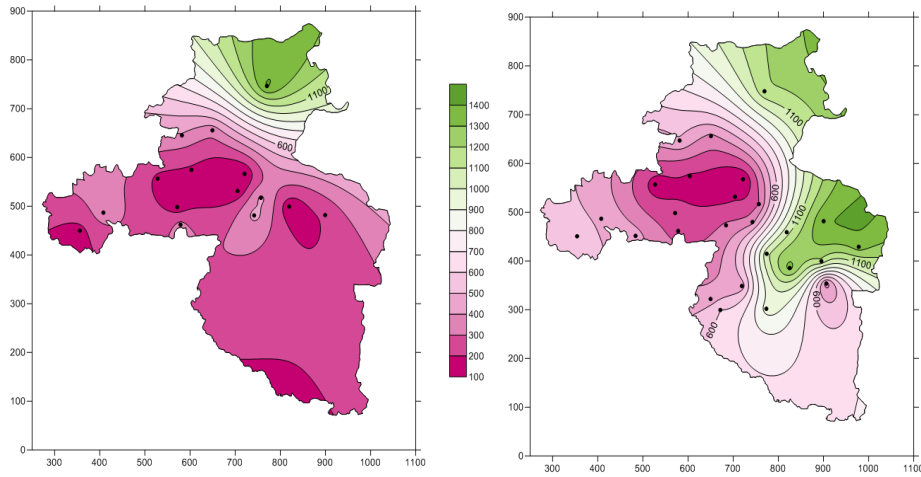


Figure 7b: Spatial Distribution of EC in Palakkad district during 2008

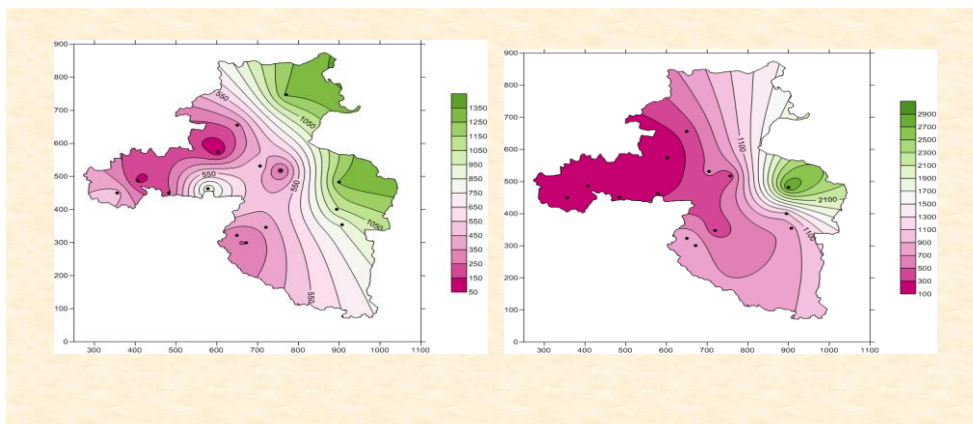


Figure 7c: Spatial Distribution of EC in Palakkad district during 2010

Total Dissolved Solids

The concentration of TDS during 2008 and 2010 were analysed and found that the values are higher than the desirable ranges. The maximum concentration observed during pre-monsoon, was 800 mg/l and the variation found was between less than 100 mg/l to 800 mg/l. In the post-monsoon, it varied from less than 200 micro-siemen/cm to 1800 microsiemen/cm. The seasonal variation of TDS during 2010 is depicted in Figure 7d.

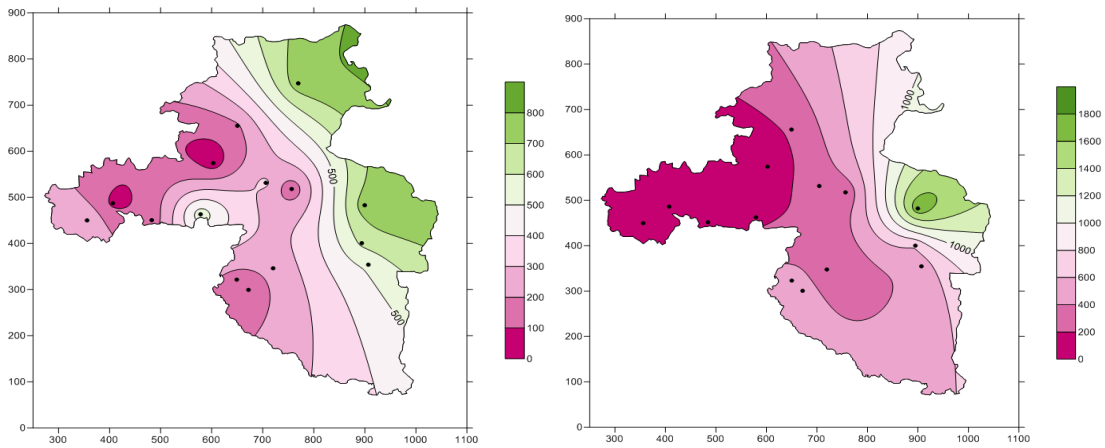


Figure 7d: Spatial Distribution of TDS in Palakkad district during 2010

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 10 mg/l to a maximum of 370 mg/l during pre-monsoon and 17 mg/l to 170 mg/l during the post-monsoon of 2010. Higher values of alkalinity were noticed in the western part of the district and it is local in nature. It is noticed that the presence of carbonate is quite negligible in almost all locations. Therefore, the total alkalinity is mainly due to bicarbonates. The distribution of bicarbonates and Total alkalinity are shown figures 7e & 7f.

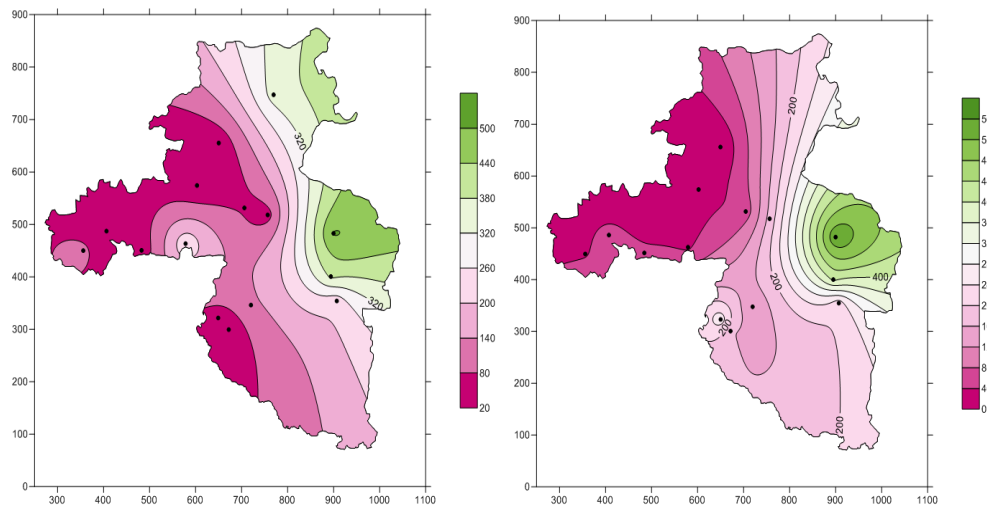


Figure 7e: Spatial Distribution of Total Alkalinity in Palakkad district during 2010

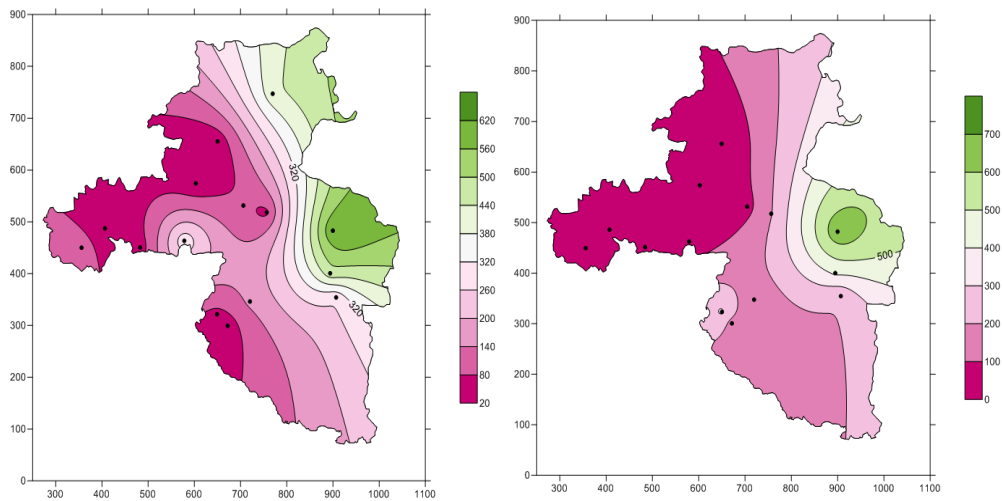


Figure 7f: Spatial Distribution of Bicarbonates in Palakkad district (2008)

Chlorides

The chloride content in the water samples varied from less than 25 mg/l to a maximum of 225 mg/l during pre-monsoon and in the post-monsoon, it varies between less than 30 mg/l and 330 mg/l. It is found that in few locations chloride concentrations was higher than the permissible limits. However, in majority of the observed wells, the concentration was within the permissible ranges. Figures 7g and 7h shows the spatial distribution of chloride in Palakkad district.

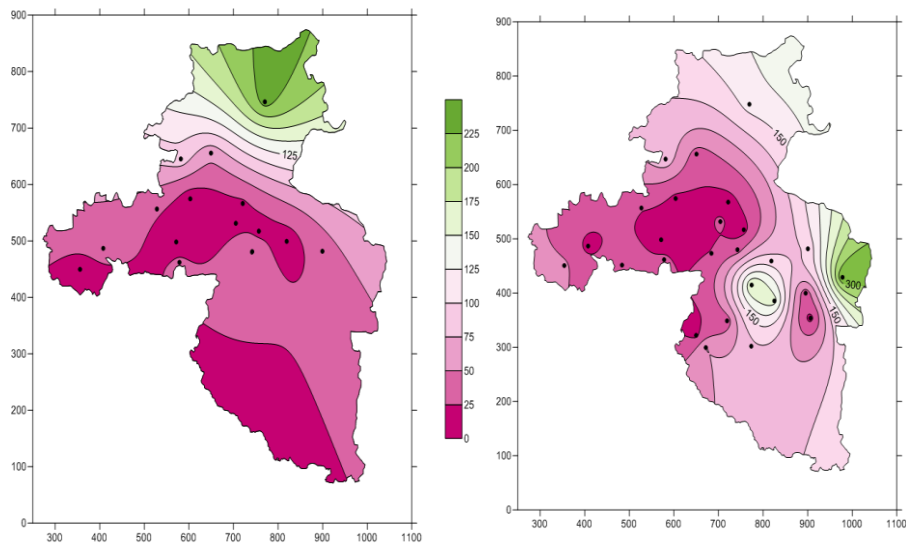


Figure 7g: Spatial Distribution of Chloride in Palakkad district during 2008

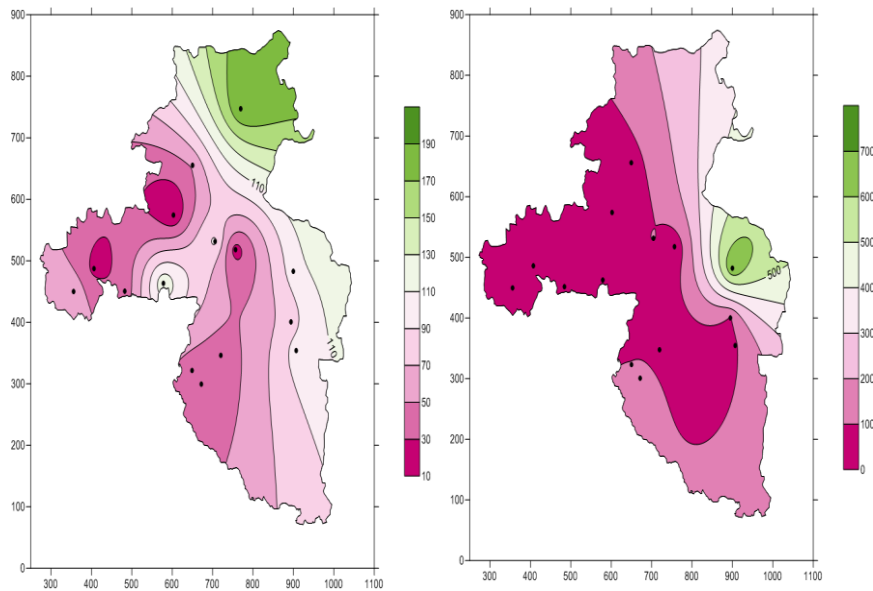


Figure 7h: Spatial Distribution of Chlorides in Palakkad district during 2010

Fluoride

The concentration of fluoride varied from 0.2 mg/l to 0.97 mg/l during pre-monsoon and 0.2 mg/l to 2.2 mg/l in the post-monsoon of 2008. In the year 2010, it is found that the concentration varies between 0.2 mg/l and 1.6 mg/l in pre-monsoon, 0.2 mg/l to 0.89 mg/l during the post-monsoon. This shows the seasonal variation of fluoride which is attributed to runoff waters which mix with the groundwater during rains. Figure 7i & 7j shows the variation of fluorides in Palakkad district.

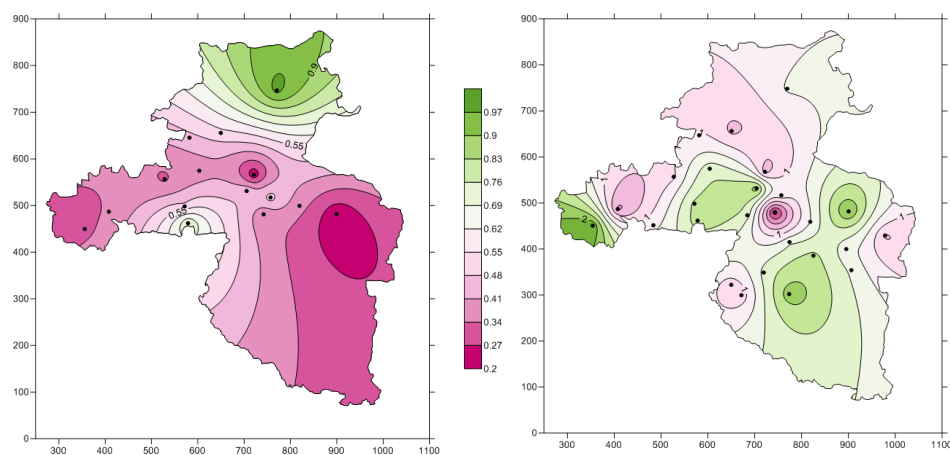


Figure 7i: Spatial Distribution of F in Palakkad district during 2008

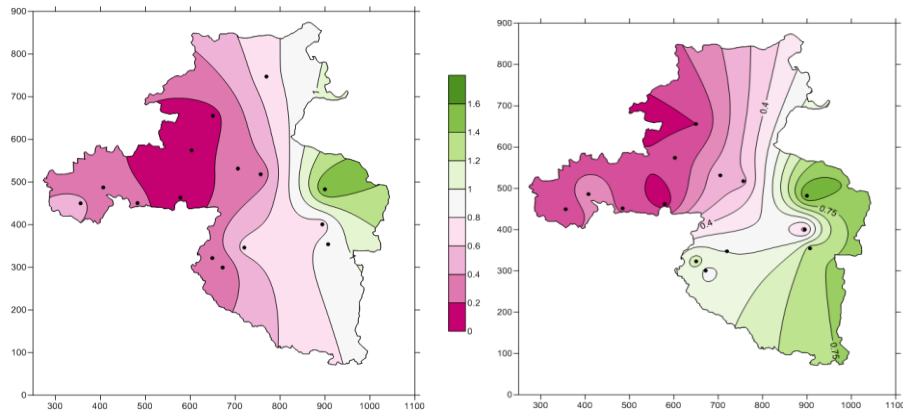


Figure 7j: Spatial Distribution of F in Palakkad district during 2010

Sulphates

The sulphate concentration ranged from 10 mg/l to 90 mg/l during pre-monsoon and in the post-monsoon, it varied between 4 mg/l and 56 mg/l. It is found that the variations of sulphates are quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 7k shows the variation of sulphates in Kollam district.

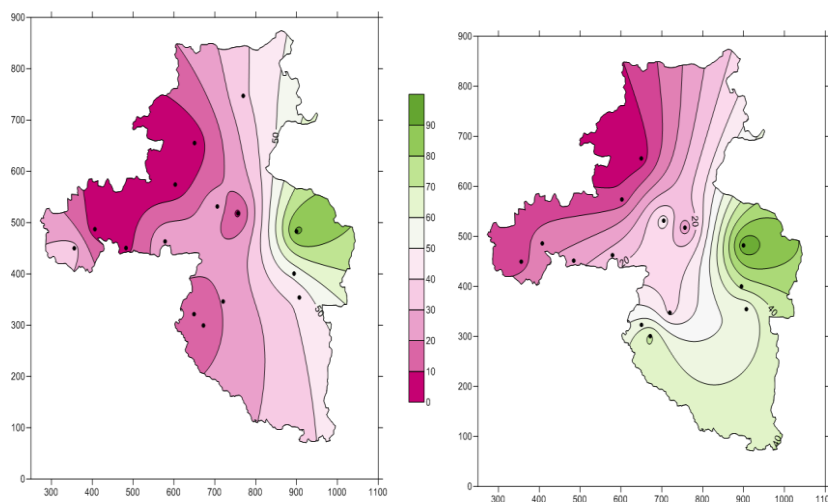


Figure 7k: Spatial Distribution of Sulphates in Palakkad district during 2010

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.7 mg/l to 6.3 mg/l during pre-monsoon and in the post monsoon it ranges between 1 mg/l and 12 mg/l. Figure 7l shows the variation of nitrates in Palakkad district in the year 2010.

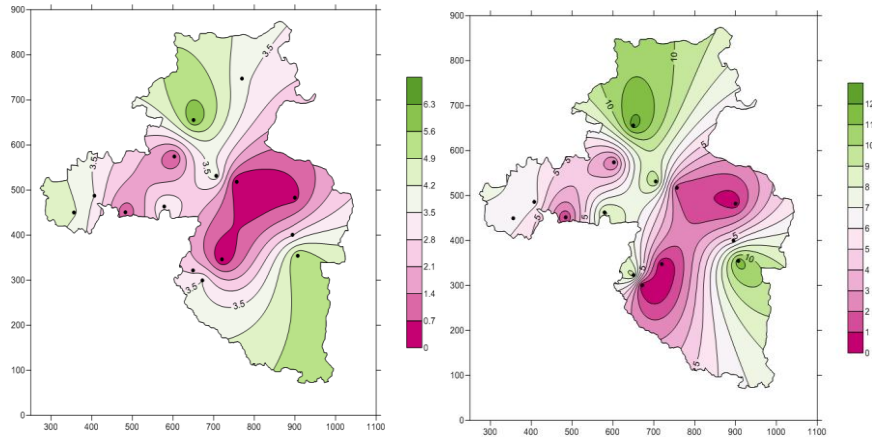


Figure 7l: Spatial Distribution of Nitrates in Palakkad district during 2010

Total Hardness

Total hardness of the water samples varied from less than 30 mg/l to 450 mg/l during pre-monsoon and in the post-monsoon, it varied between 30 mg/l to 420 mg/l in the year 2010. Total hardness showed a considerably higher concentration both during pre-monsoon and in the post-monsoon. The seasonal variation of total hardness is represented in Figure 7m.

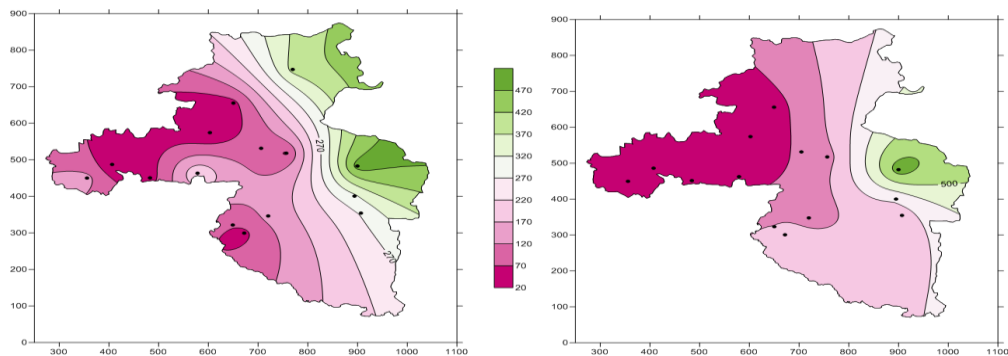


Figure 7m: Spatial Distribution of Total Hardness in Palakkad district during 2010

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (fig. 7n and 7o). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from 30 mg/l to 450 mg/l during pre-monsoon and less than 20 mg/l to 420 mg/l in the post-monsoon. The magnesium concentration varies from less than 10 mg/l to 100 mg/l in the pre-monsoon and during post-monsoon it varies from less than 10 mg/l to 90 mg/l. The observation shows that both calcium concentration is much higher than the permissible limits

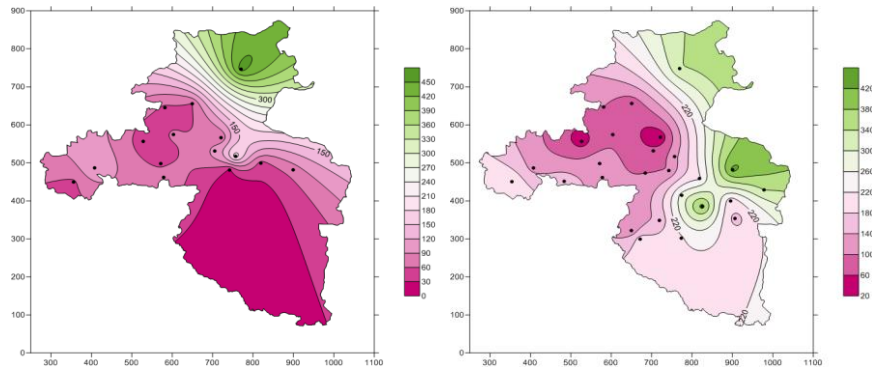


Figure 7n: Spatial Distribution of Ca in Palakkad district during 2010

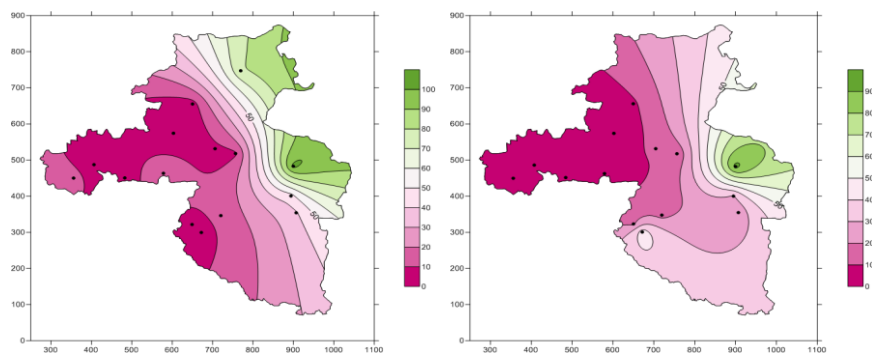


Figure 7o: Spatial Distribution of Mg in Palakkad district during 2010

Sodium and Potassium

Analysis of sodium concentration in the groundwater samples were carried out in the year 2008 and 2010. The results of 2008 & 2010 is shown in figures 7p & 7q. The observed concentration of sodium varied from less than 5 mg/l to 95 mg/l during pre-monsoon and in the post-monsoon it ranges from less than 30 mg/l to 210 mg/l. In 2010, it showed a lower concentration, i.e. 5 mg/l to 115 mg/l in pre-monsoon and 10 mg/l to 420 mg/l in the post-monsoon. The concentration of potassium varied from 1mg/l to 60 mg/l during pre-monsoon and 4 mg/l to 56 mg/l in the post-monsoon. The seasonal variation of sodium and potassium concentration is represented in figure 7p, 7q and 7r.

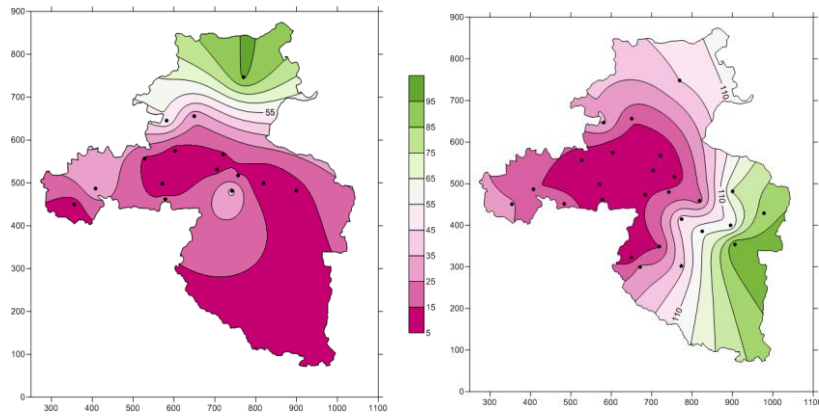


Figure 7p: Spatial Distribution of Na in Palakkad district during 2010

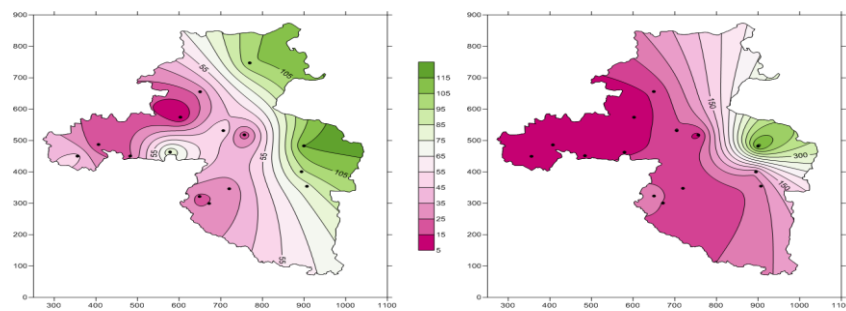


Figure 7q: Spatial Distribution of Na in Palakkad district during 2010

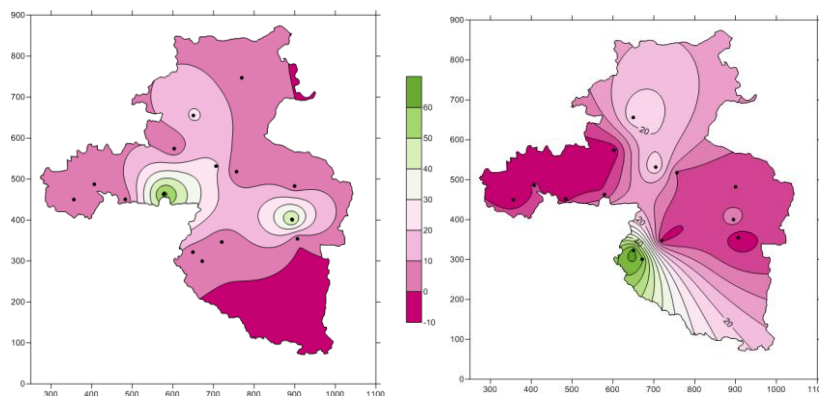


Figure 7r: Spatial Distribution of Potassium in Palakkad district during 2010

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2010 was found to vary between 0.1 mg/l to 40 mg/l which is higher than the desirable ranges. In the post-monsoon, the maximum concentration observed was 9.7 mg/l which is significantly higher than

the permissible limits however, reduction in the concentration was drastic from pre-monsoon to post-monsoon season. The figure 7s shows the variation of iron in the district.

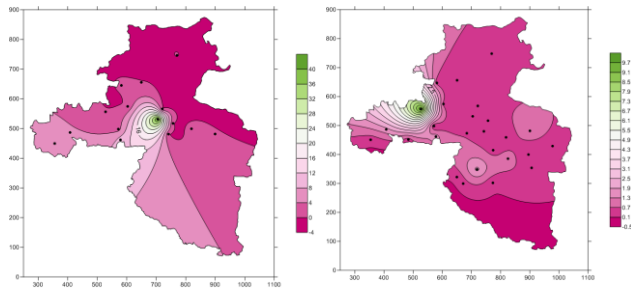


Figure 7s: Spatial Distribution of Iron during 2010

Groundwater Classification

Groundwater suitability was classified based on Piper's diagram, Chadha's method. USSL classification is also presented to understand the irrigation suitability of groundwater.

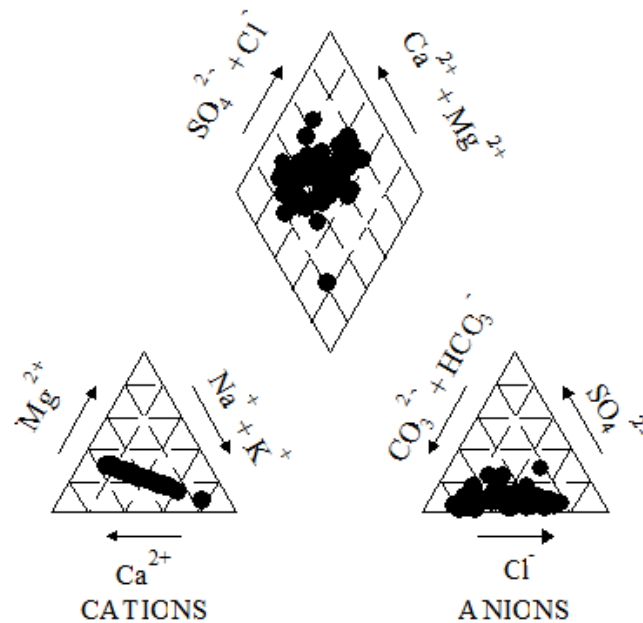


Figure 7t: Piper's classification of ground water of Palakkad district (Pre-monsoon, 2004)

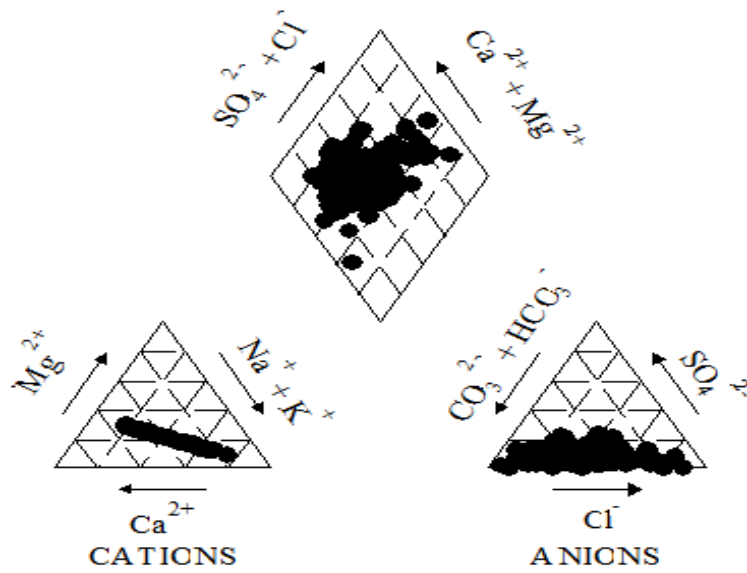


Figure 7u: Piper's classification of ground water of Palakkad district (Post monsoon, 2004)

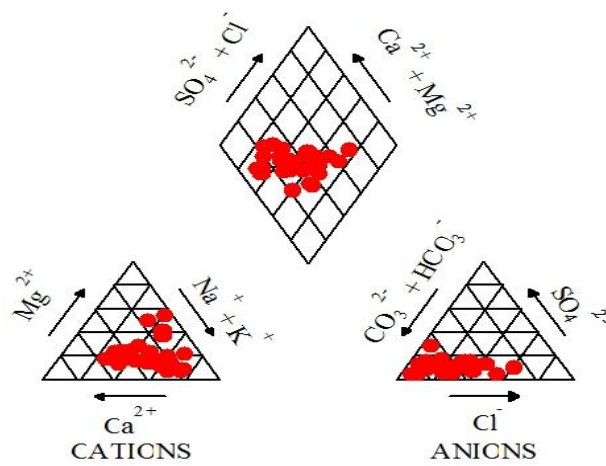


Figure 7v: Piper's classification of ground water of Palakkad district (Pre- monsoon, 2010)

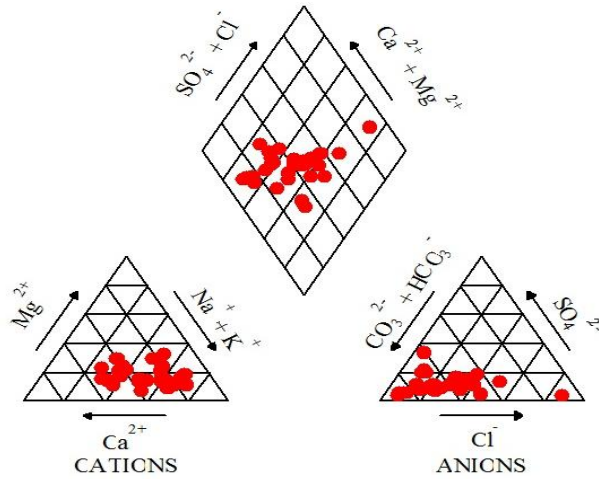


Figure 7w: Piper's classification of ground water of Palakkad district (Post- monsoon, 2010)

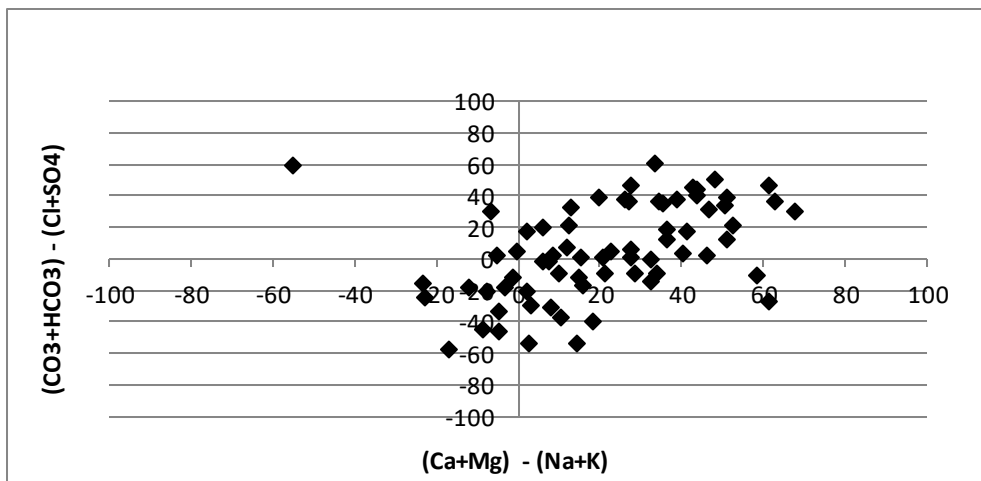


Figure 7x: Chadha's diagram of Palakkad district (Pre-monsoon, 2004)

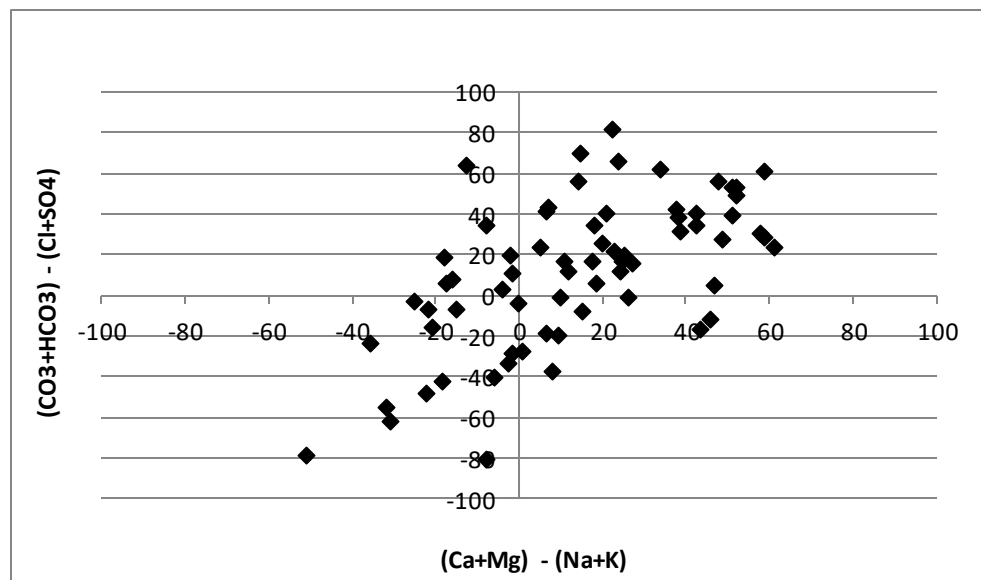


Figure 7y: Chadha's diagram of Palakkad district (Post-monsoon, 2004)

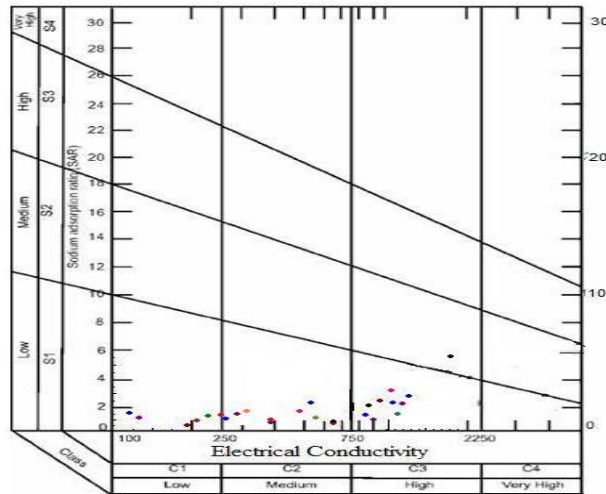


Figure 7z: USSL classification of ground water of Palakkad district (Pre- monsoon, 2010)

USSL premonsoon 2010

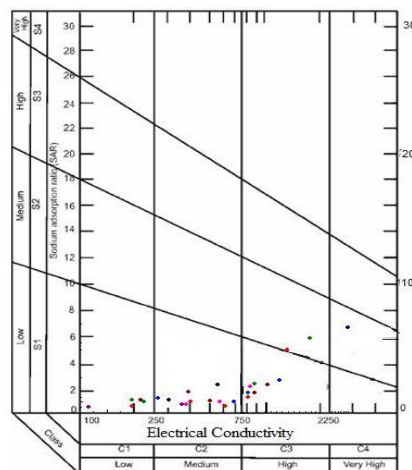


Figure 7aa: USSL classification of ground water of Palakkad district (Post- monsoon, 2010)

Heavy Metals in Palakkad District

It is observed that in Palakkad district, though the heavy metals showed the presence in some of the selected wells, no immediate threat is found due to contamination. Four samples from selected wells have been subjected to heavy metal analysis and found that in there are heavy metals like copper and mercury in groundwater of Palakkad district. It was also noticed that considerable quantity of orthophosphate in the groundwater samples. Table 7e shows the distribution of heavy metals in Palakkad district.

Table 7e: Heavy metal distribution in the Palakkad district

	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
well No								
PKD Q B1	1.783	0	0	0.03	0	0.1542	0	0
PKD Q B2	1.014	0.004	0	0.008	0	0	0	0
PKD Q B3	2.384	0	0	0	0	0.0059	0	0
PKD Q O4	0.898	0	0.017	0.011	0	0	0	0

8. 0 GROUND WATER QUALITY OF ERNAKULAM DISTRICT

The district is situated in the northern side of the state, bound by Trichur district on the north, Idukki on the east, Kottayam and Alappuzha districts on the south and the Lakshadweep Sea on the west. It has an area of 2408 sq. km. Ernakulam (Cochin) is the district headquarters. For administrative purposes, the district is divided into two revenue divisions and seven taluks. Muvattupuzha revenue division with Muvattupuzha as its headquarters comprises of Kunnathunadu, Muvattupuzha and Kothamangalam taluks, while Cochin division with its headquarters at Cochin consists of Aluva, Paravur, Cochin and Kanayanur taluks. There are 15 community development blocks, 86 village panchayats eight municipalities and one corporation in the district. The district has a population of 31,05,798 persons as per 2001 census.

About 83% of the total area of the district is cultivable land and nearly 10% of the area is under forest cover including reserve forest plantation; and water bodies constitute 5.3% and built up area for dwelling unit etc is nearly 2% of the total area. An area of 505 sq.km is under irrigation in the district. Periyar valley irrigation project with a barrage at Bootathankettu which uses the tail race water of Sengulam, Panniyur and Pallivasal Hydro-electric projects and Chalakudy diversion project are source for canal irrigation in the district.

The major crops under irrigation are paddy, coconut, rubber, banana and arecanut. The gross area under irrigation is higher than the net as more than one crop of paddy is cultivated under irrigation.

Climate & Rainfall

Ernakulam district has wet monsoon type of climate. The district experiences heavy rainfall during southwest monsoon season followed by northeast monsoon. During the other months the rainfall is considerably less. March, April and May months are the hottest. December to February months are the coldest. The annual rainfall ranges from 3233 to 3456 mm at different places of the district.

The district receive on an average 3359.2 mm (based on 1901-99 data) of rainfall annually. Rainfall during South-west monsoon season contributes nearly 67.4% of total rainfall of the year, followed by the north-east monsoon which contributes nearly 16.6% and the balance of 16% is received during the month of January to May as summer/pre-monsoon showers.

The mean monthly maximum temperature ranges from 28.1 to 31.4 °C and the minimum ranges from 23.2 to 26 °C. The maximum temperature occurs during March and April months and the minimum temperature occurs during December and January months. The humidity ranges from 68 to 89% during morning hours and 64 to 87% during evening hours. The maximum humidity is observed during May to October months. The wind speed ranges from 6.7 to 10.9 km/hour with mean speed of 9.1 km/hour. The wind speed is high during the period from March to September. The PET ranges from 94.5 to 159.2 mm. The maximum PET occurs during March and minimum occurs during June. The PET is less than the rainfall from May to November indicating water surplus for recharge into ground water regime.

Geomorphology and Soil

The district can be broadly divided into three physiographical units viz. (1) the Coastal plains (low lands) (2) the mid lands and (3) the high lands. The general elevation of the coast is less than 8.0m.amsl and that of the midlands is between 8.0 and 76 m.amsl. The highlands are having the general elevation above 76 m with the maximum of around 504 m.amsl as in Malayattur Reserve forests. The entire taluks of Kochi and Parur and major parts of Kanayannur fall under the coastal plain. The municipalities of Paravur and Tripunithura the township of Kalamasseri and the corporation of Kochi are located in the coastal plains. All the other taluks except the northeastern parts of Kunnathunad taluk fall under the mid land area.

The only high land belt of the district is the Malayattoor reserve forest in Koovappady block, which covers about 9% of the area of the district. The highest point is at Sulu Medu (534 m.amsl).

Pedology

On the basis of morphological features and physico-chemical properties, the soils of the district are classified as Lateritic, Hydromorphic saline, Brown hydromorphic, Riverine alluvium and Coastal alluvium. Lateritic soil is the most predominant soil type of the district. In Muvattupuzha, Kothamangalam, Kunnathunadu and parts of Aluva taluks lateritic soil is encountered. These soils are well drained, low in organic matter and plant nutrients. The major crops grown are coconut, tapioca, rubber, arecanut, pepper, cashew and spices. Small patches of hydromorphic saline soil are encountered in the coastal tracts of the district in Kanayannur and Cochin taluk. The tidal backwaters contribute to the salinity of the soil. Coconut is grown in these soils. Brown hydromorphic soil is the second most prevalent soil type of the district and they are encountered in valley bottoms. The soil is enriched in clay content and plant nutrients. The soil is suited for paddy cultivation.

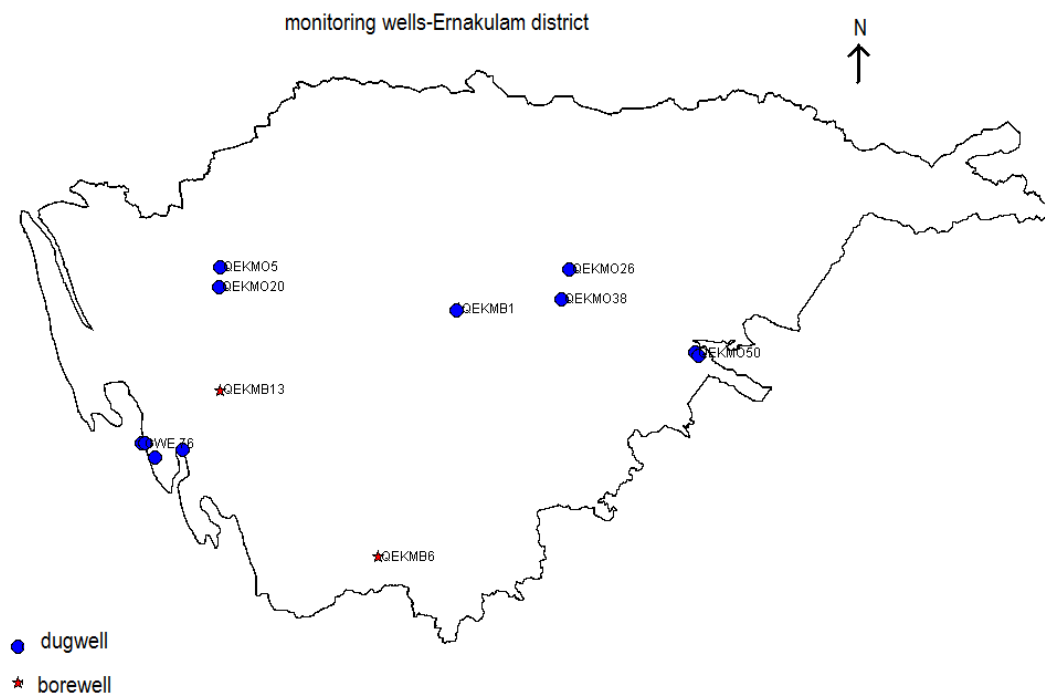


Figure 8: Locations of groundwater sampling Ernakulam district 2008

Ground Water Quality Analyses

Groundwater generally occurs under phreatic conditions in weathered and fractured crystalline rocks, laterites and unconsolidated coastal sediments. It occurs under semi-confined to confined conditions in the deep seated fractured aquifer of the crystalline rocks and Tertiary sediments. The weathered zone in the crystallines below acts as good storage for groundwater.

In Ernakulam district, water quality problems related to salinity, total hardness and iron content are very common. In this connection, 98 wells were monitored during pre-monsoon and 71 wells were selected for post-monsoon monitoring. The pH value varies between 3.7 (Kizhakambalam, Kunnathunadu tehsil) and 8.7 (Velloorkunnam, Muvattupuzha tehsil) with a mean of 7.21. The electrical conductivity showed wide variations (28 $\mu\text{S}/\text{cm}$ to 4300 $\mu\text{S}/\text{cm}$) The minimum was noticed at Asamanoor of Kunnathunadu tehsil and the maximum was in Kochi (Revenue Tower compound).

Total hardness was also very high in some of the patches which could be due to the ingress of salt water. During the pre-monsoon the total hardness varies from 5 mg/l to 990 mg/l with a mean of 73.47 mg/l. This clearly indicates that hardness is high only in very few pockets. The post-monsoon also showed similar trend, however, total hardness in some locations went up to 1740 mg/l (Kunnukkara manjali of Parur tehsil). A marginal increase in iron concentration was noticed (increased 9.4 mg/l to 9.99 mg/l), however, the mean value showed a considerable decline from the pre-monsoon condition. The Chloride concentration was also high (1355 mg/l) for the samples from the Revenue Tower. Also the same water sample shows a high Sodium concentration (682 mg/l).

In the post-monsoon season, pH value showed a minimum 3.05 at Edayar in Alwaye taluk and the maximum was noticed at Ernakulam south in Kochi taluk. The electrical conductivity showed maximum variation that is between 32 $\mu\text{S}/\text{cm}$ and 3600 $\mu\text{S}/\text{cm}$ whereas the total hardness ranging between 5 mg/l and 1740 mg/l. Incidentally, the maximum EC and TDS were observed at the same place in a bore well, i.e. at Edayar in Alwaye taluk, however, it is interesting to note that the minimum value of EC was also noticed at Edayar but in an open well (dug well). Similarly, the maximum values of chloride and sodium were found in tube wells and the minimum were found in Muvattupuzha and Kothamangalam taluks. Iron content was found to be maximum (9.99 mg/l) in Cochin village (Revenue tower compound) in Kanayannur taluk. Table 4a & 4b below shows the statistical analysis and its corresponding correlations between ions.

Table 8a: Statistical analysis of Pre-monsoon 2008

Ernakulam premonsoon 2008

parameters	No.	minimum	maximum	mean	St. Deviation
pH	98	3.72	8.69	7.21	0.88
EC	98	28	4300	267.09	551.66
TH	98	5	990	73.47	137.07
Cl	98	2.9	1355	40.15	157.10
Na	98	1.78	682	30.21	90.77
Fe	98	0.01	9.4	0.99	1.83

Table 8b: Statistical analysis of Pre-monsoon 2008

Ernakulam postmonsoon 2008					
Parameters	No.	minimum	maximum	mean	St. Deviation
pH	71	3.05	8.24	6.97	1.03
EC	71	32	3600	223.66	448.33
TH	71	5	1740	78.59	213.54
Cl	71	3.9	345	21.78	41.74
Na	71	1.86	158	16.21	26.31
Fe	71	0.02	9.99	0.73	1.67

PH

The pH values of the samples collected from selected locations of Ernakulam district in 2010, varied from 4.9 to 7.3 during pre-monsoon and 5.6 to 8 during post-monsoon. It is quite interesting to note that eastern part of the district is dominated by acidic water whereas in the western part of the district, it is alkaline. The reason is obvious as the western part is covered by estuarine canals and so the influence makes the water is alkaline. Otherwise, due to geology and soils present in the catchment render the water acidic nature. The seasonal variations of pH in waters during 2010 are given in Figure 8a.

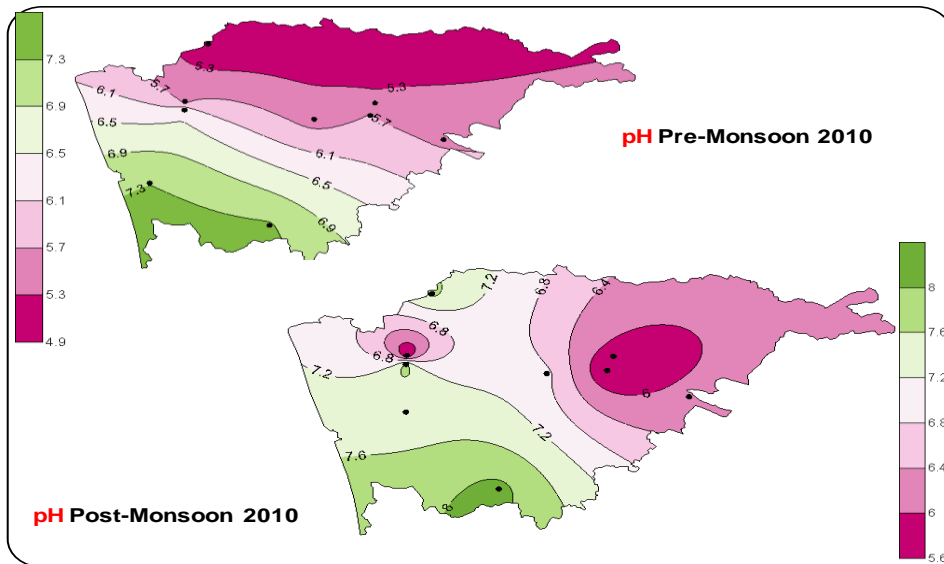


Figure 8a: Spatial variation of pH in Groundwater of Ernakulam district (Year:2010)

Electrical conductivity

Electrical conductivity of the samples varied from less than 30 micro-siemens/cm to 750 micro-siemens/cm during pre-monsoon and less than 80 micro-siemens/cm to 800 micro-siemens/cm in the post-monsoon of year 2010. Maximum EC was noticed in the south central part of the district. Results of the analysis carried out during 2008 and 2010 shows that water is potable in majority of the locations. Figure 8b shows the variation of Electrical conductivity during 2010.

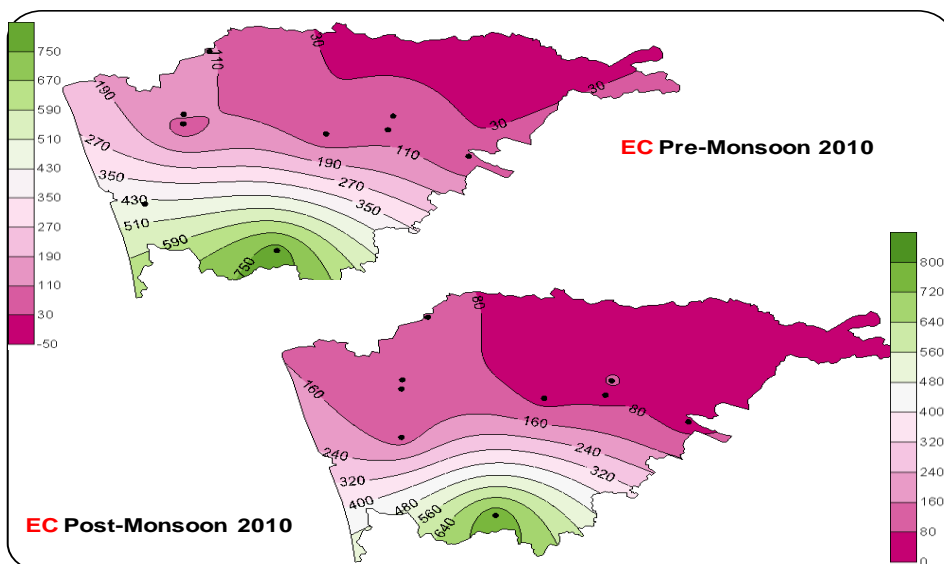


Figure 8b: Spatial variation of EC in Groundwater of Ernakulam district (Year:2010)

Total Dissolved Solids

The concentration of TDS during 2010 were analysed and found that the values are within the permissible limits. The maximum concentration observed during pre-monsoon was 480 mg/l. It varied between 20 mg/l to 480 mg/l during both pre-monsoon and post-monsoon. However, in majority of the locations TDS was below 300 mg/l. The seasonal variation of TDS during 2010 is depicted in figure 8c.

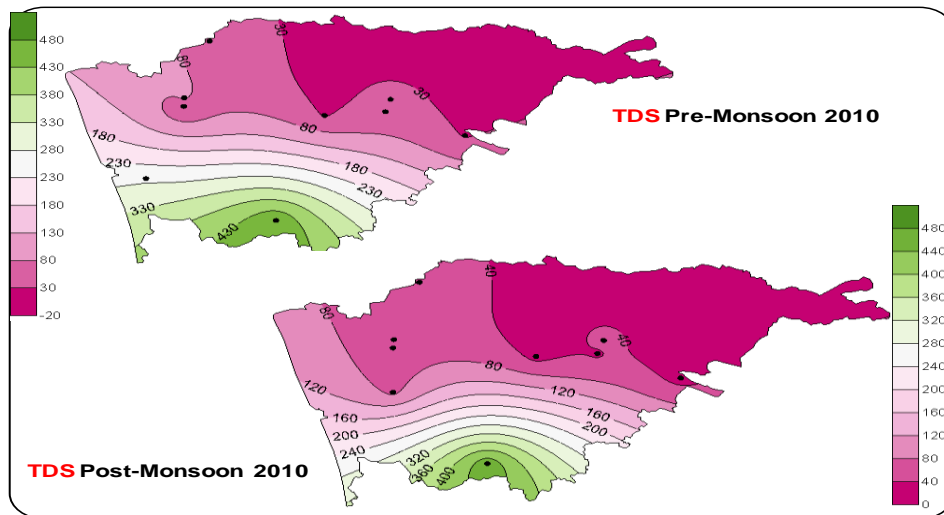


Figure 8c: Spatial variation of TDS in Groundwater of Ernakulam district (Year:2010)

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 9 mg/l to a maximum of 180 mg/l during pre-monsoon and 9 mg/l to 90 mg/l during the post-monsoon of 2010. Higher values of alkalinity were noticed in the south-western part of the district and it is local in nature. It is noticed that there is considerable quantity of carbonates in few locations. Therefore, the total alkalinity is due to bicarbonates. The distribution of bicarbonates and Total alkalinity are shown figures 8c & 8d.

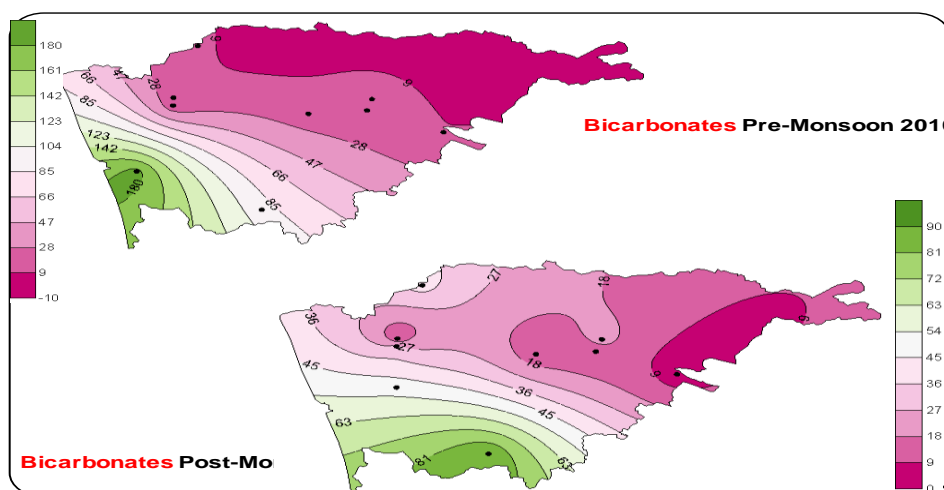


Figure 8d: Spatial variation of Bicarbonates in Groundwater of Ernakulam district (Year:2010)

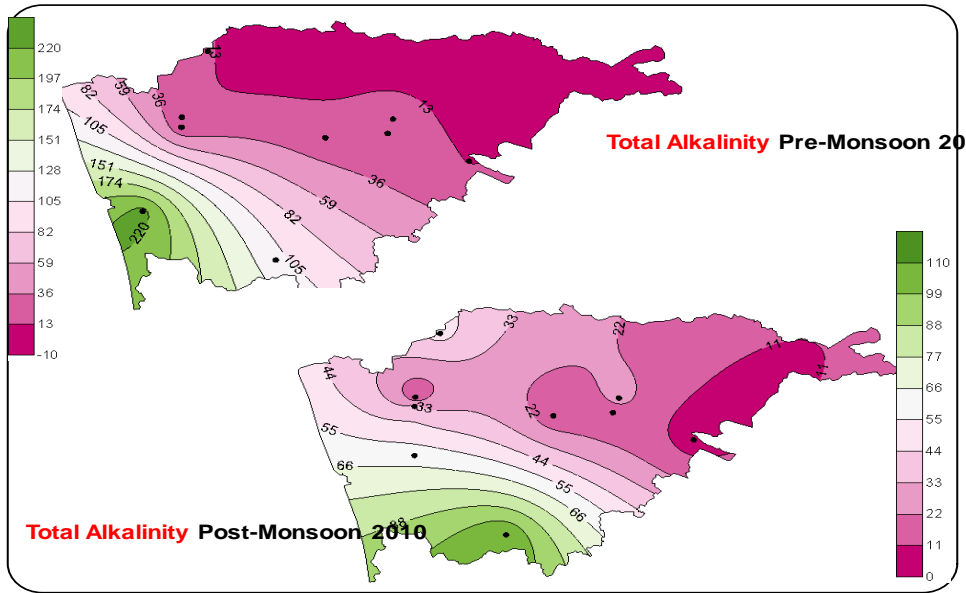


Figure 8e: Spatial variation of Bicarbonates in Groundwater of Ernakulam district (Year:2010)

Chlorides

The chloride content in the water samples varied from 10 mg/l to a maximum of 190 mg/l during pre-monsoon and in the post-monsoon, it is between 8 mg/l and 170 mg/l. The observed chloride concentration is well within the desirable ranges. Figure 8f shows the spatial distribution of chloride in Kollam district.

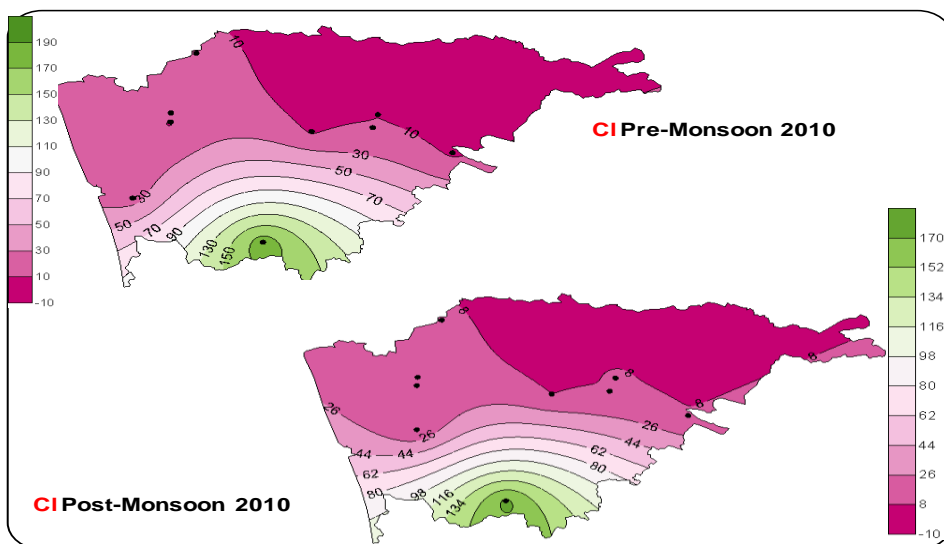


Figure 8f: Spatial variation of Chlorides in Groundwater of Ernakulam district (Year:2010)

Fluoride

The maximum concentration of fluoride observed was 0.11 mg/l during pre-monsoon in the western and eastern part of the district. The presence of fluorides is negligibly small in the district. It is found that the concentration of fluoride is much less than the required quantity in the groundwater. During post-monsoon, the fluoride content showed an increase to 0.44 mg/l. Figure 8g shows the variation of fluorides in Ernakulam district.

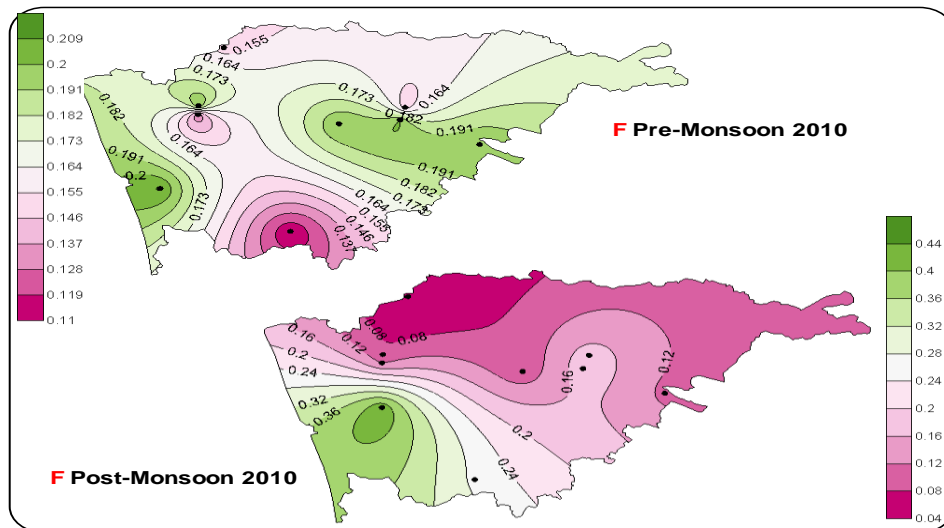


Figure 8g: Spatial variation of Fluorides in Groundwater of Ernakulam district (Year:2010)

Sulphates

The sulphate concentration ranged from 4 mg/l to 32 mg/l during pre-monsoon and in the post-monsoon, it varied between 1 mg/l and 31 mg/l. It is found that the variations of sulphates are quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 8h shows the variation of sulphates in Kollam district.

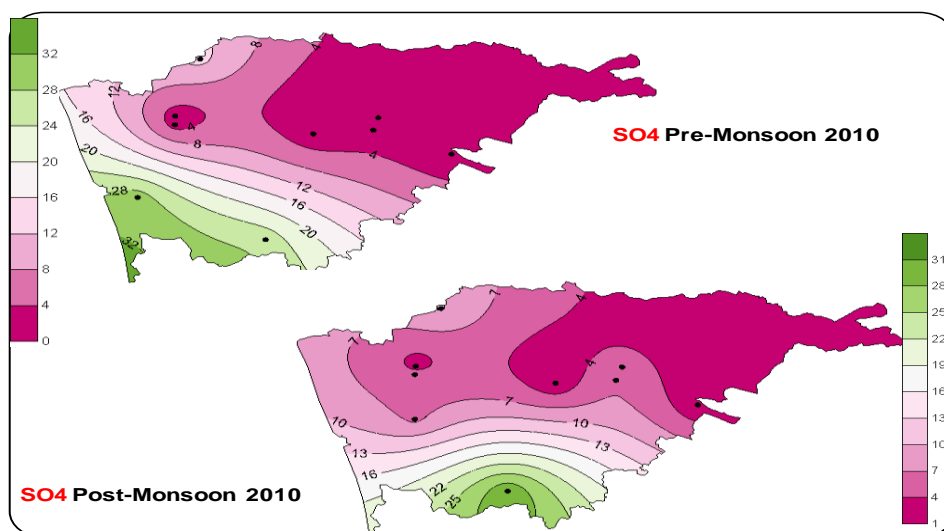


Figure 8h: Spatial variation of Sulphates in Groundwater of Ernakulam district (Year:2010)

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.2 mg/l to 4.2 mg/l during pre-monsoon and in the post monsoon it ranges between 0.09 mg/l and 1.44 mg/l. Figure 10n shows the variation of nitrates in Kollam district in the year 2010.

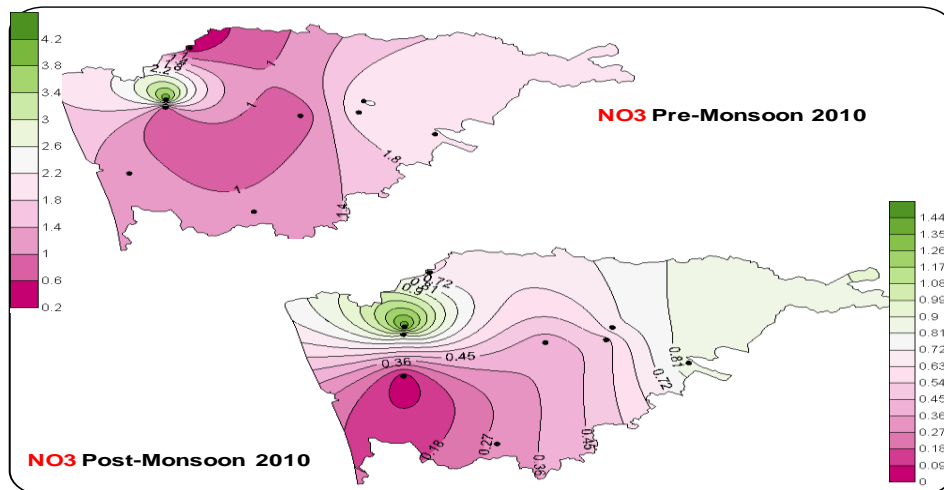


Figure 8i: Spatial variation of Nitrates in Groundwater of Ernakulam district (Year:2010)

Total Hardness

Total hardness of the water samples varied from less than 10 mg/l to 280 mg/l during pre-monsoon and in the post-monsoon, it varied between 30 mg/l to 270 mg/l in the year 2010. Total hardness showed a slightly higher concentration during pre-monsoon and it showed a marginal decline. The seasonal variation of total hardness is represented in Figures 10 o & 10 p.

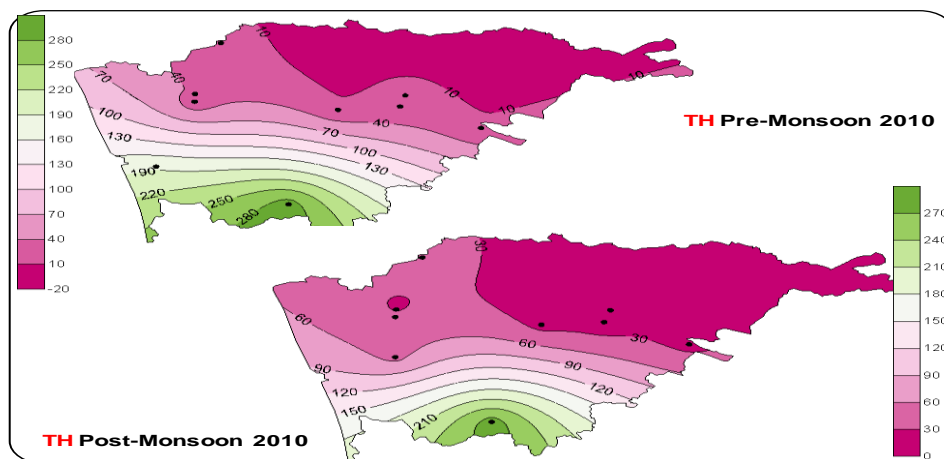


Figure 8j: Spatial variation of Total Hardness in Groundwater of Ernakulam district (Year:2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figures 8k and 8l). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from 2 mg/l to 65 mg/l during pre-monsoon and 2 mg/l to 56 mg/l in the post-monsoon. The magnesium concentration varies from less than 2 mg/l to 34 mg/l during both pre-monsoon and post-monsoon. This indicates the source of magnesium is common and stable in nature.

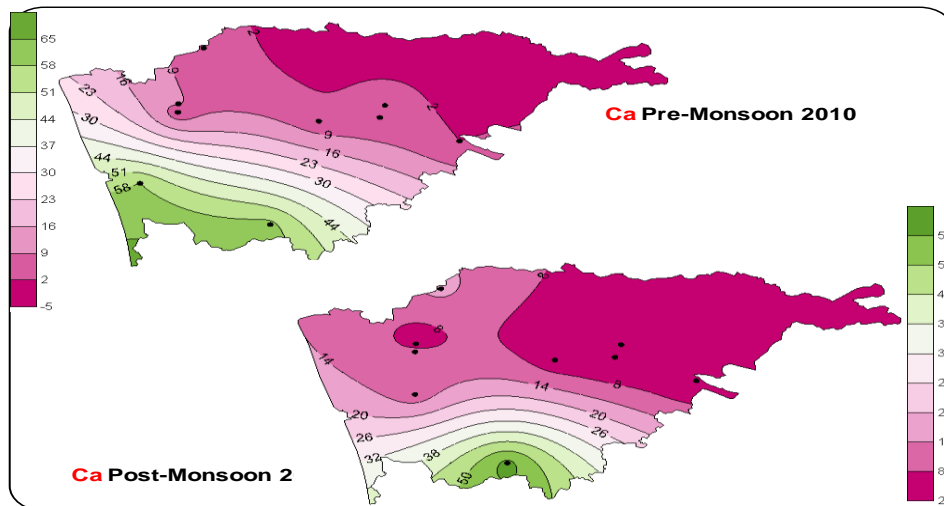


Figure 8k: Spatial variation of Ca in Groundwater of Ernakulam district (Year:2010)

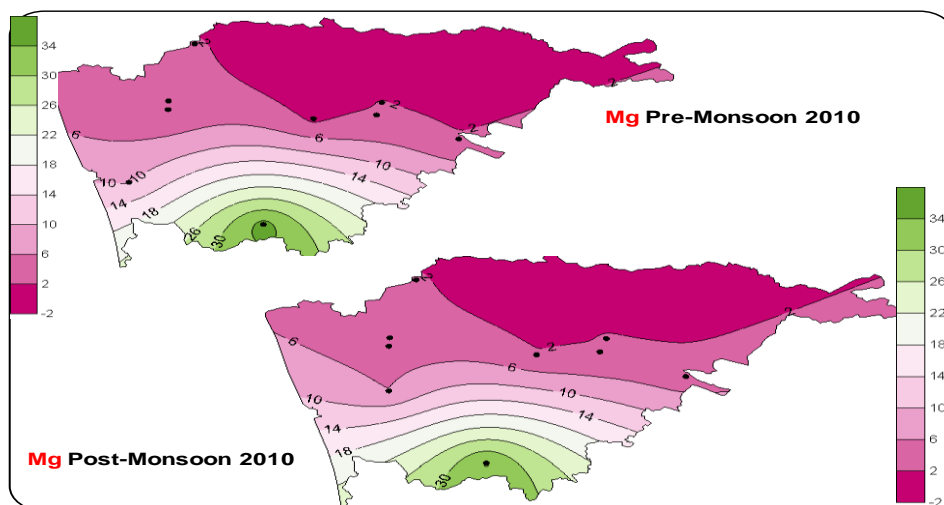


Figure 8l: Spatial variation of Mg in Groundwater of Ernakulam district (Year:2010)

Sodium and Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2010. The result of 2010 is shown in figures 10. The observed concentration of sodium varied from less than 4 mg/l to 40 mg/l both during pre-monsoon and post-monsoon. The

concentration of potassium varied from 2 mg/l to 20 mg/l during pre-monsoon and 1 mg/l to 5.2 mg/l in the post-monsoon. The seasonal variation of sodium and potassium concentration is represented in figure 8m & 8n.

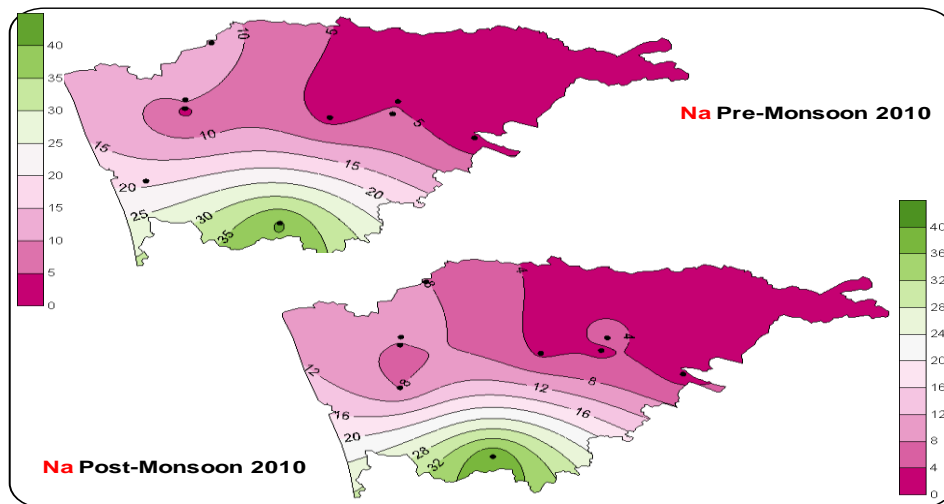


Figure 8m: Spatial variation of Sodium in Groundwater of Ernakulam district (Year:2010)

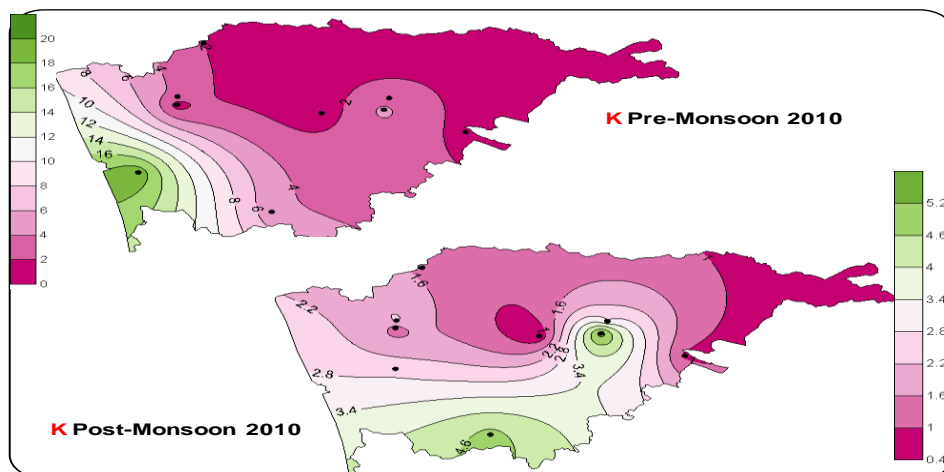


Figure 8n: Spatial variation of Potassium in Groundwater of Ernakulam district (Year:2010)

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2010 was found to be 0.34 mg/l which is more or less within the desirable ranges. The concentration varied between 0.02 mg/l to 0.34 mg/l during pre-monsoon and 0.01 mg/l to 0.29 mg/l in the post-monsoon. The figure 8o shows the variation of iron in the district.

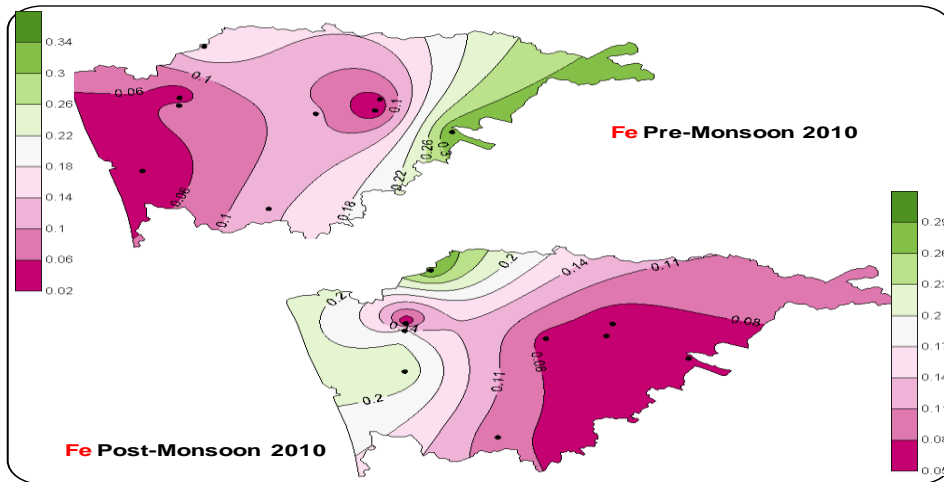


Figure 8o: Spatial variation of Iron in Groundwater of Ernakulam district (Year:2010)

Piper's Classification

The figure a & b shows that more than 90% of the samples can be classified as strong acids exceed weak acids (area 4) and carbonate hardness exceeds 50%, i.e. chemical properties are dominated by alkalies and strong acids both during pre-monsoon and post-monsoon season. The variations between the two seasons are found to be quite minimal. This further demonstrates the influence of coastal waters in the region.

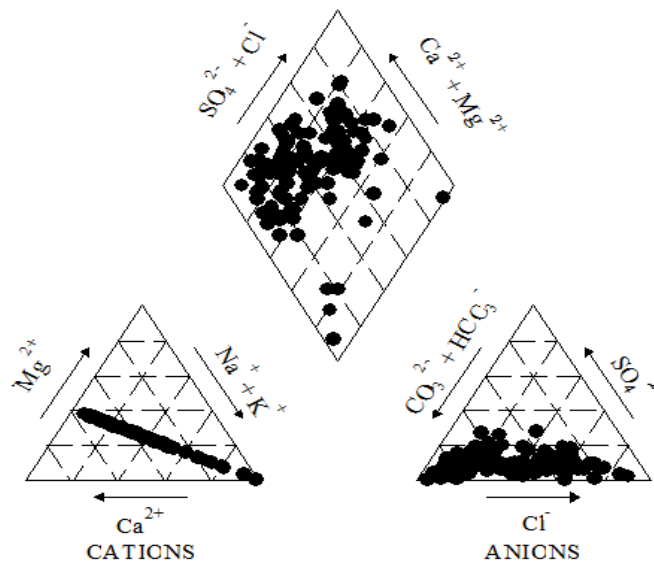


Figure 8p: Piper's classification of ground water of Ernakulam district (Pre-monsoon, 2007)

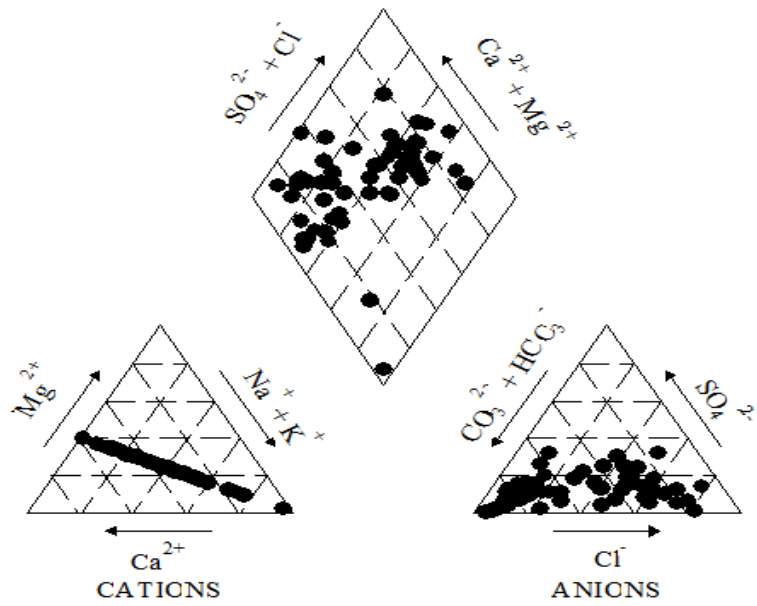


Figure 8q: Piper's classification of ground water of Ernakulam district (Post-monsoon, 2007)

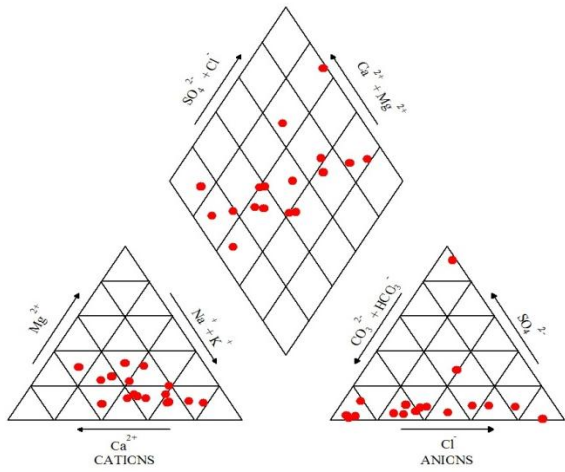


Figure 8r: Piper's classification of ground water of Ernakulam district (Pre-monsoon, 2010)

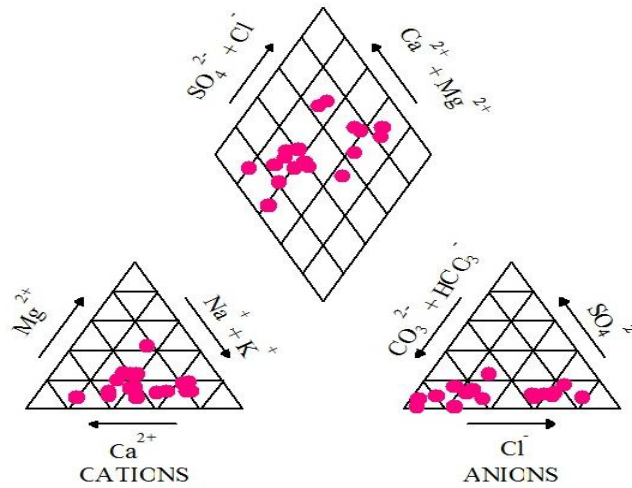


Figure 8s: Piper's classification of ground water of Ernakulam district (Post-monsoon, 2010)

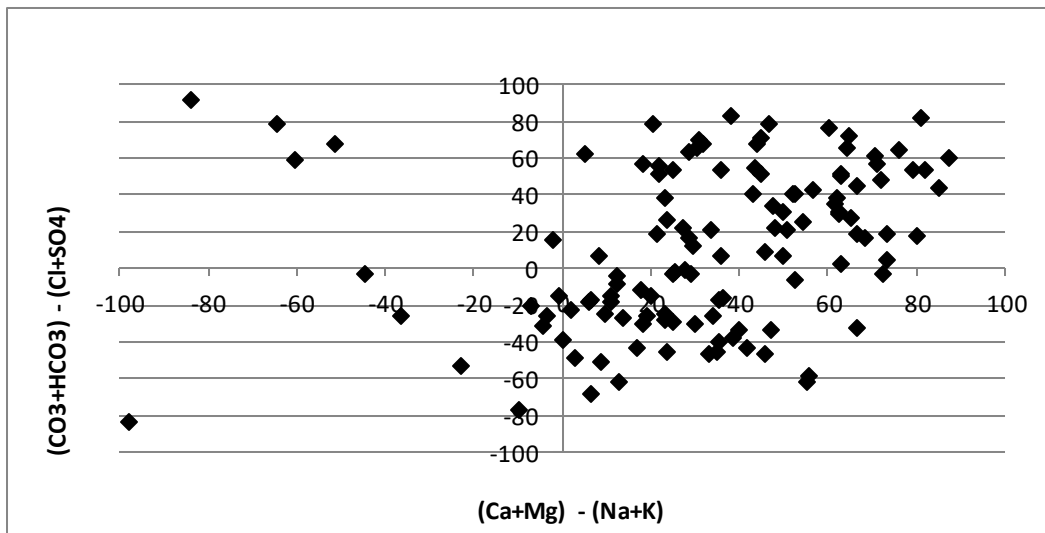


Figure 8t: Chadha's diagram of Ernakulam district (Pre-monsoon, 2007)

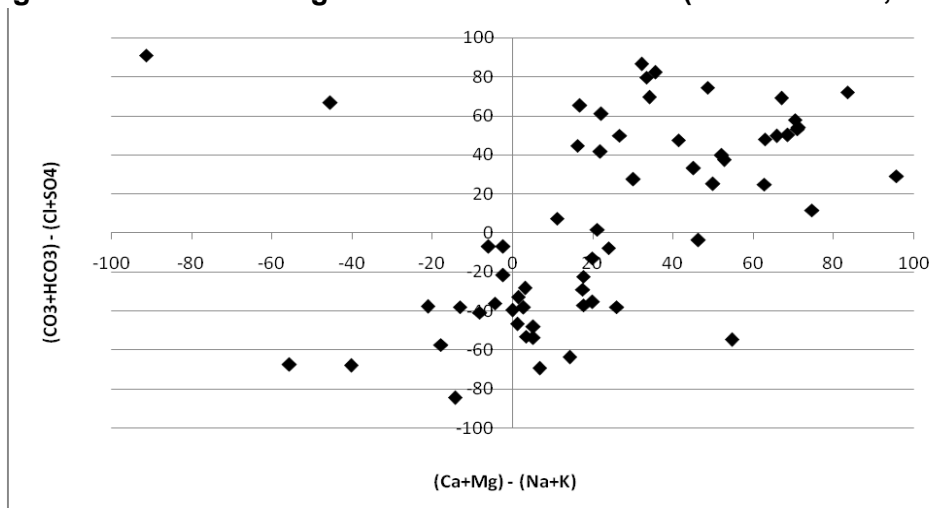


Figure 8u: Chadha's diagram of Ernakulam district (Post-monsoon, 2007)

The Chadha's diagram presented in the figure a & b also confirm the chemical processes in ground waters of the coastal region region. Therefore, in Ernakulam district, Ca – Mg – HCO₃ type, Ca- Mg- dominant HCO₃ type or HCO₃- dominat Ca- Mg- type waters are most predominating one followed by alkalines earth's exceed alkali metals and strong acidic anions exceed weak acidic anions.

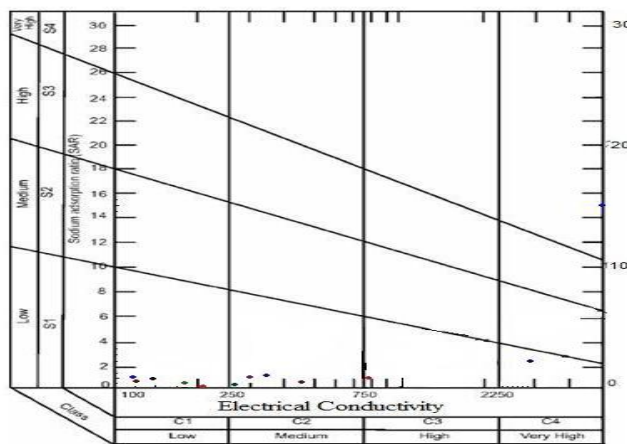


Figure 8v: USSL irrigation classification of ground water of Ernakulam district (Pre-monsoon, 2010)

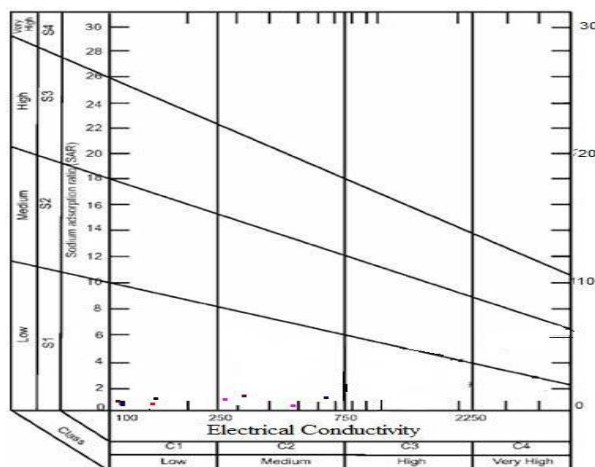


Figure 8w: USSL irrigation classification of ground water of Ernakulam district (Post-monsoon, 2010)

Based on the data collected during 2008, correlation coefficients were determined and presented below (Table 8c & 8d)

Table 8c: Correlation between various ions during Premonsoon 2008

	pH	EC	TH	Cl	Na	Fe
pH	1					

EC	0.173	1				
TH	0.238	0.863	1			
Cl	0.033	0.911	0.631	1		
Na	0.13	0.943	0.653	0.943	1	
Fe	0.169	0.608	0.644	0.487	0.507	1

Table 8d:Correlation between various ions during Pre-monsoon 2008

	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	-0.268	1				
TH	-0.295	0.938	1			
Cl	-0.011	0.551	0.302	1		
Na	-0.091	0.816	0.619	0.831	1	
Fe	0.017	0.779	0.623	0.779	0.850	1

Heavy Metals in Ernakulam District

It is observed that in Ernakulam district, heavy metals such as cadmium, copper, lead, zinc and nickel were detected in few observation wells. Arsenic and mercury were absent in all the seven samples. The concentration was comparatively high, though it is found to be below the permissible limits. It was also noticed that orthophosphates are present in all the wells. Therefore, the results indicate that there is a need to take appropriate measure to control the contamination. Table 8e shows the distribution of heavy metals in Palakkad district.

Table 8e: Heavy metal distribution in Ernakulam district

	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
well No								
GWE 76	0.02	0	0.006	0	0.027	0	0	4.4
GWE-77	0.02	0	0.006	0.014	0.009	0	0	2.3
GWE78	0.02	0	0	0.008	0.041	0	0.0014	0.24
QEKMB12	0.15	0	0.014	0.02	0.012	0	0.0313	11.1
QEKMO15	0.08	0	0.005	0	0.013	0	0	4.203
QEKMO9	0.01	0	0	0	0	0		0
QEKMT1	1.39	0	0.015	0.074	0	0	0	3.776

9.0 GROUND WATER QUALITY OF KOTTAYAM DISTRICT

9.1 General Physical features of the District

The Kottayam district is popularly known as land of latex and letters. This is one of the leading places in the country for production of rubber and most of the Malayalam dailies and weekly magazines are published from here only. Kottayam is the first town to acquire cent percent literacy in the State and first English school in the State was started here. The district is famous for the largest inland water body in the State i.e.Vembanad lake.

The Kottayam district is divided into two revenue divisions viz. Kottayam and Pala. There are five taluks in the district viz Kottayam, Changanacherry, Vaikom, Meenachil and Kanjirapally. There are four municipalities Kottayam, Changanacherry, Pala and Vaikom and 11 blocks namely Madapally, Pallom, Ettumanoor, Kaduthuruthy, Vaikom, Uzhavoor, Lalam, Erattupetta, Kanjirapally, Vazhoor and Pampady. The total number of grama panchayats and revenue villages are 74 and 95 respectively.

The total population of the district is 19,53,646 which accounts to 6.13% of the total population of the State .The total population living in rural area is 1653838 and urban area is 299808 and indicates that the people living in rural population is 84.65 %. The density of the population is 887 per sq.km.

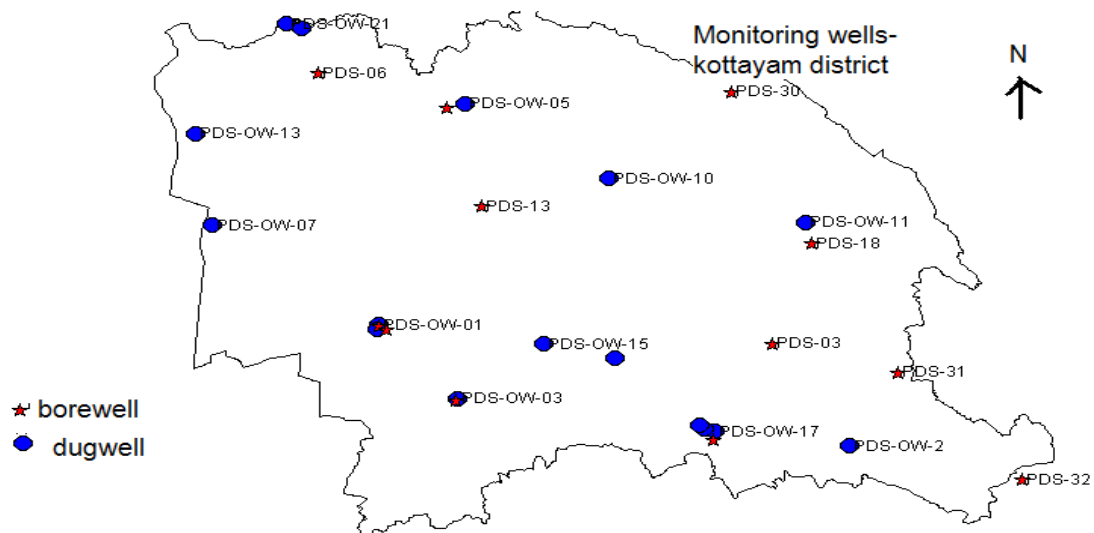


Figure 9: Location of Wells selected for monitoring during the study period

Climate & Rainfall

The normal rainfall of the district is 3347.8 mm based on 1981-92 data and the major contribution of rainfall is during South West monsoon followed by the North East monsoon. The analysis of rainfall data reveals that the distribution of rainfall increases from west to east. The highest rainfall recorded at Pala while the lowest recorded at Ettumannur. The annual rainfall ranges from 2694.2 to 3786.1 mm.

In general the district has wet type of climate and four seasons are seen in this district. The hot summer season from March to May, the South West monsoon season from June to September, the North East monsoon season from October to December and cool climate prevails during January and February. The South-west monsoon contributes nearly 64.10 % of the total rainfall and 19.0% from North-east monsoon.

Temperature

The temperature is more during the months of March to May and less during November, December and January. The maximum temperature ranges from 23.8 °C to 26.0 °C. The average annual maximum temperature is 29.8 °C and the minimum temperature is 24.4 °C. The average mean monthly maximum temperature ranges from 29.2 to 33.4 °C and minimum temperature ranges from 19.7 to 25 °C.

Relative Humidity

The relative humidity is generally high, during the morning hours its goes up to 79 % and during evening hours it is around 76%.

Wind

The general direction of wind is from east to north east during morning hours and west to northwest direction during evening hours. The wind speed ranges from 6.7 to 10.9 km/h.

Potential Evapotranspiration (PET)

The annual Potential Evapotranspiration is 1424.1 mm based on Penman's method at Cochin meteorological station which is close to the district boundary. In general Potential Evapotranspiration is less during April to November while compare to the other months and hence possibilities of recharge are more during these months. The monthly Potential Evapotranspiration ranges from 119.3 to 177.0mm.

Geomorphology and Soil Types

The district is naturally divided into three well defined physiographical units namely lowland, midland and high land. The lowland is the area with an elevation of less than 7.5 m amsl which covers around 398.4 sq km and midland area having an elevation of 7.5 to 75 m amsl covered around 1287.75 sq km and the highland area with an elevation of more than 75 m amsl covers around 508.8 sq km which are mainly found in eastern part of the district. The low lands are seen along the western portion of Vaikom, Changanessery and Kottayam taluks where as the Meenachil and Kanjirapally taluks are occupied by the highlands. Major part of Kottayam, Changanacherry and Vaikom taluks fall in midland region. Around upper Kuttanad (part of Changanacheery taluk) particularly Pallom, Ettumanoor and Kaduthuruthy the ground elevation is generally 1 to 1.5 m below mean sea level. The maximum elevation is 1193 m amsl at Kursimudi.

The soil types occurring in Kottayam district can be broadly grouped into four types on the basis of their physico-chemical properties and morphological features. They are (a) Lateritic soil. (b) Riverine alluvium, (c) Brown hydromorphic, and (d) Forest loams.

Ground Water Scenario

Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystalline rocks whereas in the deep fractured crystalline rocks the groundwater occurs under semi confined to confined conditions.

Hydrogeology

There are four types of hydrogeological units encountered in the district viz., Crystallines (shallow & deeper), Tertiary sediments, Laterites and Alluvium. The crystalline rocks consist of charnockite gneisses of archean age intruded by dolerite/gabbro dykes and pegmatite and quartz veins.

Groundwater Quality

58 samples were collected during the pre-monsoon period of 2008. The ground water quality observations on pH, EC, Total hardness, Chloride and sodium showed that the quality of water is highly pleasant and potable in most of the observation wells. pH during pre-monsoon varied between 6.6 and 8.8, indicating an alkaline nature. The minimum pH was observed in Manimala basin (6.6) and maximum was observed at Panachikadu in Kottayam taluk. The electrical conductivity ranged from 43 μ S/cm to 803 μ S/cm with a mean of 187.62 μ S/cm. Total hardness of the water is significantly low indicating the high potability nature in the district. The major cation sodium and anion chloride also found to be at the permissible level.

Table 9a: Statistical analysis of Pre-monsoon 2008

Kottayam pre-monsoon 2008

parameters	No.	minimum	maximum	mean	St. Deviation
pH	58	6.6	8.8	7.40	0.46
EC	58	43	803	187.62	134.33
TH	58	5.1	186	55.24	35.82
Cl	58	3.8	91.2	16.96	13.37
Na	58	1.8	52	10.79	9.51

The post-monsoon analysis data (56 samples) indicated that the water is highly acidic in some of the locations, i.e. the minimum observed was 4.7 (Vijayapuram of Kottayam taluk). The maximum pH in the area was found to be 8.1. A considerable decline was noted in the mean value of pH (reduced from 7.4 to 6.43). However, the mean values of Electrical conductivity, Total hardness, chloride and sodium showed a resemblance to pre-monsoon data.

Table 9b: Statistical analysis of Post-monsoon 2008

Kottayam post-monsoon 2008					
parameters	No.	minimum	maximum	mean	St. Deviation
pH	56	4.7	8.1	6.43	0.86
EC	56	26	545	186.54	143.96
TH	56	14	190.5	57.86	38.02
Cl	56	2.1	103	18.67	22.45
Na	56	1.8	82.9	17.02	21.80

The data available from the regular monitoring wells showed that in majority of the major cations and anions are within permissible limits in all stations. However, in some stations large values of pH was noticed; Nattokom (3.90), Vadavathur (4.70), Kumarakom (8.60), Uzhavoor (8.70) and Chingavanam (8.80). Higher values for Electrical Conductivity were recorded at Vaikom (845 $\mu\text{S}/\text{cm}$) and Kanam (803 $\mu\text{S}/\text{cm}$). Like in most of the district in the Kerala state, iron content was on the higher side, particularly in areas such as Madappalli (14.00 mg/l) and Kumarakom (9.62 mg/l).

PH

The pH values of the samples collected from selected locations of Kottayam district varied from 6.7 to 8.30 during pre-monsoon and 5.7 to 8.1 during post-monsoon of 2010. It is quite interesting to note that major part of the study area falls under acidic to neutral groups. Barring one station in the pre-monsoon in western side and one during post-monsoon in the eastern side, all other falls show pH below 8. It is also noticed that, during post-monsoon water becomes more acidic indicating the influence of eroded materials from the surrounding areas. This clearly indicate that the modifications and runoff waters plays significant role in pH variation. The seasonal variation of pH in water during 2010 are given in Figures 9a.

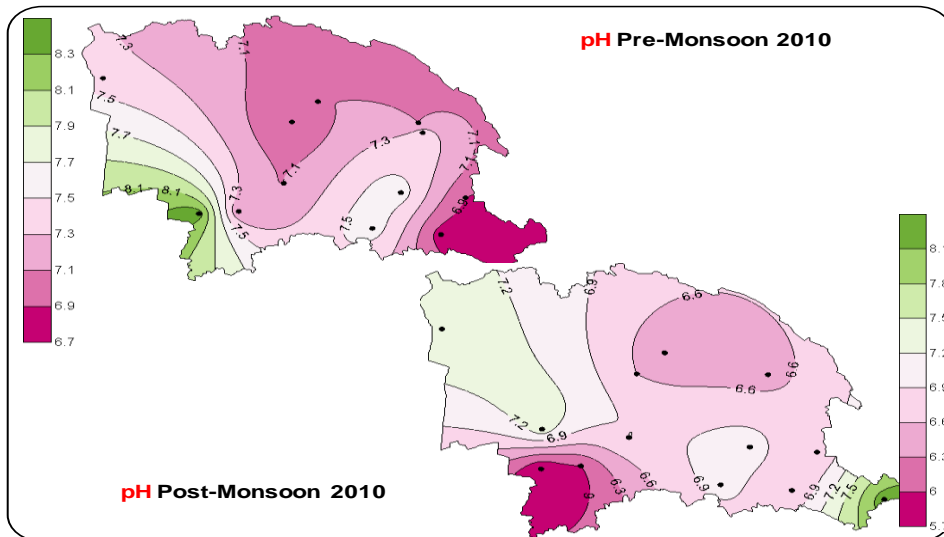


Figure 9a: Spatial Distribution of pH in Kottayam district

Electrical conductivity

Electrical conductivity of the samples varied from less than 40 micro-siemens/cm to 580 micro-siemens/cm during pre-monsoon and less than 40 micro-siemens/cm to 580 micro-siemens/cm in the post-monsoon in the year 2010. However, it is noticed that highest EC was found in almost in a central part of the district. The study shows that the water in the district is all within the permissible limits and quite stable both during pre-monsoon and post-monsoon. Figure 9b shows the variation of Electrical conductivity during 2010.

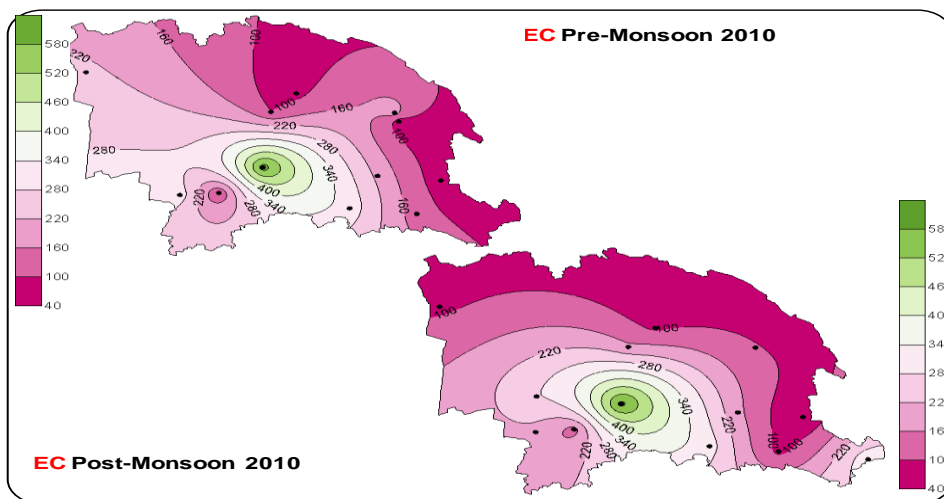


Figure 9b: Spatial Distribution of EC in Kottayam district

Total Dissolved Solids

The concentration of TDS during 2010 were analysed and found that the values are within the permissible limits. The maximum concentration observed during pre-monsoon was 380 mg/l. It varied between 40 mg/l to 380 mg/l during pre-monsoon and 20 mg/l to 130 mg/l during the post-monsoon. It is noticed that there is a drastic reduction in the TDS values during post-monsoon which needs further evaluation. The seasonal variation of TDS during 2010 is depicted in Figure 9c.

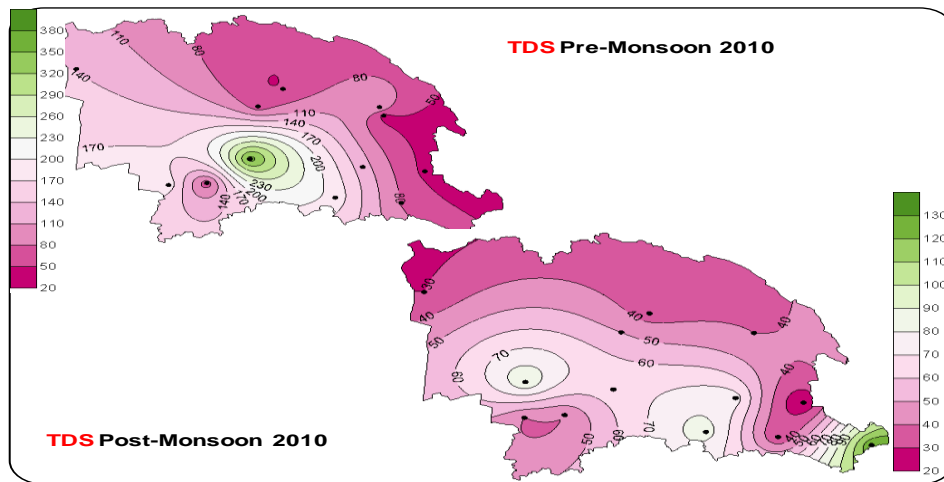


Figure 9c: Spatial Distribution of TDS in Kottayam district

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 10 mg/l to a maximum of 136 mg/l during pre-monsoon and 5 mg/l to 170 mg/l during the post-monsoon of 2010. It is noticed that the presence of carbonate is quite negligible in almost all locations. Bicarbonate is the sole contributor during pre-monsoon and in the post-monsoon carbonate seems to contribute reasonable quantity. The distribution of bicarbonates and Total alkalinity are shown figures 9d & 9e.

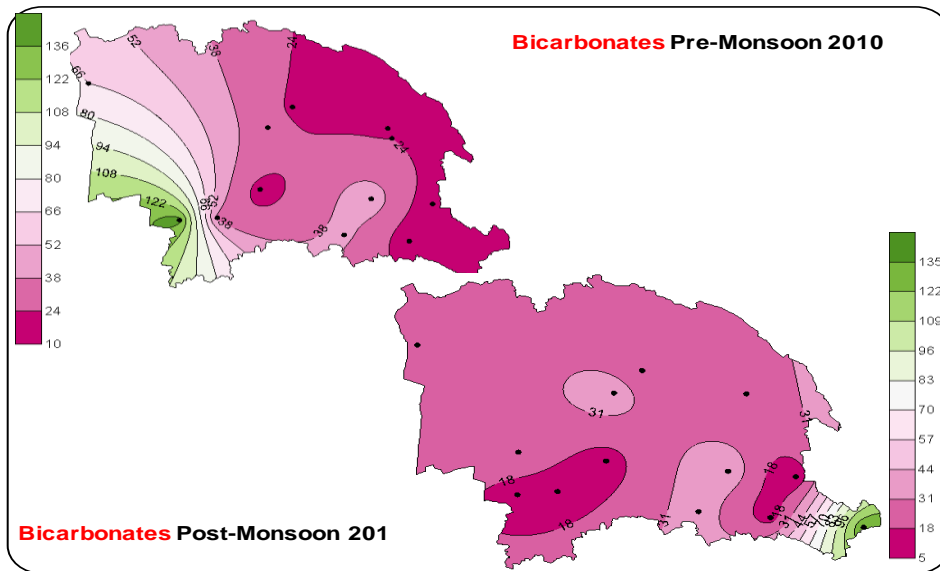


Figure 9d: Spatial Distribution of Bicarbonates in Kottayam district

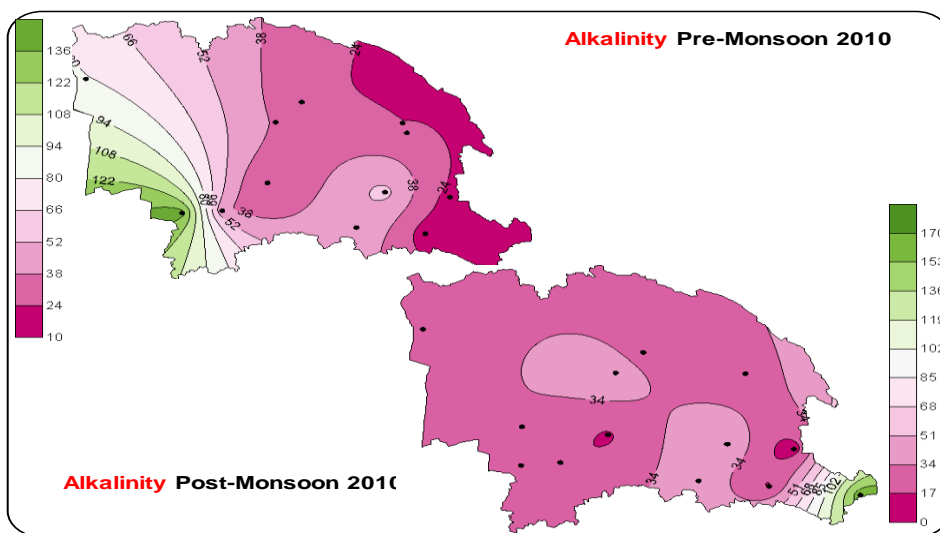


Figure 9e: Spatial Distribution of Alkalinity in Kottayam district

Chlorides

The chloride content in the water samples varied from 17 mg/l to a maximum of 170 mg/l during pre-monsoon and in the post-monsoon, it is between 7 mg/l and 160 mg/l. The observed chloride concentration is well within the desirable ranges. Figure 9f shows the spatial distribution of chloride in Kottayam district.

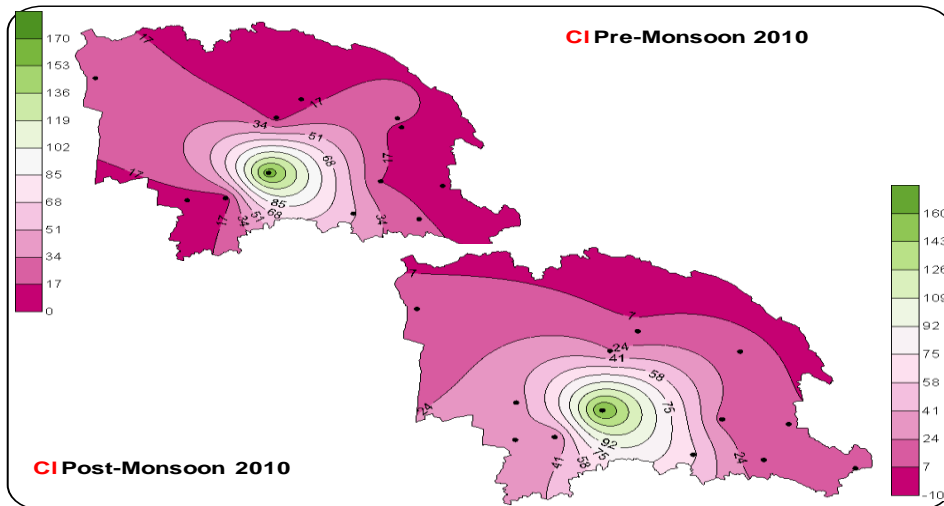


Figure 9f: Spatial Distribution of Chlorides in Kottayam district

Fluoride

The maximum concentration of fluoride observed was 0.087 mg/l during pre-monsoon in the western and central part of the district. The presence of fluorides is negligibly small in the district. It is found that the concentration fluoride much less than the required quantity in the groundwater. During post-monsoon, the fluoride content is almost negligible in percentage. Figure 9g shows the variation of fluorides in Kottayam district.

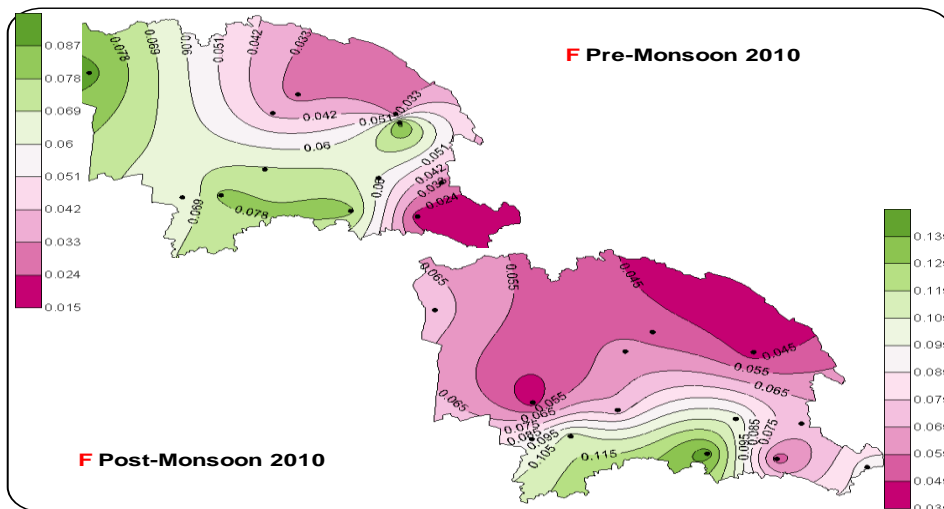


Figure 9g: Spatial Distribution of Fluorides in Kottayam district

Sulphates

The sulphate concentration ranged from 3 mg/l to 30 mg/l during pre-monsoon and in the post-monsoon, it varied between 1 mg/l and 34 mg/l. It is found that the variations of sulphates are quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 9h shows the variation of sulphates in Kottayam district.

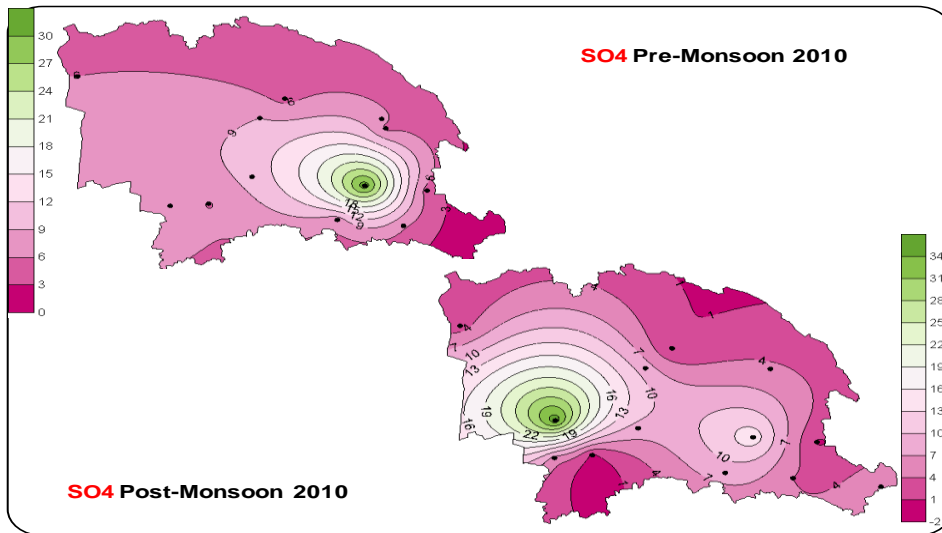


Figure 9h: Spatial Distribution of Sulphates in Kottayam district

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.9 mg/l to 9 mg/l during pre-monsoon and in the post monsoon it ranges between 1 mg/l and 11 mg/l. Figure 9i shows the variation of nitrates in Kottayam district in the year 2010.

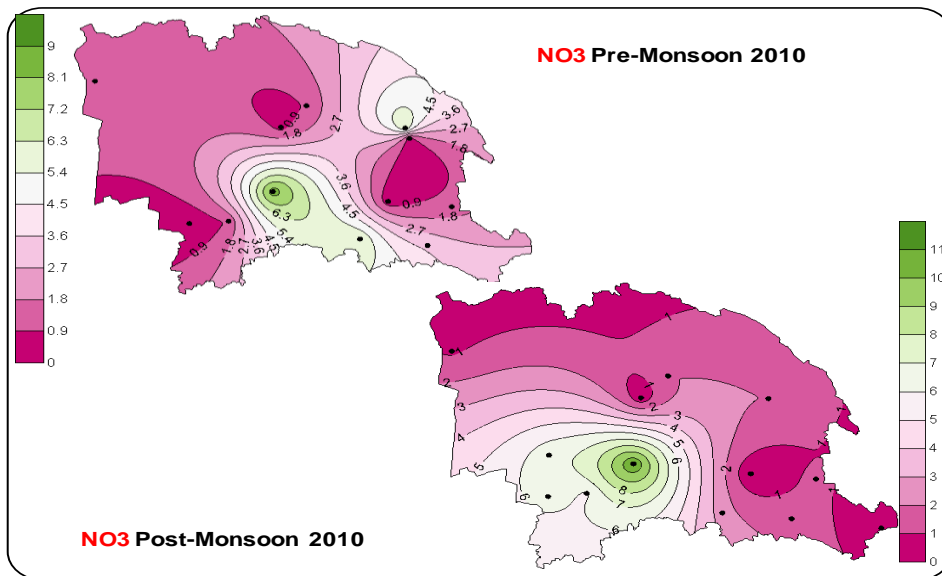


Figure 9i: Spatial Distribution of Nitrates in Kottayam district

Total Hardness

Total hardness of the water samples varied from less than 20 mg/l to 132 mg/l during pre-monsoon and in the post-monsoon, it varied between 30 mg/l to 130 mg/l in the year 2010.. The seasonal variation of total hardness is represented in Figure 9j.

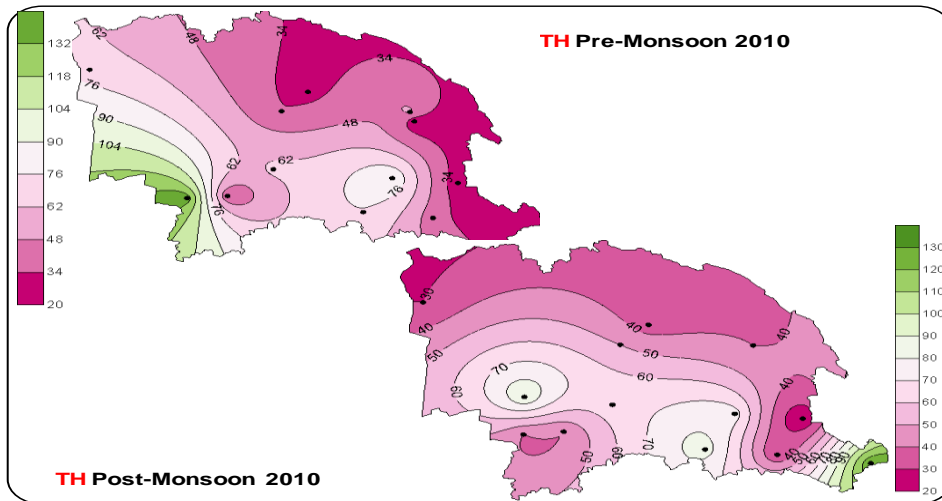


Figure 9j: Spatial Distribution of Total Hardness in Kottayam district

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (fig. 9k and 9l). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from 2 mg/l to 42 mg/l during pre-monsoon and 4 mg/l to 44 mg/l in the post-monsoon. The magnesium concentration varies from less than 1 mg/l to 11 mg/l in the pre-monsoon and during post-monsoon it varies from less than 2 mg/l to 11 mg/l.

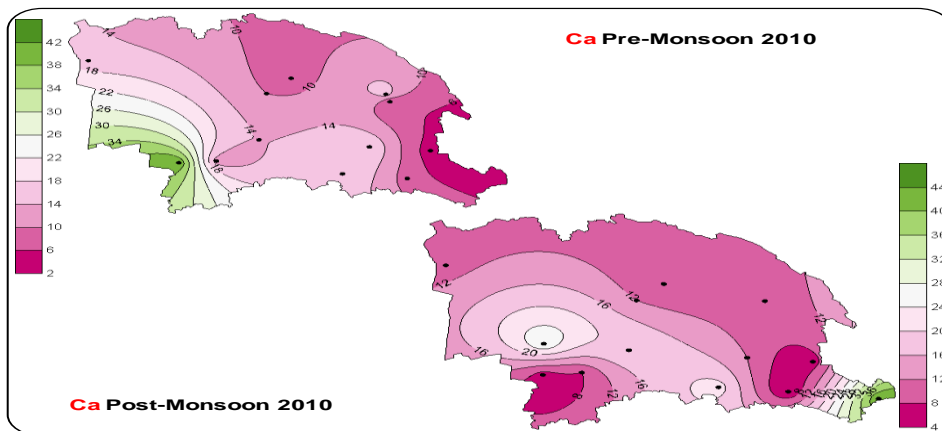


Figure 9k: Spatial Distribution of Ca in Kottayam district

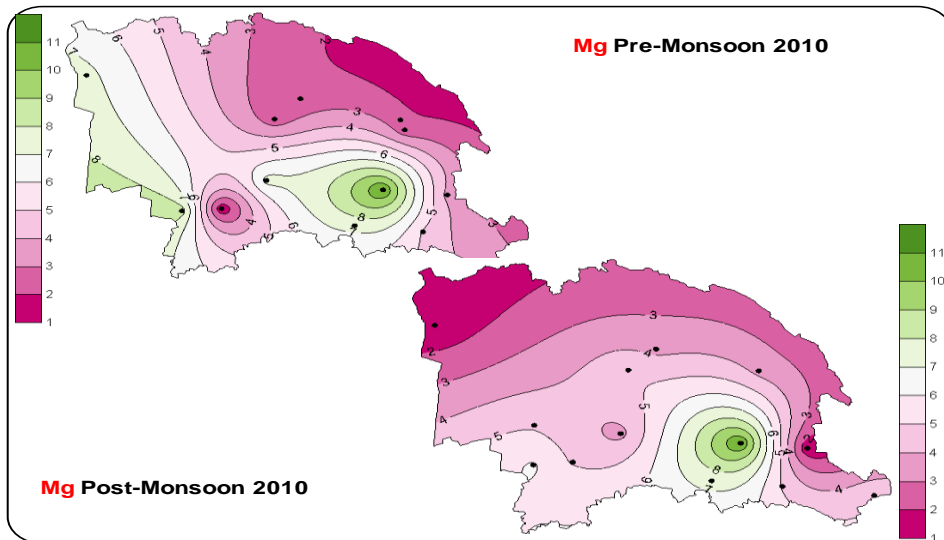


Figure 9l: Spatial Distribution of Mg in Kottayam district

Sodium and Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2010. The observed concentration of sodium varied from less than 9 mg/l to 100 mg/l during pre-monsoon and in the post-monsoon it ranges from 5 mg/l to 95 mg/l. In 2010, it showed a lower concentration. The concentration of potassium varied from 1 mg/l to 9.1 mg/l during pre-monsoon and 1 mg/l to 13.5 mg/l in the post-monsoon. The seasonal variation of sodium and potassium concentration is represented in figure 9m & 9n.

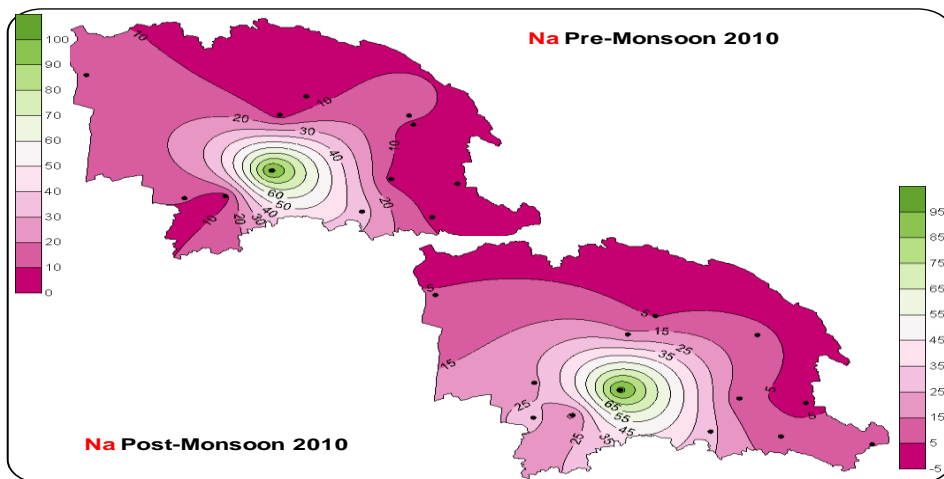


Figure 9m: Spatial Distribution of Na in Kottayam district

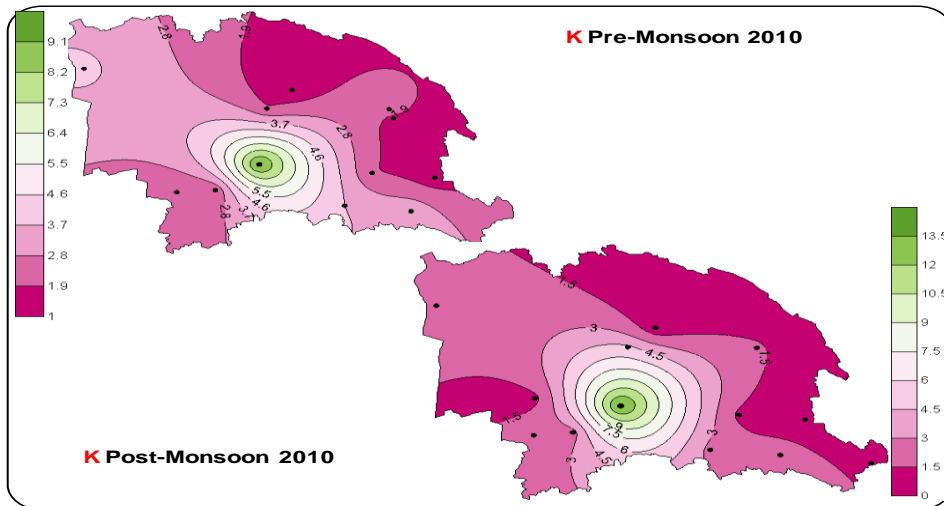


Figure 9n: Spatial Distribution of K in Kottayam district

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2010 was found to be 0.93 mg/l which is higher than the desirable ranges. In 2010, the concentration varied from 0.01 mg/l to 0.93 mg/l during pre-monsoon and in the post-monsoon concentration showed significant increase varying between 0.2 mg/l to 7.2 mg/l indicating the influence of runoff water. The figure 9o shows the variation of iron in the district.

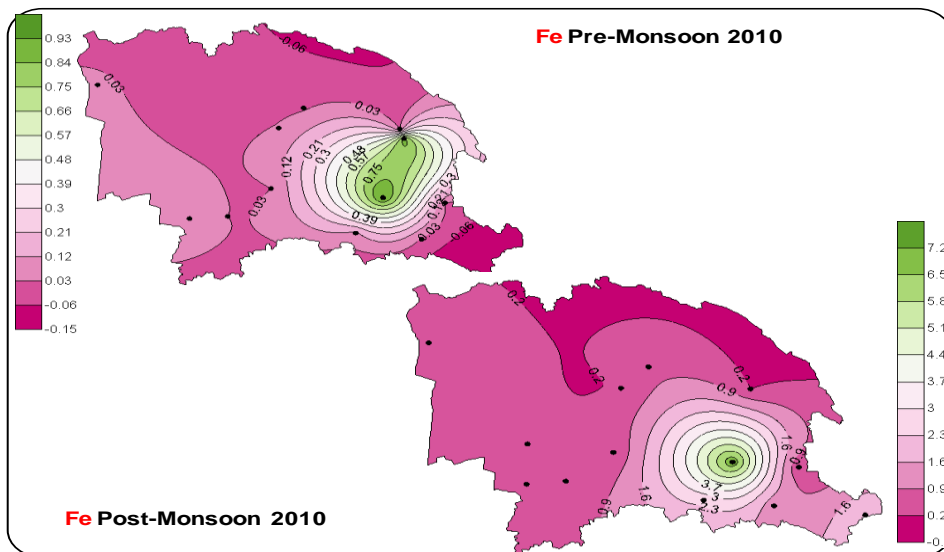


Figure 9o: Spatial Distribution of Iron in Kottayam district

Groundwater Classification

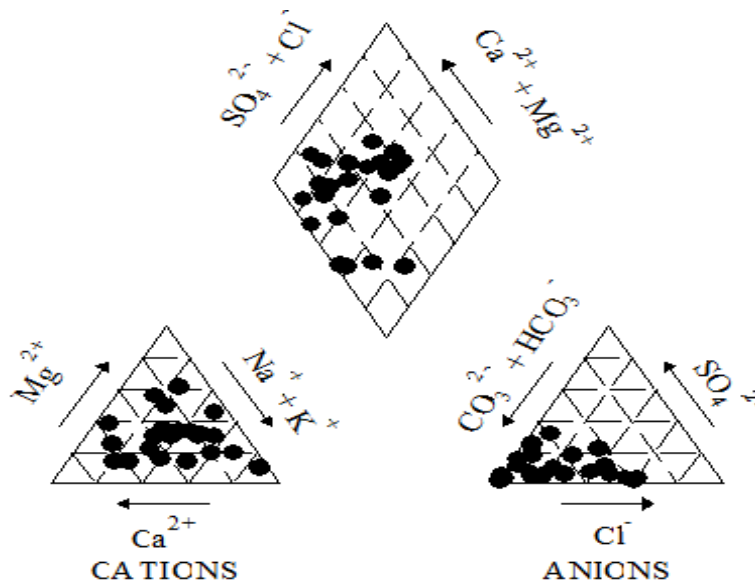


Figure 9p: Piper's classification of ground water of Kottayam district (Pre-monsoon, 2007)

From the figure, during the pre-monsoon, it is found that the ground water can be classified based on the water quality parameters into 4 areas. 50% of the region falls under area 5 indicating carbonate hardness, this is followed by area 4 covering about 27.27%, which is dominated by strong acids exceed weak acids. 18.18% area showed the predominance of carbonate alkali exceeds 50% . A small area is covered by a neutral type of water.

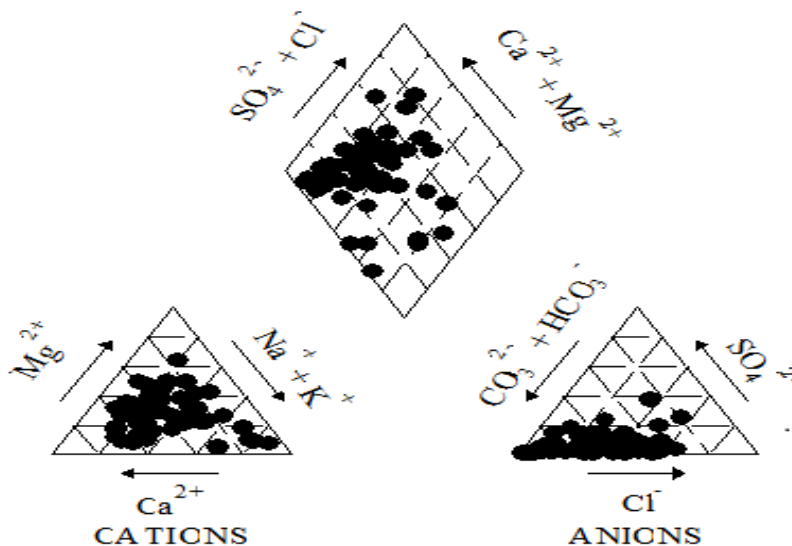


Figure 9q: Piper's classification of ground water of Kottayam district (Post-monsoon, 2007)

Figure 9q shows the classification of ground water during the post-monsoon season. It is evident from the figure that 66.67% of the samples fall under area 5 further confirming the presence of carbonate hardness. 13.73% represent the area 4 indicating the presence of strong acids exceed weak acids. Area 9 which shows that no one cation-anion pair exceeds 50%, is covered by 11.76%. The distribution of carbonate alkali exceeds 50% is quite negligible (2.96%).

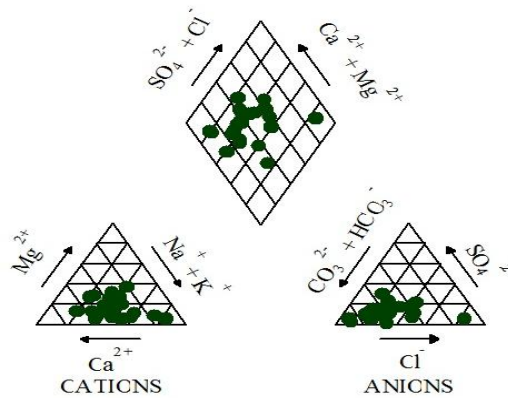


Figure 9r: Piper's classification of ground water of Kottayam district (Pre-monsoon, 2010)

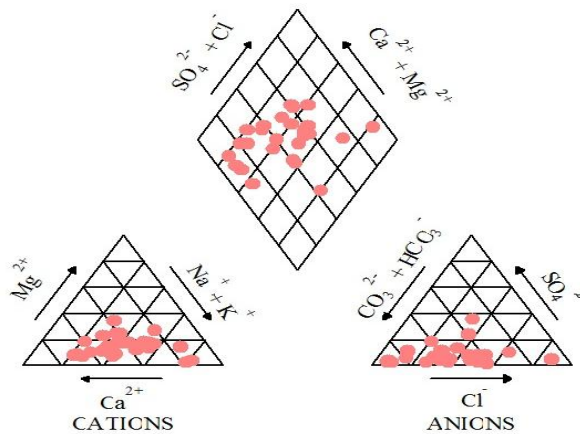


Figure 9s: Piper's classification of ground water of Kottayam district (Post-monsoon, 2010)

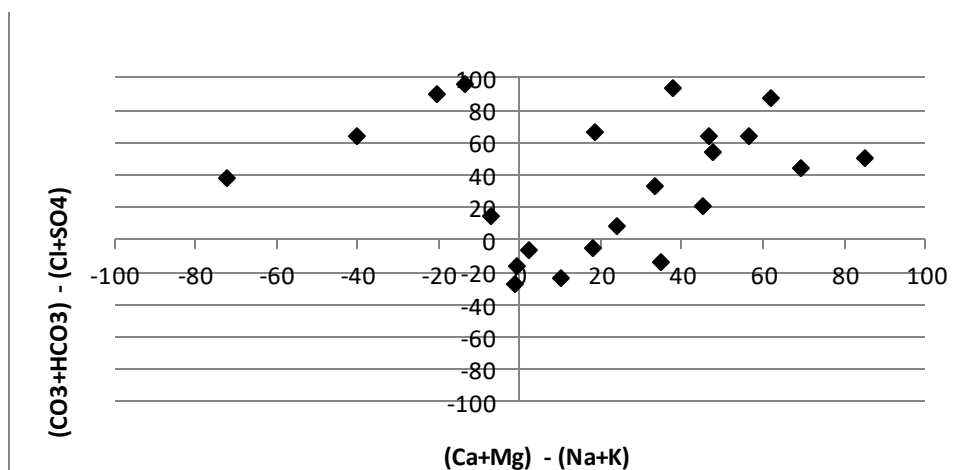


Figure 9t: Chadha's diagram of Kottayam district (Pre-monsoon, 2007)

Based on Chadha's classification, the majority samples during pre-monsoon, fall under area 5, dominated by Ca-Mg-HCO₃ type, Ca- Mg- dominant HCO₃ type (50%). 22.73% is covered by alkali metals exceed alkaline earth's and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use. About 18% of the samples exhibited Ca-Mg-Cl type, ca- Mg dominant chloride type water.

During the post-monsoon (figure 9u), it is found that, 65% of the samples fall under area 5 indicating the dominance of Ca-Mg-CO₃ type water. 15.7% of the samples are predominantly Ca-Mg-Cl type water and 13.7% were alkali metals exceed alkaline earth's and weak acidic anions exceed strong acidic anions.

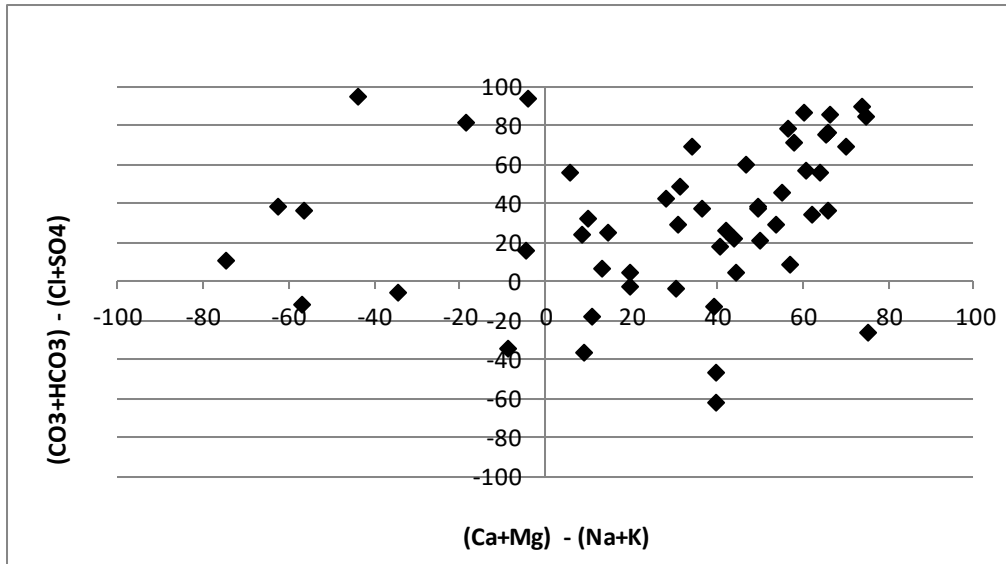


Figure 9u: Chadha's diagram of Kottayam district (Post-monsoon, 2007)

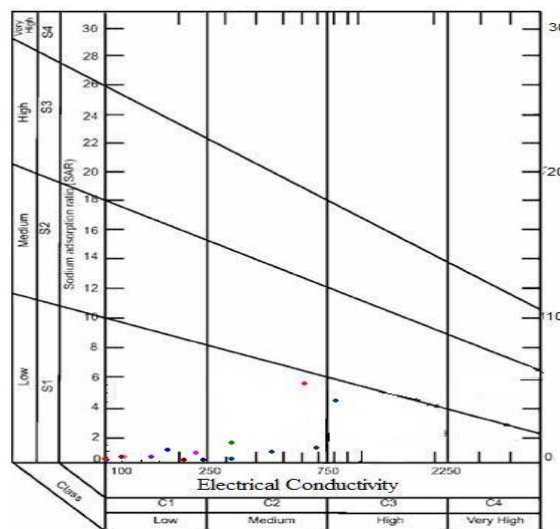


Figure 9v: Piper's classification of ground water of Kottayam district (Pre-monsoon, 2010)

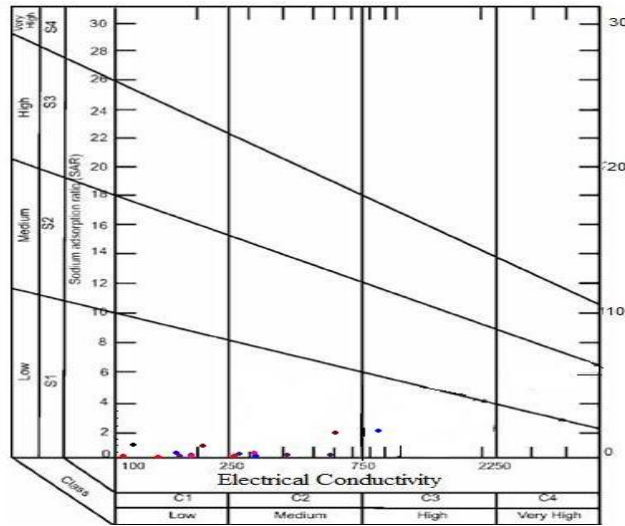


Figure 9v: Piper's classification of ground water of Kottayam district (Pre-monsoon, 2010)

Statistical Analysis of Groundwater Quality data of 2008

Table 9c: Correlation between various ions during Post-monsoon 2008

	pH	EC	TH	Cl	Na
pH	1				
EC	-0.025	1			
TH	0.474	0.238	1		
Cl	0.293	0.316	0.52	1	
Na	0.416	0.370	0.45	0.91	1

Table 9d: Correlation between various ions during Post-monsoon 2008

	pH	EC	TH	Cl	Na
pH	1				
EC	0.196	1			
TH	0.398	0.641	1		
Cl	-0.147	0.781	0.156	1	
Na	0.115	0.785	0.199	0.761	1

Heavy Metal Distribution in Kottayam District

It is observed that in Kottayam district, heavy metals such as copper, lead and zinc were detected in the observation wells. Only 3 samples were subjected to heavy metal analysis and it is found that there is no evidence of pollution in all the three observed wells. Orthophosphate, Arsenic, Cadmium, Mercury and Nickel were absent in all three samples..

Table 9e. Heavy Metal Distribution in Kottayam District

well No	Ortho Phosphate	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
PDS-OW-03	0	0	0	0.0112	0	0	0	0.0317
PDS-OW-21	0	0	0	0.0099	0.0054	0	0	0
PDS-OW-22	0	0	0	0.115	0	0	0	0.0263

10.0 GROUNDWATER QUALITY OF IDUKKI DISTRICT

Sampling was done at 57 bore/dug wells in Idukki district. Water quality parameters, except pH and Iron concentration, were within permissible limits. Generally, most of the samples showed pH value less than 7, with sample from Mattupetty and Kanjar recorded the lowest values; 3.58 and 4.56 respectively. Iron content was also on higher side in most of the sampling stations. High values of Iron are recorded at Vandamattom (10.46 mg/l), Kanthalloor (5.98 mg/l), Udumbannur (4.5 mg/l), Vazhithala (4.35 mg/l) and Kulamavu (4.0 mg/l).

pH

The pH values of the samples collected in the year 2010 (pre-monsoon and post-monsoon) from selected locations of Idukki district were acidic to slightly alkaline in nature. Water was found to be acidic in central part of the district. Study show that a small patch in the western part and also a small portion in the east were slightly alkaline. The influence of seawater in the western region and agriculture activities in the northern region may contribute to the alkaline nature of water. The seasonal variation of pH in waters in the year 2010 are given in Figure 10a .

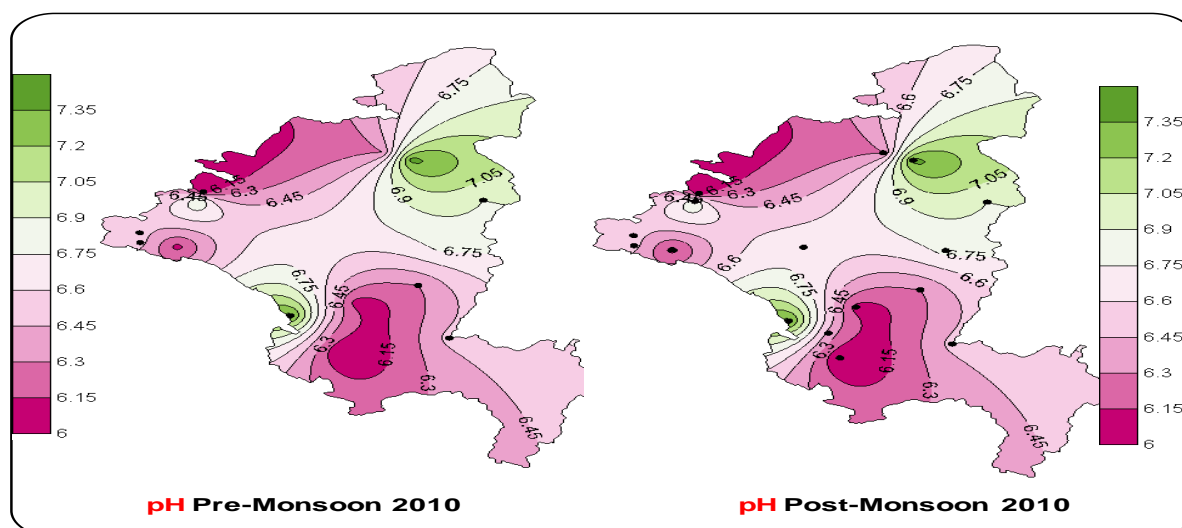


Figure 10a: Spatial distribution of pH in Idukki district during 2010

Electrical conductivity

Electrical conductivity of the samples varied from 90 micro-siemen/cm to 300 micro-siemen/cm during pre-monsoon and 20 micro-siemens/cm to 335 micro-siemen/cm during the post-monsoon of 2010. All parameters are within the highly within the permissible ranges. Figure 10b shows the variation of Electrical conductivity in Idukki district.

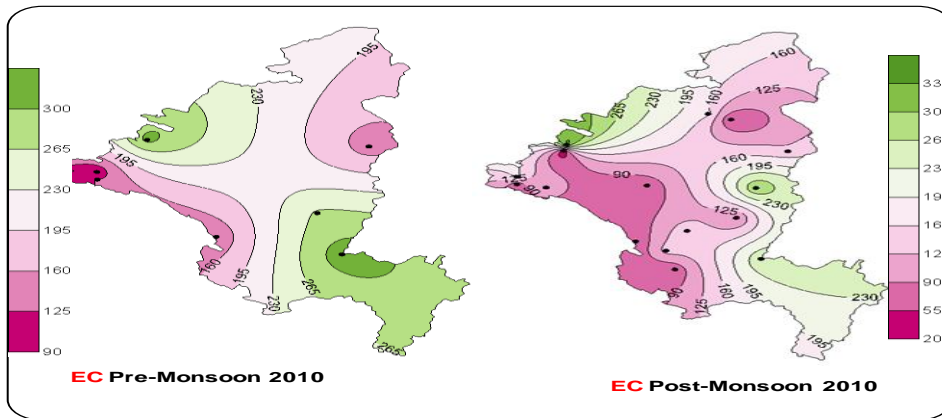


Figure 10b: Distribution of EC in Idukki district during 2010

Total Dissolved Solids

Analyses were carried out during the period from 2008, 2009 and 2010. Total dissolved solids concentration is found to be within the permissible limits. Detailed analysis taken during the year 2010 showed that the concentration vary from 55 mg/l to 195 mg/l during pre-monsoon and 20 mg/l to 195 mg/l in the post-monsoon seasons of 2010. The observed values are within the desirable limits specified by BIS. The seasonal variation of TDS during 2010 is depicted in figure10c.

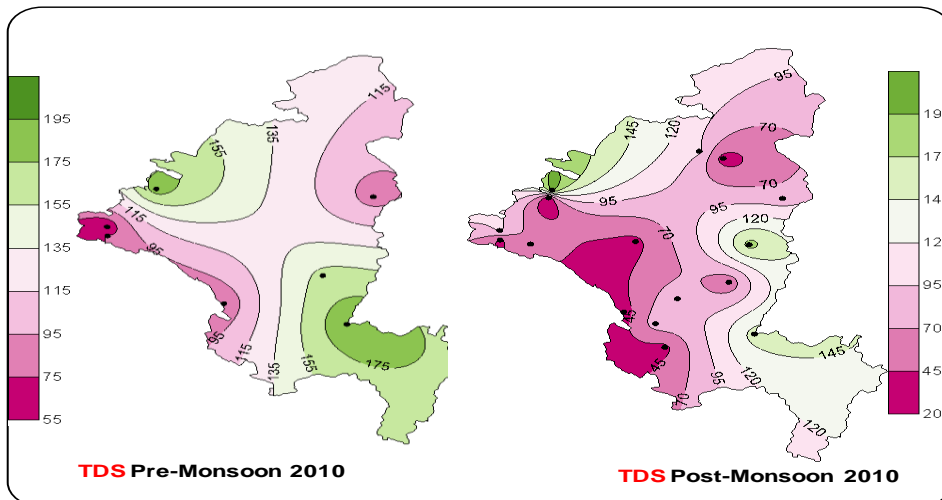


Figure 10c: Spatial distribution of TDS in Idukki district during 2010

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 5 mg/l to slightly more than 125 mg/l during the pre-monsoon of 2010. In the post-monsoon, it showed a declines and varies from 8 mg/l to 56 mg/l. More than 95% of the wells showed the absence of carbonates. The total alkalinity of the water samples were found to be within the permissible

limit for all the samples as per BIS (1991). The seasonal variation of bicarbonates and Total alkalinity are shown in figures 10d & 10e.

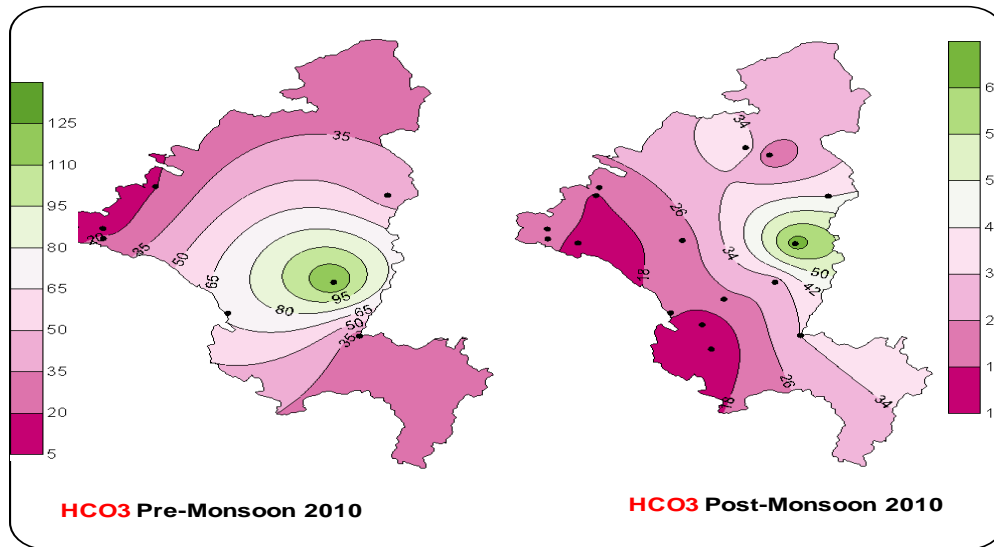


Figure 10d: Spatial distribution of HCO₃ in Idukki district during Pre and post monsoon of 2010

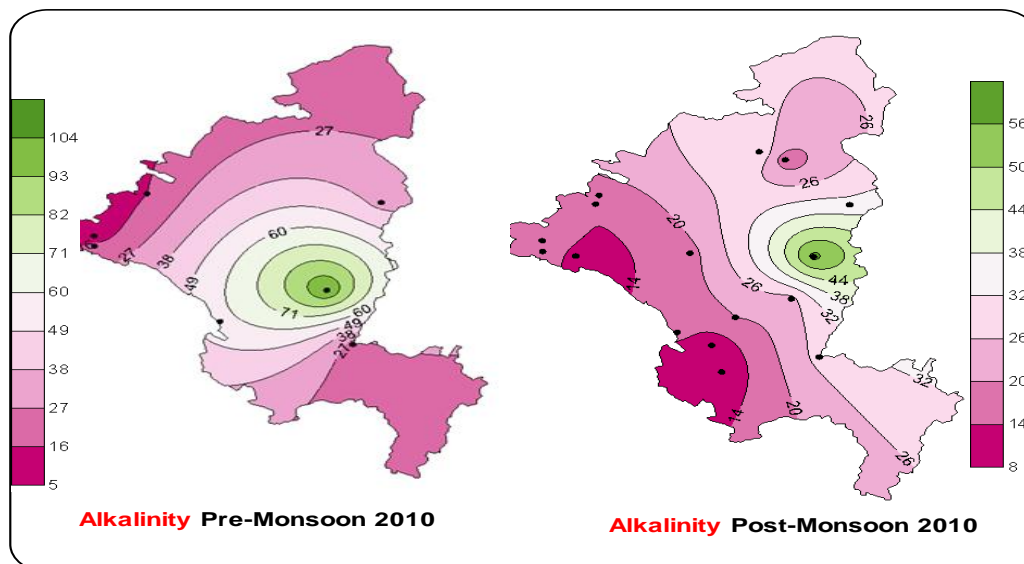


Figure 10e: Spatial distribution of Total Alkalinity in Idukki district during 2010

Chlorides

In majority of the locations, the maximum chloride content in the water samples varied from less 12 mg/l to 61 mg/l during 2010 pre-monsoon and during post-monsoon 4 mg/l to 46 mg/l. Therefore the chloride content is well within the desirable ranges. Figure 10f depicts the variation of chlorides.

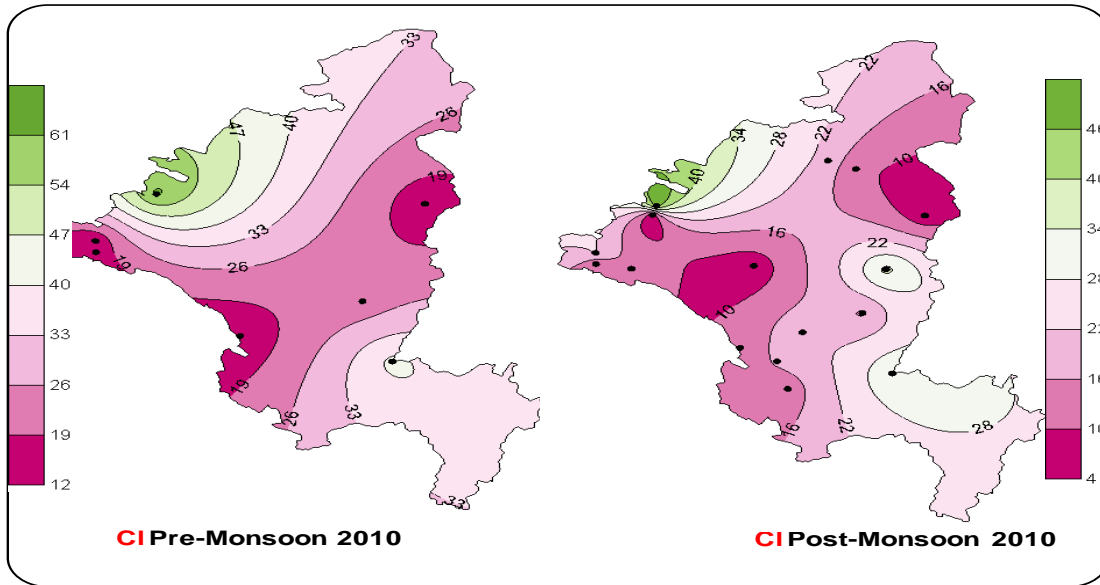


Figure 10f: Distribution of chlorides in Idukki district during Pre and post monsoon of 2010

Sulphates

The sulphate concentration ranged from 2.0 mg/l to 50 mg/l during pre-monsoon and in the post-monsoon, the concentration declined to less than 2 mg/l to 20 mg/l. The comparatively higher rainfall occurred in the year 2010 may be the reason for reduction in sulphate concentration. Figure 10g depicts the variation of chlorides.

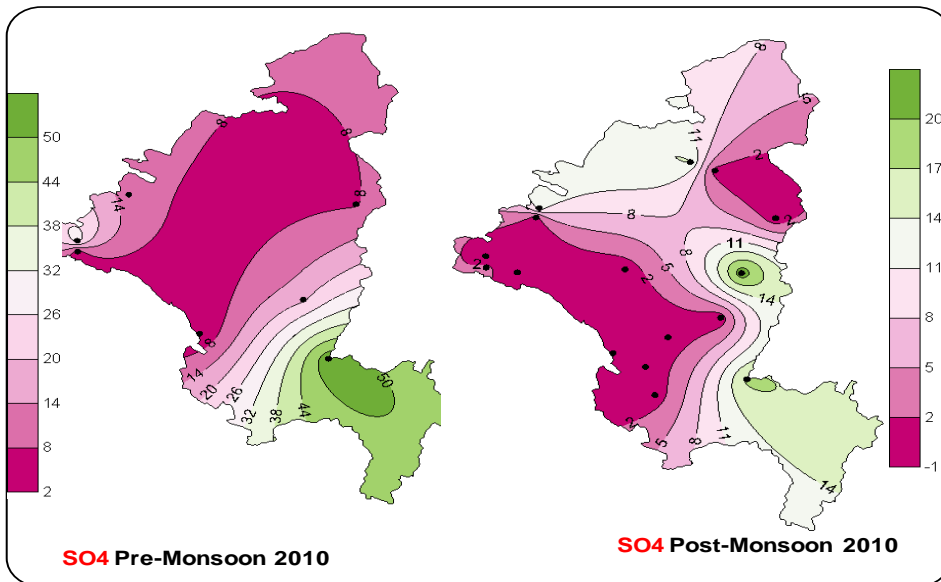


Figure 10g: Distribution of Sulphates in Idukki district during 2010

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.3 mg/l to 4.4 mg/l and in the post monsoon it showed an increase to 12 mg/l. Therefore, the agriculture as well as plantation activities bring more nitrate concentration in the eastern areas in comparison to western

parts. This necessitates the monitoring of wells which is quite necessary in these areas. Figure 10f depicts the variation of chlorides. Figure 10h depicts the variation of chlorides.

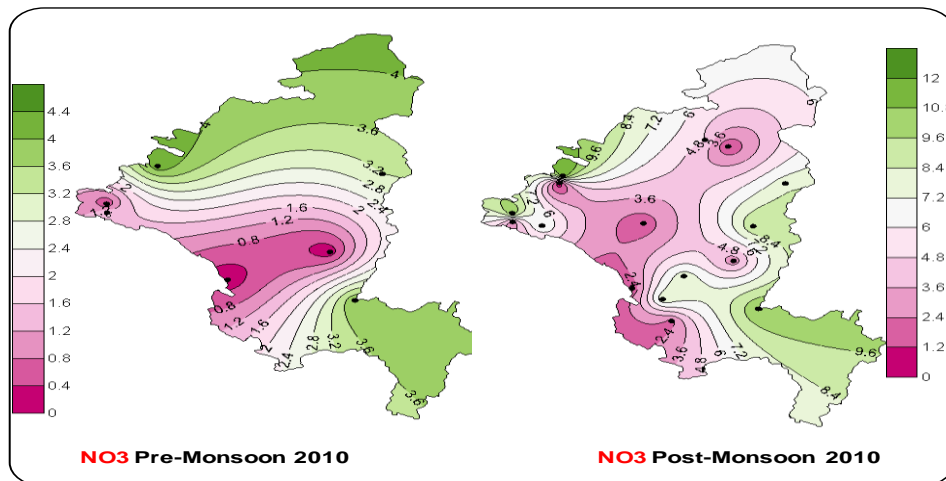


Figure 10h: Spatial distribution of Nitrates in Idukki district during 2010

Fluoride

The maximum concentration of fluoride observed was 0.35 mg/l during pre-monsoon and 0.56 mg/l during post-monsoon 2010. Fluoride concentration was found to be within the permissible limit during all the seasons. Figure 10i depicts the variation of chlorides.

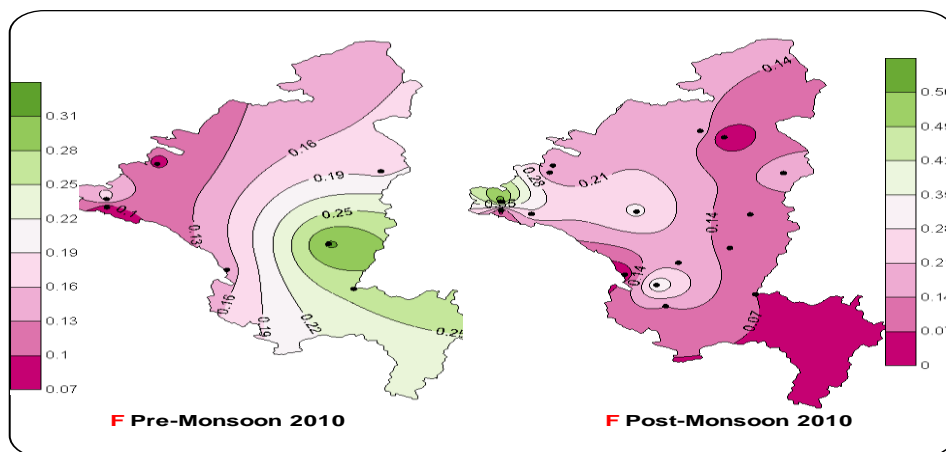


Figure 10i: Distribution of Fluorides in Idukki district during 2010

Iron

The maximum concentration of iron in the study area during 2010 is found to be less than 0.2 mg/l to a maximum of 1.6 mg/l in the pre-monsoon, that is quite higher than the permissible limit of 0.3 mg/l. The highest concentration was found on the western part of the study area during the pre-monsoon season. In the post-monsoon of 2010 it was found to be less than 0.03 mg/l to 0.75 mg/l. This wide spread occurrence of iron in this part of the state quite common as the rocks are acidic and iron rich in concentration. Figure 10j depicts the variation of chlorides.

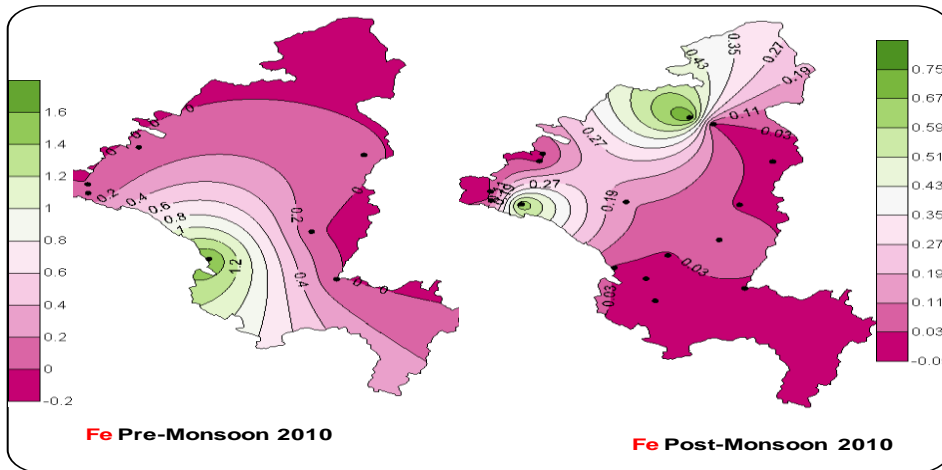


Figure 10j: Distribution of Iron in Idukki district during Pre and post monsoon of 2010

Total Hardness

Analysis of ground water samples were carried out during 2008 to 2010. Total hardness of the water samples varied from 30 mg/l to 120 mg/l during pre-monsoon and 15 mg/l to 95 mg/l during post-monsoon. This clearly indicates that the water is free from hardness and well suited for all purposes. Figure 10k depicts the variation of chlorides.

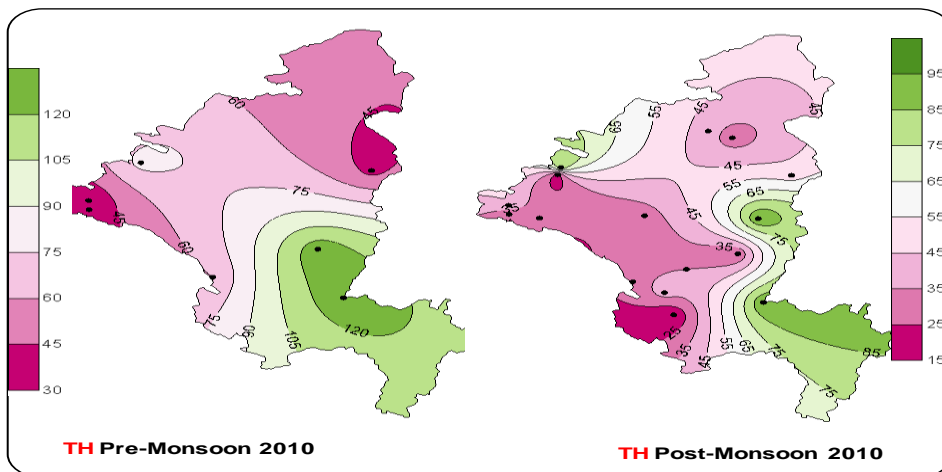


Figure 10k: Distribution of Total Hardness in Idukki district during 2010

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figures 10l & 10m). It is observed that both calcium and magnesium concentrations are much below the permissible limit. The concentration of calcium varies between 6 mg/l and 24 mg/l during pre-monsoon and in the post monsoon it varies from 3 mg/l to 21 mg/l. It is also noticed that the proportion of magnesium concentration is relatively higher than the normally expected.

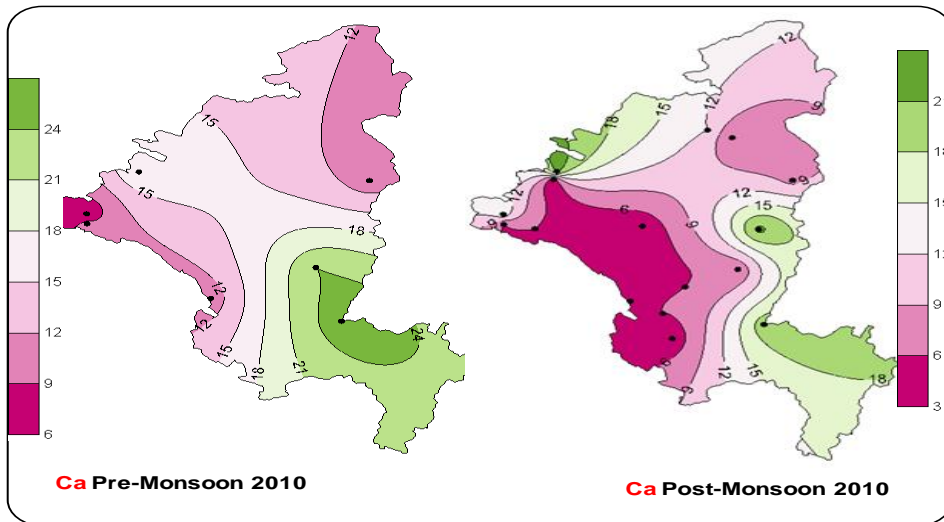


Figure 10l: Distribution of Calcium in Idukki district during 2010

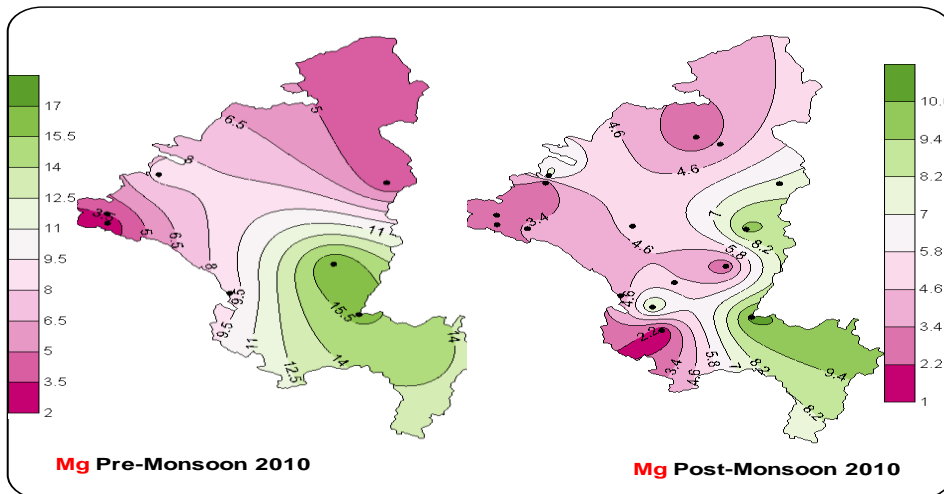


Figure 10m: Distribution of Magnesium in Idukki district during 2010

Sodium and Potassium

Analysis of sodium concentration in the ground water samples from 2008 to 2010, shows that there is no significant change in the content during the study period. The observed concentration is below the permissible ranges. Similar observation was found in the case of potassium. The concentration of sodium varies between 3.0 mg/l to 17 mg/l, during pre-monsoon and 11 mg/l to 34 mg/l during post-monsoon of 2010. The potassium concentration varied from 1.4 mg/l to 5.6 mg/l during the pre-monsoon of and 0.7 mg/l to 6.3 mg/l during post-monsoon 2010. The seasonal variation of sodium and potassium concentration is represented in figures 10n & 10o.

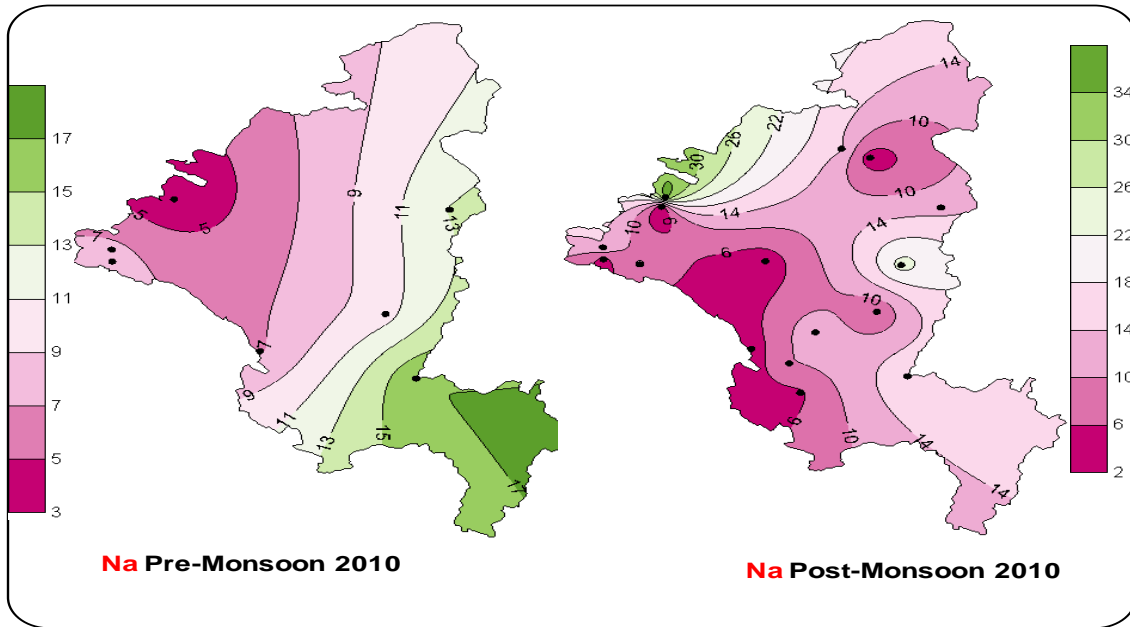


Figure 10n: Distribution of Sodium in Idukki district during 2010

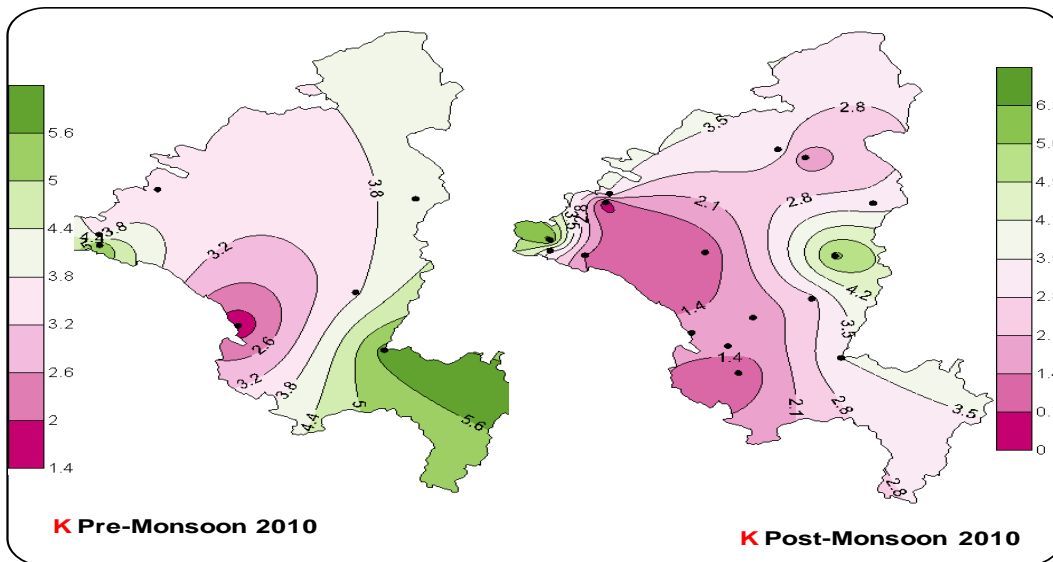


Figure 10o: Distribution of Potassium in Idukki district during 2010

Groundwater Classification: Classification of groundwater based on Piper’s diagram is shown in figures 10p and 10q. USSSL classification was also shown in figures 10r and 10s.

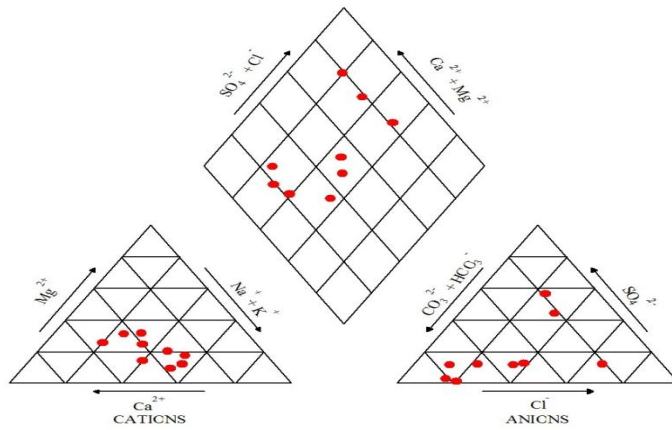


Figure 10p: Piper's classification of ground water of Idukki district (Pre-monsoon, 2010)

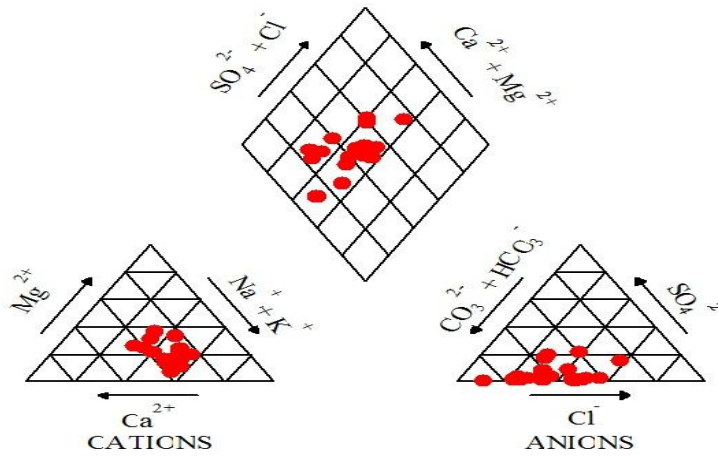


Figure 10q: Piper's classification of ground water of Idukki district (Post-monsoon, 2010)

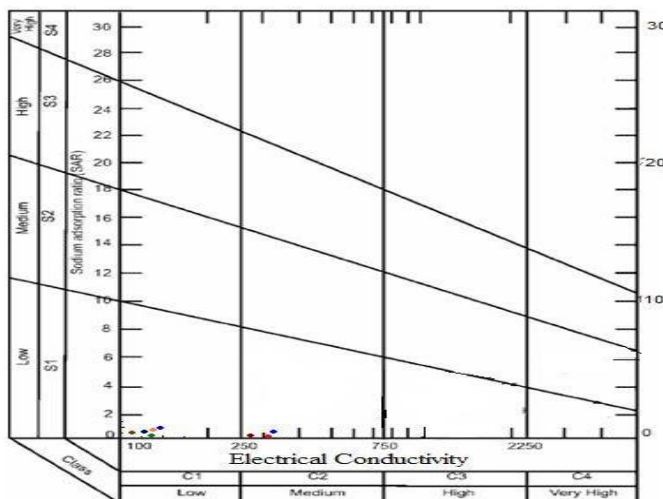


Figure 10r: USSL classification of ground water of Idukki district (Pre-monsoon, 2010)

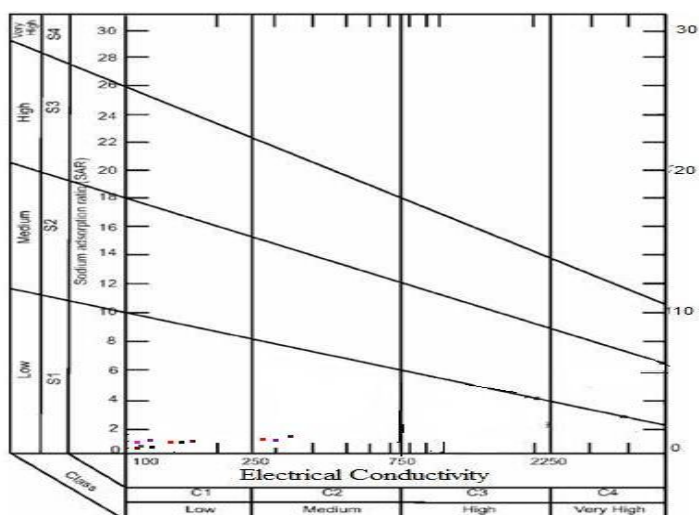


Figure 10s: USSL classification of groundwater of Idukki district (Post-monsoon, 2010)

Heavy Metal Distribution in Idukki District

Sixteen samples were subjected to heavy metal analysis from Idukki district. It is observed that, heavy metals such as zinc, cadmium, lead, copper, leadn nickel and orthophospahes were detected in the observation wells. However, none of the heavy metals are above the permissible limits.

10a. Heavy Metal Distribution in Idukki District

well No	Zinc	Cadmium	Lead	Copper	Mercury	Arsenic	Nickel	Ortho Phosphate
IDKO-01	0.069	0	0.012	0	0	0	0	0.005
IDKO-03	0.137	0	0.013	0.008	0	0	0	0.005
IDKO-05	0	0.025	0.012	0.011	0	0	0	0.002
IDKO-08	0.066	0	0.014	0.009	0	0	0	0.005
IDKO-09	0.167	0.006	0.019	0.013	0	0	0	0.005
IDKO-13	0.098	0.004	0.016	0.008	0	0	0.0003	0.013
IDKO-14	0.145	0.004	0.017	0.013	0	0	0.0041	0.005
IDKO-16	0	0.004	0.013	0	0	0	0	0.002
IDKO-18	0.102	0	0.012	0.01	0	0	0.0033	0.005
IDKO-20	0.016	0.003	0.01	0.005	0	0	0	0.005
IDKO-22	0.167	0.004	0.017	0.011	0	0	0	0.005
IDKO-24	0.102	0	0.019	0.013	0	0	0	0.007
IDKO-25	0	0	0.01	0	0	0	0	0.007
IDKO-28	0.0129	0.008	0.01	0	0	0	0	0.005
IDKO-30	0.196	0.004	0.014	0.006	0	0	0	0.008
IDKO-39	0.133	0	0.012	0.008	0	0	0	0.005
IDKO-40	0.007	0	0.015	0.008	0	0	0	0.026
IDKO-43	0	0.006	0.012	0	0	0	0.001	0.005

11.0 GROUND WATER QUALITY OF ALAPPUZHA DISTRICT

The district has a tropical humid climate with a very hot summer followed by an excessive rainfall. The period from March to the end of May is the summer season. This is followed by the southwest monsoon, which continues till the end of September. Alappuzha (Alleppey) is one of the well-developed coastal districts in southern part of Kerala State covering an area of 1,414 sq.km. and is the smallest district accounting 3.64% of the area of the State. It is surrounded by Lakshadweep sea on the west, Kottayam and Pathanamthitta districts in the east, Kollam district in the south and Ernakulam district in the north. The district has 6 taluks viz. Sherthalai, Ambalappuzha, Kuttanad, Karthikapally, Chengannur and Mavelikara which comprises 12 blocks, 71 panchayats and 5 municipalities. Alappuzha is well known for its coir industry with innumerable outlets for various finished coir products.

The district has a population of 21, 05,349 persons as per 2001 census. The population density is 1489 persons/sq.km, the highest among all the districts of the State. The district has a total of 2611 industries mostly medium and small scale sectors. Out of these 769 are agro based, 297 forest, 7 animal husbandry, 214 chemical.

Rainfall & Climate

The district receives an average of 2965 mm as the normal rainfall. Out of this, southwest monsoon contributes nearly 60.3% of the annual rainfall. This is followed by the northeast monsoon season from October to December, which contributes about 20.9% of the annual rainfall, and the balance 18.8% is accounted for January to May months.

Temperature

Generally March and April months are hottest and December and January months are coldest. At Alappuzha the maximum temperature ranges from 28.8 to 32.7°C whereas the minimum temperature ranges from 22.6 to 25.5°C. The average annual maximum temperature is 30.7°C and the average annual minimum temperature is 23.9 °C.

Wind

The wind is predominantly from east and northeast during morning hours and during the evening hours the predominant wind direction is from west and northwest. The wind speed is low in Kayamkulam. The wind speed is high during May (13.6 kmph) at Alappuzha.

Humidity

The humidity is higher during the monsoon period, June to September. It is around 87% at Alappuzha and 84% at Kayamkulam. All through the year, the humidity is high during the morning hours.

Geomorphology and Soil Types

A major part of the district is covered by coastal plains. The general elevation of the area is less than 6 m above mean sea level with some parts of the area below mean sea level in the range of 1-2 m. Typical coastal geomorphic features such as beaches, shore platforms, spit and bars, beach ridges are also seen in many places. A portion in the southeast part of the district is classified as mid land. Kuttanad, known as the rice bowl of Kerala lies east and southeast of Alappuzha town. It represents low-lying deltaic region characterized by wet lands. The beach ridges are suggestive of marine regression. Beach is very narrow and straight. On the basis of morphological and physico-chemical properties, the Soil Survey Division of Department of Agriculture, Govt. of Kerala have classified the soils of the district into four types viz. (1) Coastal alluvium (Entisols), (2) Riverine Alluvium (Inceptisols) (3) Brown hypidimorphic soil (Alfisols) and (4) Lateritic soil (Oxisols).

Ground Water Quality Analyses

The crystalline formation occurs in the southeastern part of the district mostly capped by thick laterite formation. The groundwater occurs under phreatic and semi-confined conditions in the crystallines. Exploratory drillings by CGWB shows low potential fractures (yield range of about 60-120 lpm) in this part of the crystalline formation. The Tertiary formations constitute the major aquifer in Kuttanad and coastal area with total thickness of sediments range from 90.0 to more than 600 m covering extensive area. They are underlain by crystalline basement and overlain by laterite and unconsolidated formations.

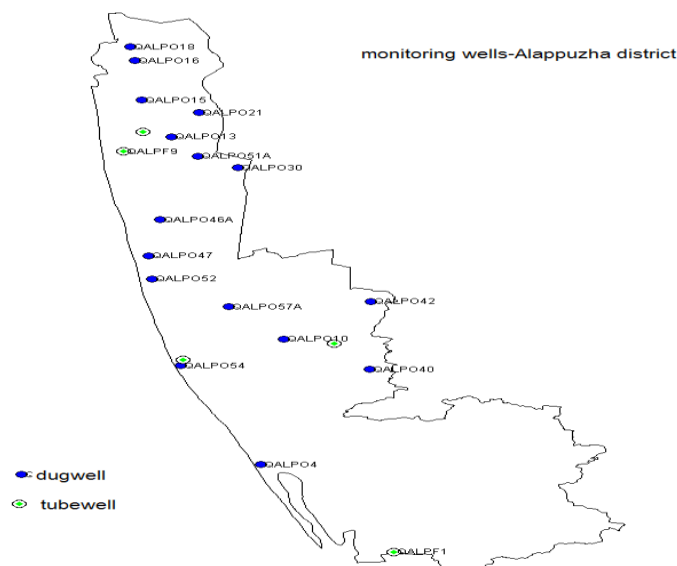


Figure 11: Location of Wells in Alappuzha District

In the present study, 61 ground water samples were collected during the pre-monsoon of 2008 from the entire Alappuzha district during 4 seasons in the year 2008. Physico-chemical parameters were analysed by statistical means. Observations show that pH varies between 5.4 and 8.5 with a mean of 7.3. Electrical conductivity showed variations from 55 $\mu\text{S}/\text{cm}$ to 6940 $\mu\text{S}/\text{cm}$ with a mean of 546 $\mu\text{S}/\text{cm}$. The data showed that in most of the locations, the EC, Cl and Na found to be considerably high. The maximum EC (6940 $\mu\text{S}/\text{cm}$) was observed at Vayalar village in Cherthala taluk. The historical data provided showed that Karumady (6940 $\mu\text{S}/\text{cm}$) Chanthirur (3820 $\mu\text{S}/\text{cm}$) and Kainakary (3760 $\mu\text{S}/\text{cm}$) also have EC. Total hardness was also very high in Karumady which exhibited a maximum value of 1030 mg/l. Along the coastal zone, the Chloride concentration showed a maximum value of 958 mg/l at Vayalar with a sodium concentration of 673 mg/l. Fluoride was considerably less except in Vayalar (1.15 mg/l). Iron is the major contamination in this part of the state where the maximum reported was 21.65 mg/l from Moncombu of Kuttanad taluk. Table 2a and 2b shows the statistical analysis of Pre-monsoon samples.

Table 11a: Statistical analysis of selected parameters during Pre-monsoon 2008

parameters	No.	Minimum	maximum	mean	St. Deviation
pH	61	5.4	8.5	7.30	0.71
EC	61	55	6940	545.69	931.77
TH	61	18.6	957.9	127.67	125.00
Cl	61	3.8	719.1	60.24	108.34
Na	61	2.3	672.5	42.86	97.06
F	61	0.42	1.15	0.75	0.18
Fe	60	0.02	21.65	1.502	3.40

During the post-monsoon of 2008, 42 sample data were selected for detailed analysis based on which it is found that the mean pH has shown a marginal increase as compared to pre-monsoon samples (7.48). However, parameters such as electrical conductivity total hardness, chloride, sodium and iron concentration reduced drastically. Fluoride concentration also decreased considerably except at few locations. Table 11a & 11b shows the ranges of selected parameters in the district.

Table 11b: Statistical analysis of selected parameters during Post-monsoon 2008

Parameters	No.	Minimum	maximum	Mean	St. Deviation
pH	42	5.2	8.6	7.48	0.70
EC	42	63	2390	373.43	392.74
TH	42	30	430	106.79	73.52
Cl	42	1.1	315	34.41	51.30
Na	42	2.7	306	32.44	51.73
F	42	0.03	1.65	0.33	0.36

Fe	42	0.01	3.22	0.434	0.61
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A preliminary analysis of historical data showed that the chloride content increase up to 1927 g/l at Karumadi followed by Chanthirur (997 mg/l) and Kainakari (897 mg/l). Sodium concentration also showed a high value (752 mg/l) at Karumady and 636 mg/l at Chanthirur. Fluoride showed a maximum concentration of 1.77 mg/l at Arattuvazhy. However, the iron concentration is highly unpleasant and showed a concentration of 21.65 mg/l at Moncombu, 14.60 mg/l at Eera and 8.24 mg/l at Karuvatta.

PH

The pH values of the samples collected from selected locations of Alappuzha district varied from 6.65 to 8.05 during pre-monsoon and 6.3 to 8.3 during post-monsoon in the year 2010. In general, in majority of the places water was found to be acidic except in a small patch near to the western border close to coastal area, the water is found to be alkaline. The seasonal variation of pH in waters during 2010 are given in Figure 11a.

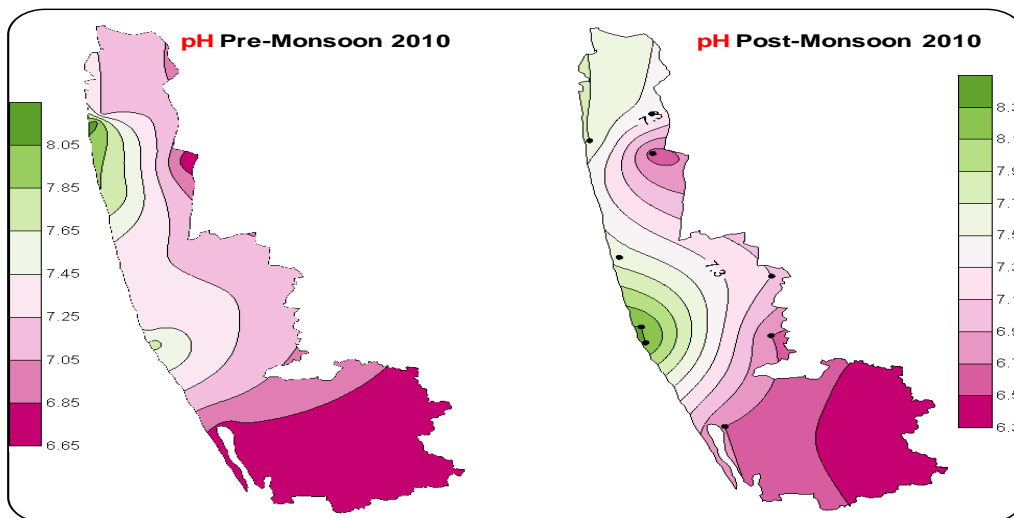


Figure 11a: Spatial variation of pH in Groundwater of Alappuzha district (Year:2010)

Electrical conductivity

Electrical conductivity of the samples varied from less than 55.0 micro-siemens/cm to 800 micro-siemens/cm during pre-monsoon and 100 microsiemencm to 700 micro-siemen/cm in the post-monsoon. However, the highest values were observed near to the coastal area. In majority of the area EC values are less than 300microsiemen/cm. The data obtained for 2008 showed comparatively higher EC. Table 11a shows the descriptive statistics of the year 2008. Figures 11b shows the variation of Electrical conductivity during 2010.

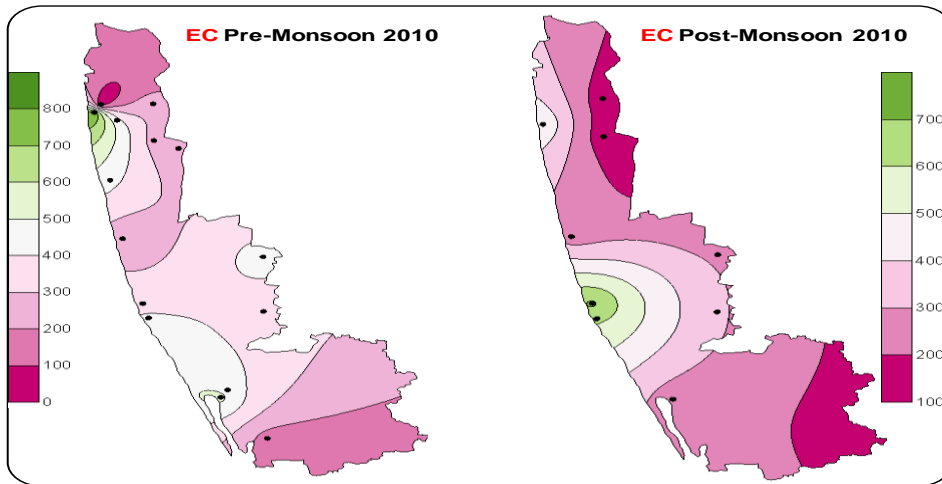


Figure 11b: Spatial variation of EC in Groundwater of Alappuzha district (Year:2010)

Total Dissolved Solids

The concentration of TDS during 2010 were analysed and found that the values are within the permissible limits. The maximum concentration observed during pre-monsoon was 480 mg/l. It varied between 80 mg/l to 480 mg/l during pre-monsoon and 60 mg/l to 420 mg/l during the post-monsoon. However, in majority of the locations TDS was below 300 mg/l. The seasonal variation of TDS during 2010 is depicted in Figure 11c.

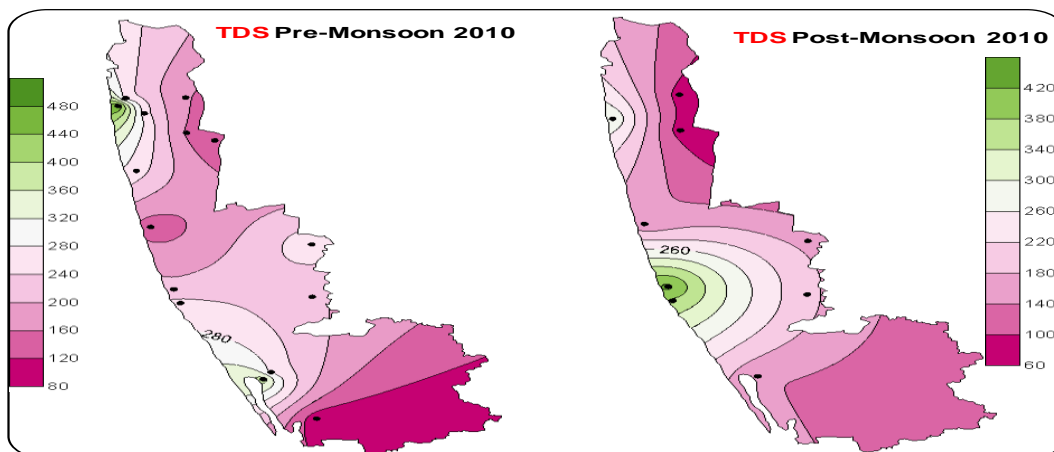


Figure 11c: Spatial variation of TDS in Groundwater of Alappuzha district (Year:2010)

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 30 mg/l to a maximum of 230 mg/l during pre-monsoon and 20 mg/l to 220 mg/l during the post-monsoon of 2010. It is noticed that the presence of carbonate is quite negligible in almost all locations. Therefore, the total alkalinity is mainly due to bicarbonates. Bicarbonates are less than 160 mg/l in majority of the study area. The distribution of bicarbonates and Total alkalinity are shown figures 11d & 11e.

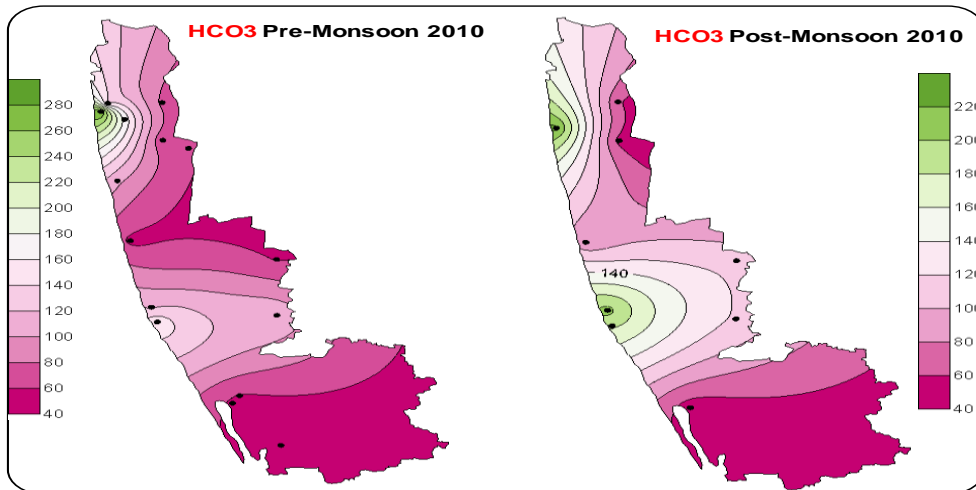


Figure 11d: Spatial variation of Bicarbonates in Groundwater of Alappuzha district (Year:2010)

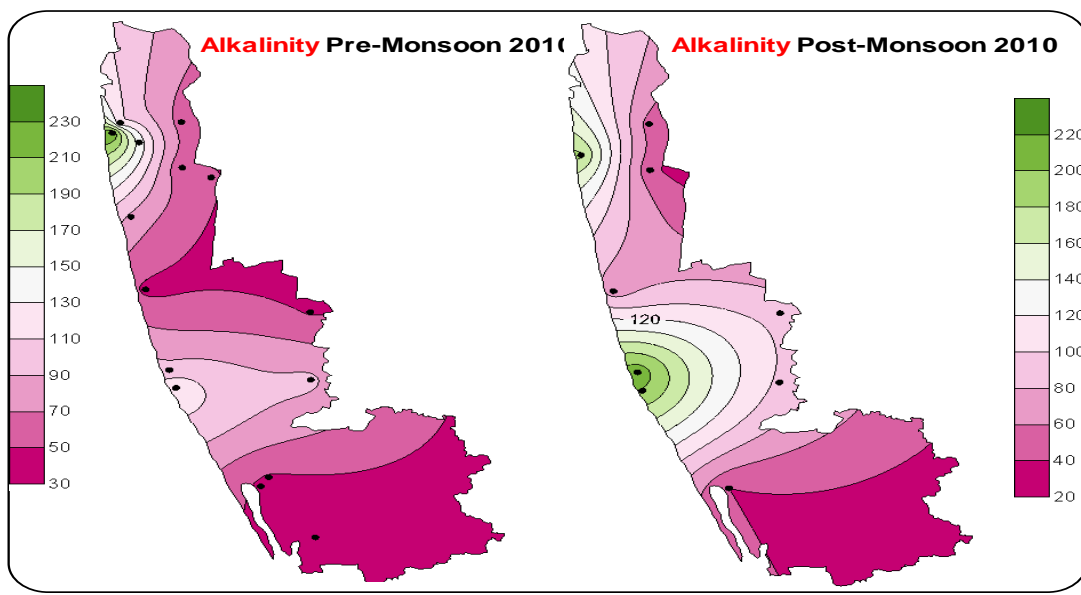


Figure 11e: Spatial variation of Total Alkalinity in Groundwater of Alappuzha district (Year:2010)

Chlorides

In majority of the locations, the maximum chloride content in the water samples varied from 10 mg/l to a maximum of 140 mg/l during pre-monsoon and in the post-monsoon, it is between 5 mg/l and 75 mg/l. The observed chloride concentration is well within the desirable ranges. Figure 11f shows the spatial distribution of chloride in Alappuzha district.

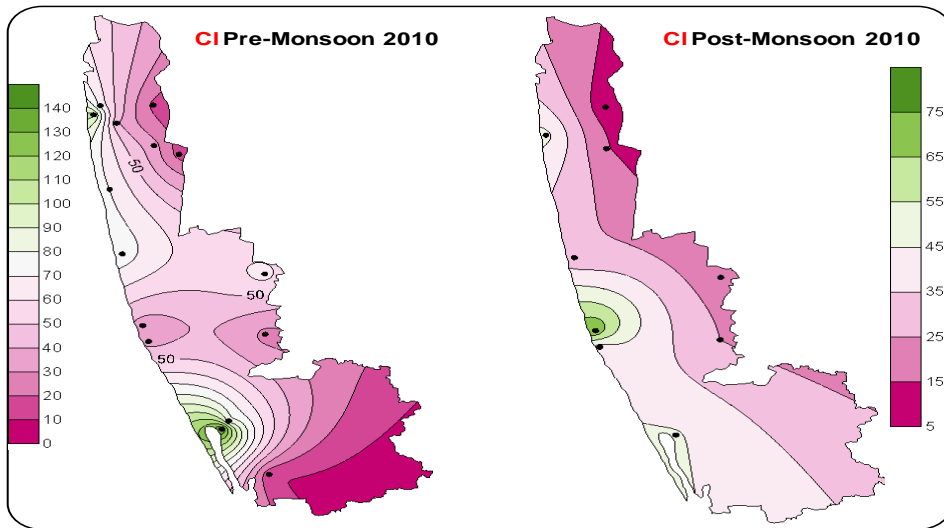


Figure 11f: Spatial variation of Chlorides in Groundwater of Alappuzha district (Year:2010)

Fluoride

The maximum concentration of fluoride observed was 0.22 mg/l during pre-monsoon in the eastern border of the district. The presence of fluorides is negligibly small in the district. It is found that the concentration of fluoride is much less than the required quantity of fluoride for consumption. This needs to be evaluated in detail. Figure 11g shows the variation of fluorides in Alappuzha district.

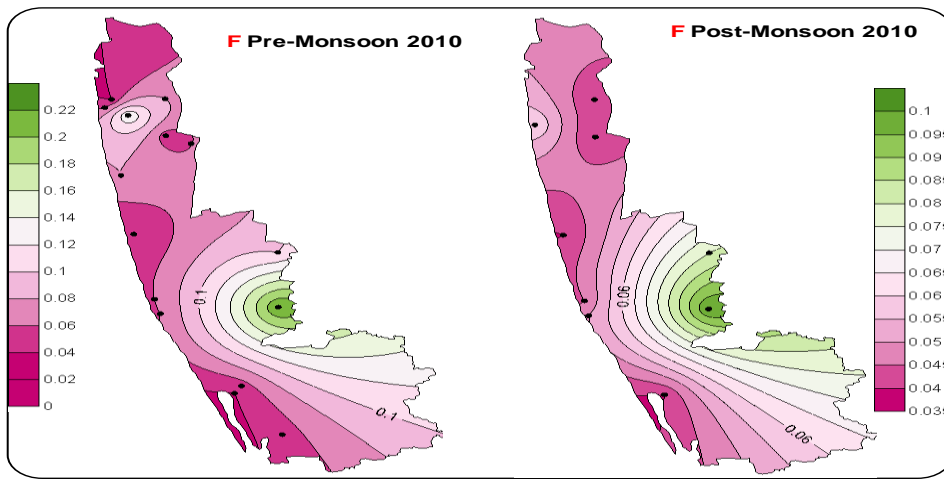


Figure 11g: Spatial variation of Fluorides in Groundwater of Alappuzha district (Year:2010)

Sulphates

The sulphate concentration ranged from less than 2 mg/l to 58 mg/l during pre-monsoon and in the post-monsoon, it varied between less than 1 mg/l and 32 mg/l. It is found that the

variations of sulphates are quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 11h shows the variation of sulphates.

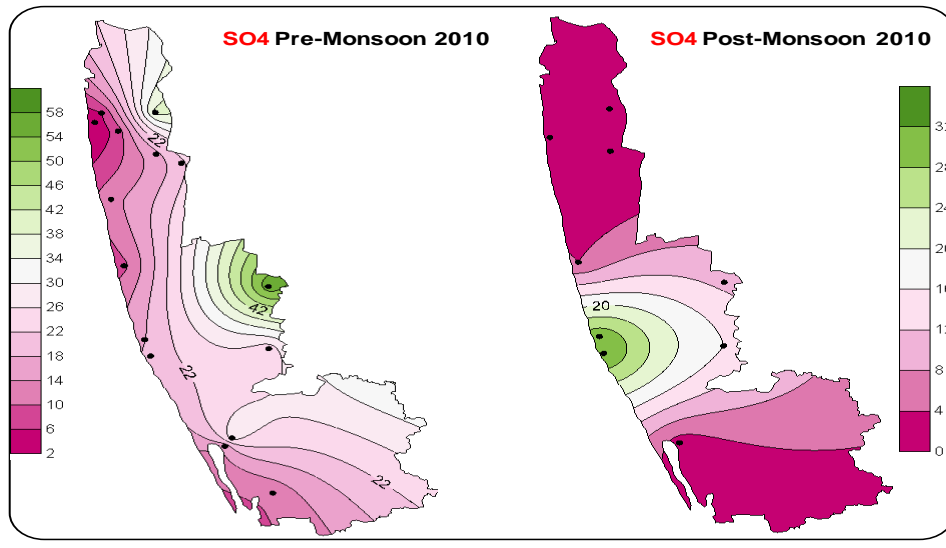


Figure 11h: Spatial variation of Total Alkalinity in Groundwater of Alappuzha district (Year:2010)

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.4 mg/l to 3 mg/l during pre-monsoon and in the post monsoon it ranges between 0.2 mg/l and 8 mg/l. Therefore, it is presumed that, a considerable quantity of agriculture wastes as well as domestic wastes reach the well water during the monsoonal months. Figure 11i shows the variation of nitrates in Alappuzha district in the year 2010.

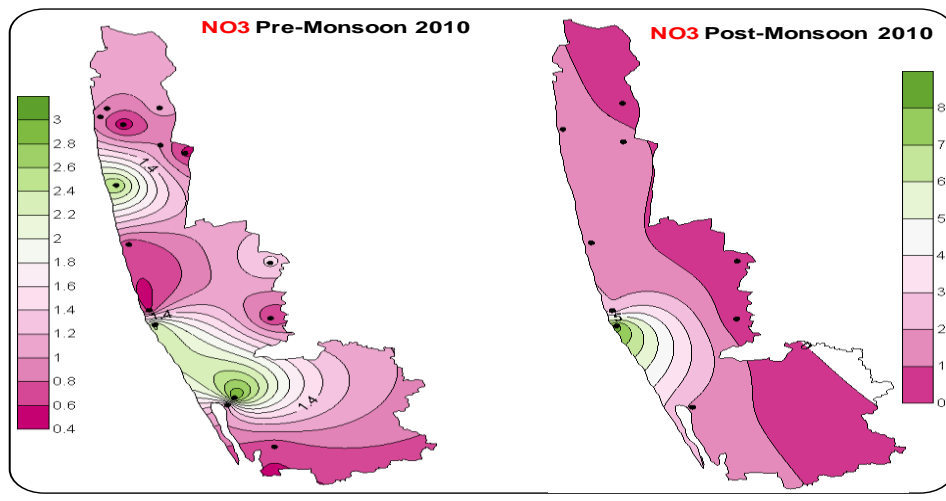


Figure 11i: Spatial variation of Nitrates in Groundwater of Alappuzha district (Year:2010)

Total Hardness

Total hardness of the water samples varied from less than 40 mg/l to more than 240 mg/l during pre-monsoon. A maximum of 240 mg/l was noticed at the north western part of the district. In the post-monsoon of 2010, the TH varied from 30 mg/l to 250 mg/l. Maximum was observed at the south central part of the district. However, it is important to note that the Total hardness is less than 160 mg/l in majority of the study area. The seasonal variation of total hardness is represented in Figure 11j

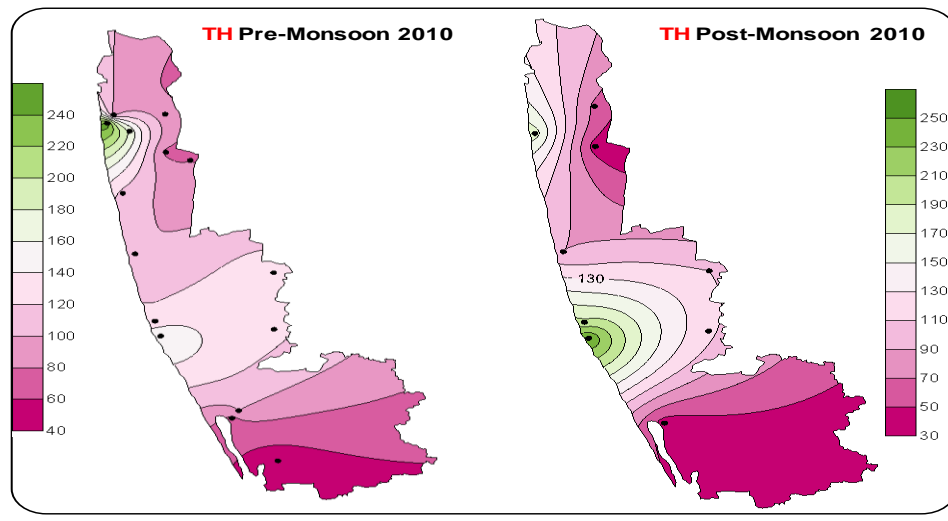


Figure 11j: Spatial variation of Total Alkalinity in Groundwater of Alappuzha district (Year:2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figures 11k and 11l). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from 12 mg/l to 52 mg/l during pre-monsoon and less than 2 mg/l to 80 mg/l in the post-monsoon. It is found that unlike other districts, concentration of magnesium is more than the calcium during pre-monsoon, where as it came d monsoon. It is observed that magnesium concentration varies from less than 10 mg/l to 110 mg/l in the pre-monsoon and during post-monsoon it reduced to less than 10 mg/l. As the district is surrounded by Vembanad estuary which may influence the presence of magnesium.

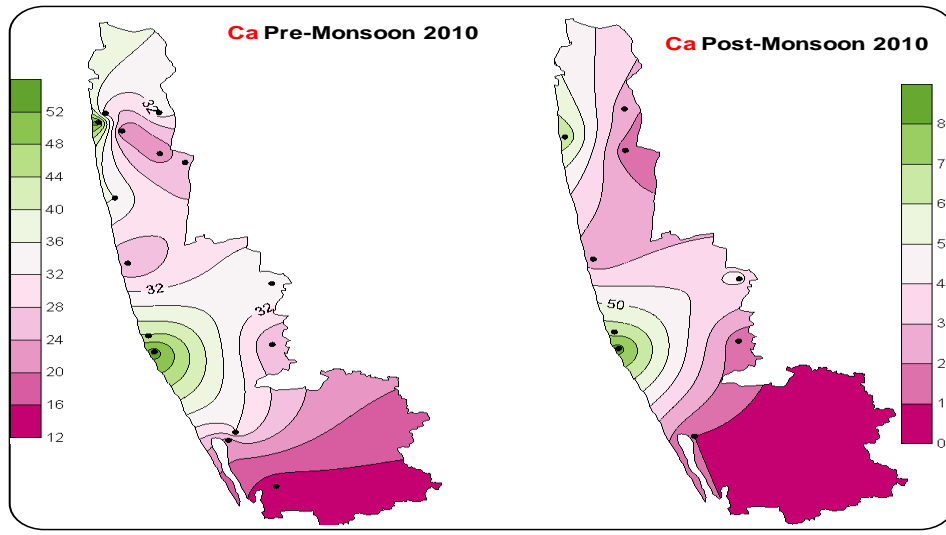


Figure 11k: Spatial variation of Calcium in Groundwater of Alappuzha district (Year:2010)

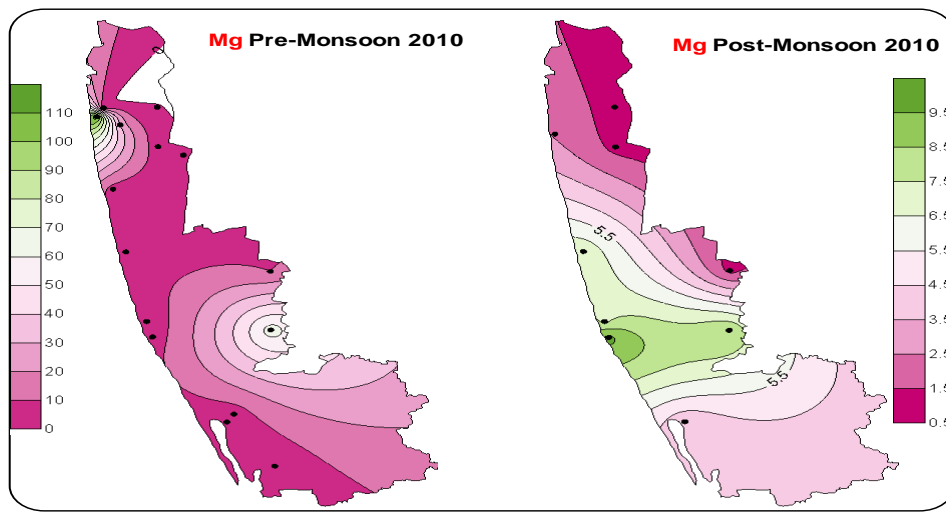


Figure 11l: Spatial variation of Magnesium in Groundwater of Alappuzha district (Year:2010)

Sodium and Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2008 and 2010. The result of 2010 is shown in figure 11m. The observed concentration of sodium varied from less than 10 mg/l to 80 mg/l during pre-monsoon and in the post-monsoon it ranges from 8 mg/l to 72 mg/l. Relatively higher concentration was found in coastal area. The concentration of potassium varied from 0.4 mg/l to 6.4 mg/l during pre-monsoon and 1 mg/l to 8 mg/l in the post-monsoon. The seasonal variation of sodium and potassium concentration is represented in figure 11n.

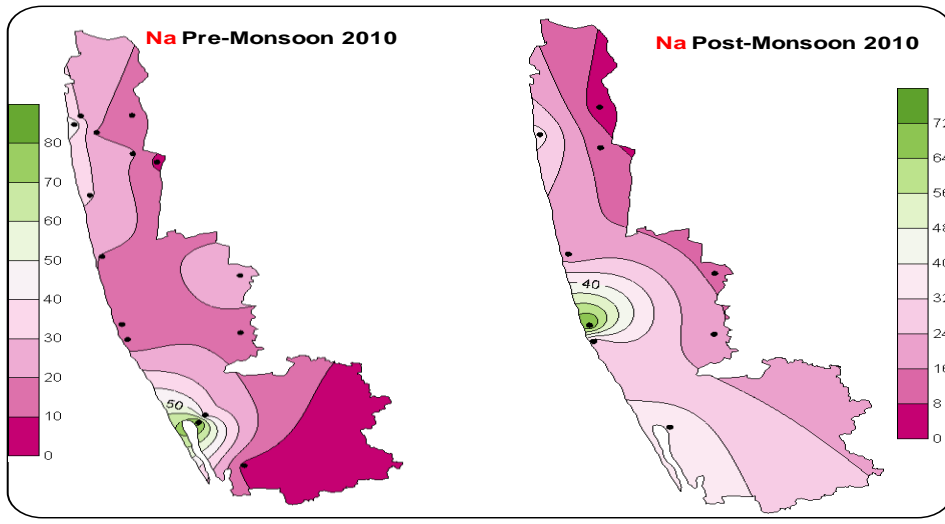


Figure 11m: Spatial variation of Sodium in Groundwater of Alappuzha district (Year:2010)

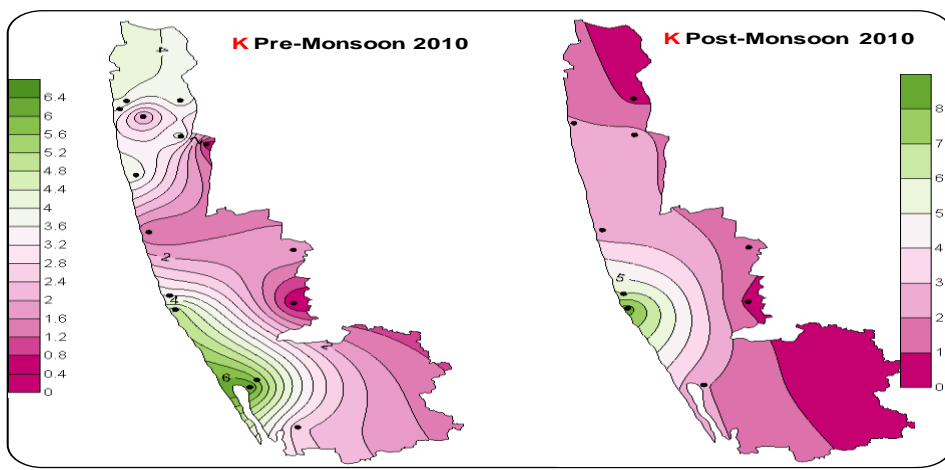


Figure 11n: Spatial variation of Potassium in Groundwater of Alappuzha district (Year:2010)

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2010 was 6.3 mg/l which is much higher than the desirable ranges. It is quite surprising to note that the maximum concentration gone up to 60 mg/l during post monsoon in a well located at the north western part of the district. This kind of observation needs further evaluation to arrive at definite conclusions. The figure 11o shows the variation of iron in the district.

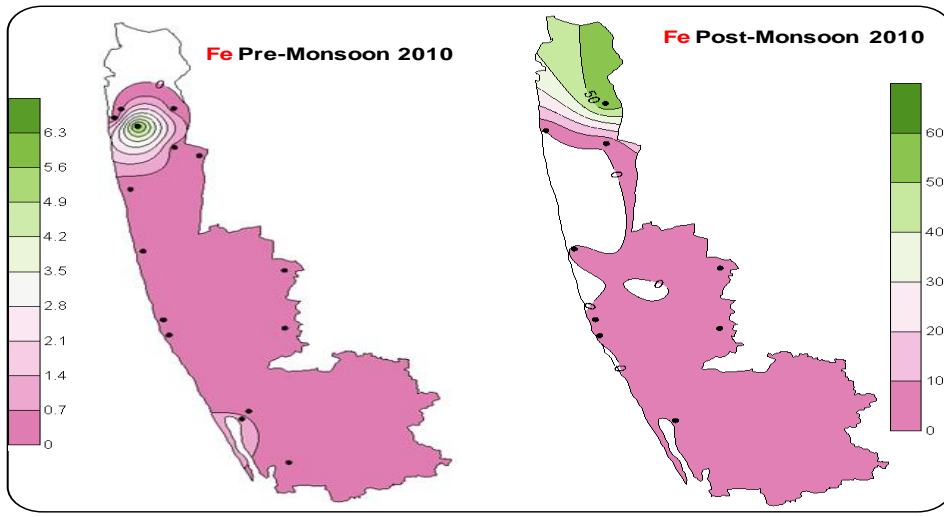


Figure 11o: Spatial variation of Iron in Groundwater of Alappuzha district (Year:2010)

Groundwater Classification

Piper's Classification: Among the pre-monsoon samples, 3 major groups are found in this category. The dominating is area 5 (58.33%), showing carbonate hardness exceeds 50%. The second category is area 4 (25%), strong acids exceed weak acids. 16.67% area is covered by non-carbonate alkali exceeds 50%.

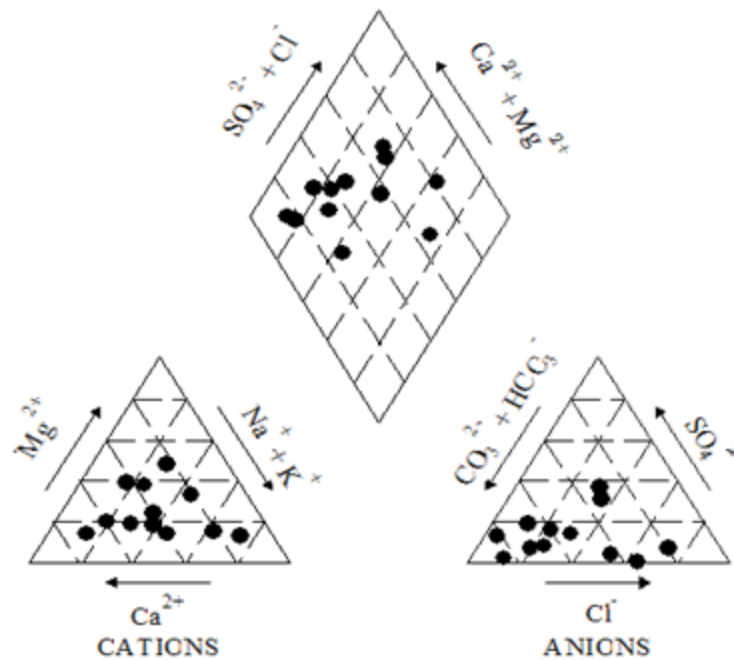


Figure 11p: Piper's diagram of Alappuzha district (Pre-monsoon 2007)

The post-monsoon samples fall under 4 areas..i.e area 5 (61.7%), area 4 (19.15%), area 7 (12.77%) and area 9 (6.38%). The majority of the samples shows that chemical properties are dominated by alkaline earth's weak acids.

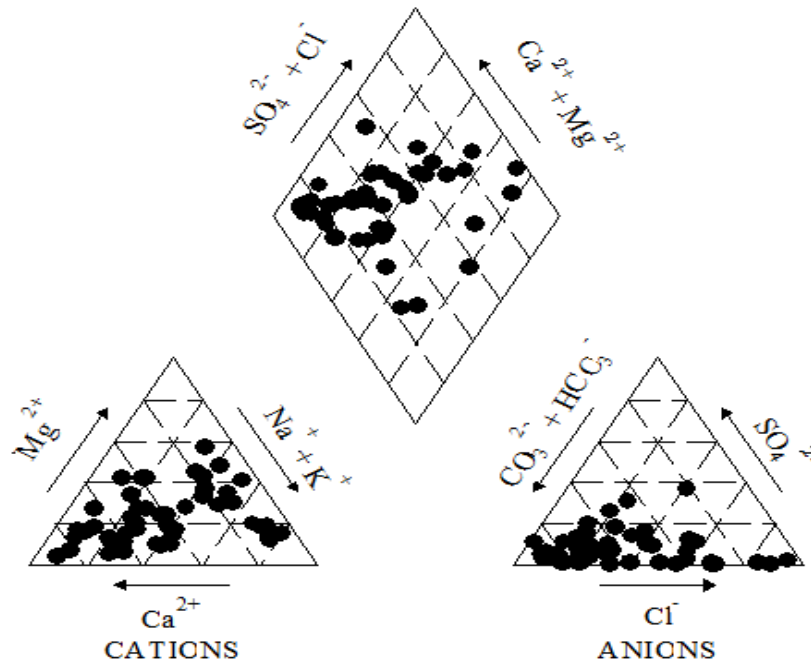


Figure 11q: Piper's Classification of Ground water during Post-monsoon 2007

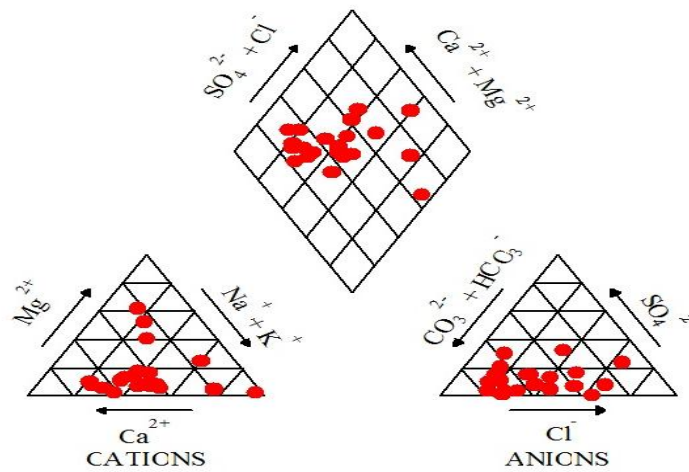


Figure 11r: Piper's Classification of Ground water during Pre-monsoon 2010

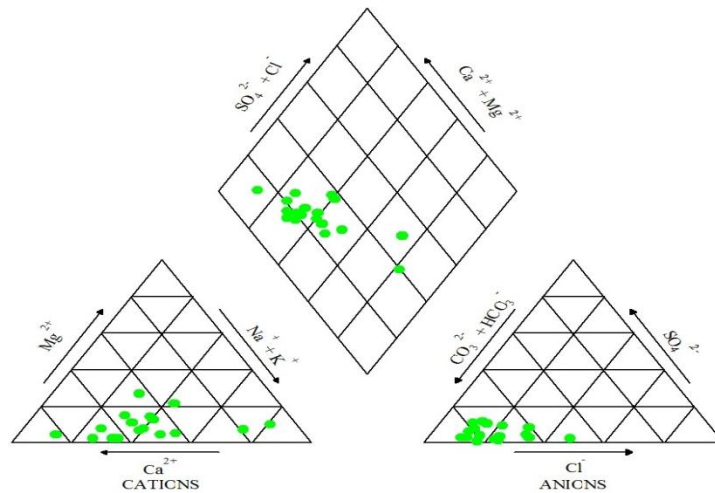


Figure 11s: Piper's Classification of Ground water during Post-monsoon 2010

Chadha's Classification: Based on Chadha's classification, the ground water samples fall under area 5 (58.33%), area 6 (25%) and area 7 (17%). Area 5 shows the presence of Alkaline earth's and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness, i.e., Ca- Mg- HCO₃ type, Ca- Mg dominant HCO₃ type or HCO₃ – dominant Ca- Mg- type waters. Area 6 represent the alkaline earth's exceed alkali metals and strong acidic anions exceed weak acidic anions which indicated permannet hardness.

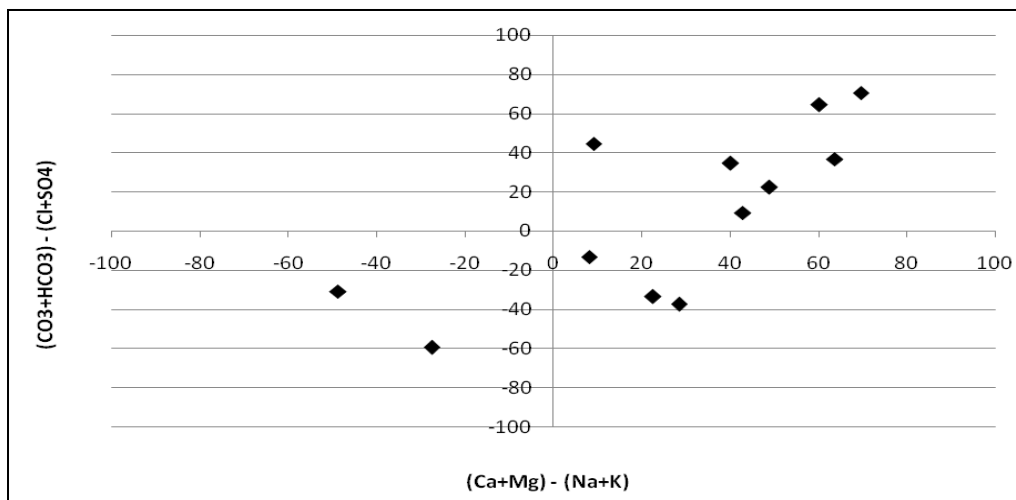


Figure 11t: Chadha's diagram of Alappuzha district (Pre-monsoon, 2007)

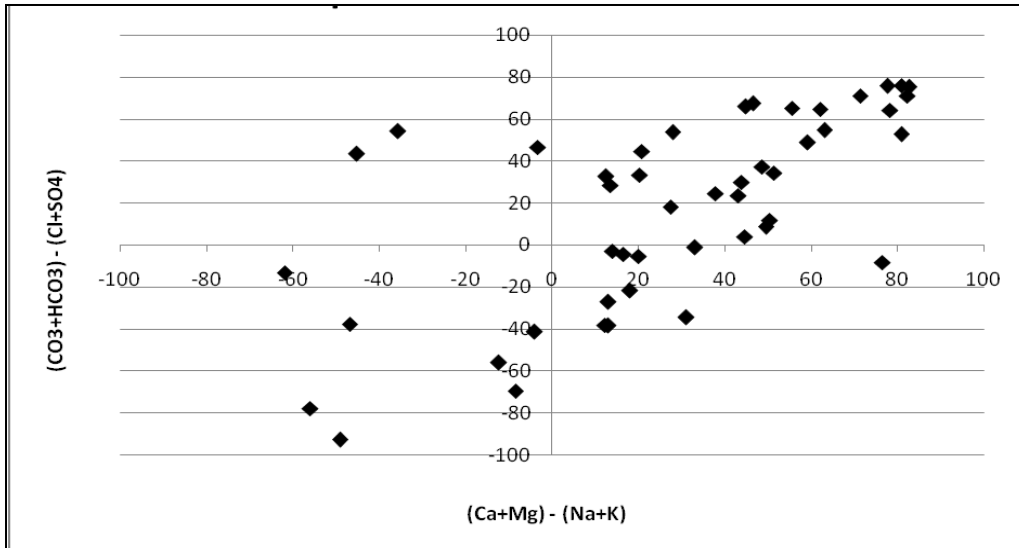


Figure 11u: Chadha's diagram of Alappuzha district (Post-monsoon, 2007)

In Alappuzha both pre-monsoon and post-monsoon samples behave in a similar way which shows that there were no changes in the quality of water in two seasons.

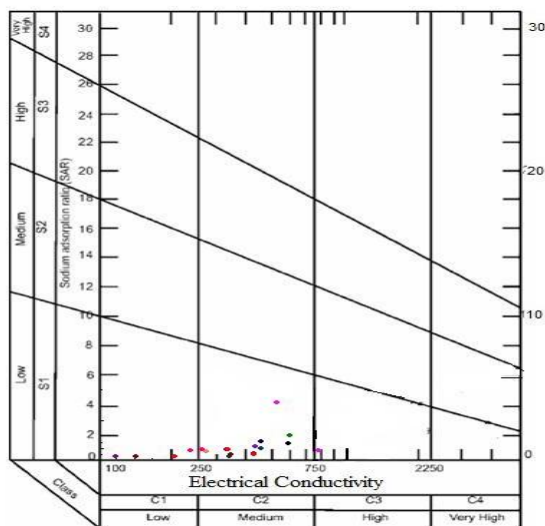


Figure 11v: USSL Classification of Ground water during Pre-monsoon 2010

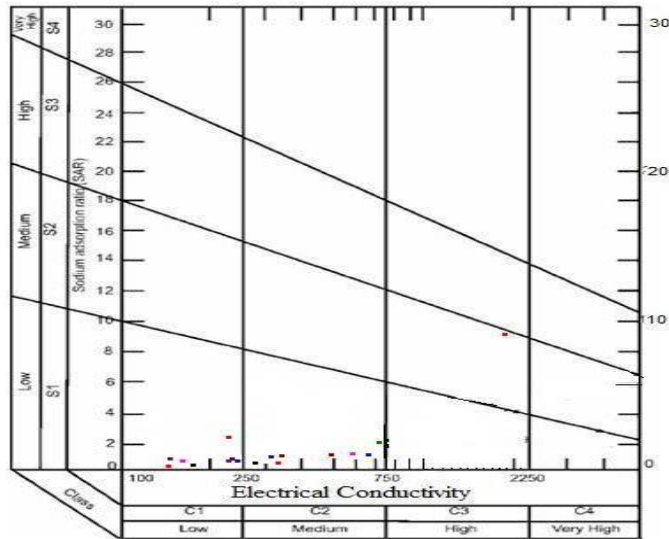


Figure 11w: USSL Classification of Groundwater during Post-monsoon 2010

Statistical Analysis of Groundwater quality data of 2008

Table 11c: Correlation between various parameters during Pre-monsoon of 2008

Parameters	pH	EC	TH	Cl	Na	F	Fe
pH	1						
EC	0.233	1					
TH	0.357	0.953	1				
Cl	0.186	0.973	0.895	1			
Na	0.179	0.984	0.912	0.99	1		
F	0.313	0.401	0.395	0.397	0.381	1	
Fe	0.007	0.107	0.11	0.151	0.098	0.169	1

Table 11c: Correlation between various parameters during Post-monsoon of 2008

	pH	EC	TH	Cl	Na	F	Fe
pH	1						
EC	0.192	1					
TH	0.285	0.928	1				
Cl	0.103	0.954	0.822	1			
Na	0.177	0.969	0.836	0.97	1		
F	0.218	0.401	0.325	0.325	0.463	1	
Fe	0.291	0.358	0.298	0.362	0.368	0.098	1

12.0 GROUNDWATER QUALITY OF KOLLAM DISTRICT

Kollam (Earlier known as Quilon), one of the famous trading towns of Kerala has a distinctive place in the mineral map of Kerala. The district has a single revenue division with headquarters at Kollam. Pathanapuram, Kunnathur, Kottarakkara, Karunagapally and Kollam are the five Taluks in the district. The district is divided into thirteen development blocks, 71 panchayaths and 103 villages. Paravoor and Punalur are municipal towns and Kollam is the corporation.

The district is underlain by crystalline rocks of Archaean age above which sedimentary formations of Miocene to Recent ages are seen. Groundwater occurs in all the geological formations from Archaean crystallines to Recent alluvium. The quality of water in the coastal aquifer is generally good however there is considerable change in the quality of groundwater along the coastal stretch. Groundwater pollution is being reported from two areas of the district namely Chavara and Pozhikara. Because of the highly porous nature of the laterite, the dug wells tapping laterite get recharged fast in the initial stages of monsoon showers itself, however this water escapes as sub-surface flow and the water level falls quite fast especially in wells located on topographic high and slopes.

Rainfall & Climate

The major source of rainfall is South West monsoon from June to September which contributes nearly 55% of the total rainfall of the year. The North East monsoon season from October to December contributes about 24% and the balance 21% is received during the month of January to May as pre-monsoon showers. Out of the total 119 rainy days, 70.1 rainy days occur in the southwest monsoon season. The district receives an average 2555mm of rainfall annually.

Temperature

The temperature is more during the months of March to May and is less during December and January. The average mean monthly maximum temperature ranges from 29.9 to 36.4⁰ C and minimum temperature ranges from 19.4 to 23.8⁰ C.

Relative Humidity

The Relative humidity is higher during the monsoon period and all through the year it is higher during the morning hours.

Evaporation

Evaporation is more during summer months of January to April and it is low during the rainy months May to August. The maximum rate of 4.8 mm per day is recorded in March and the lowest rate of 2.6 mm is recorded during July.

Sunshine Hours

Sunshine ranges from 4.3 to 9.7 hours/day. Maximum sunshine is during the month of February. The months of June to August record the minimum sunshine due to the cloudy sky. Generally good sunshine hours are recorded in the months of November to May.

Wind

The wind speed ranges from 1.3 to 2.1 km/hour. The wind speed is high during the months of March to June and less during the months of September to December.

Potential Evapotranspiration (PET)

PET values are lower than the monthly rainfall during the month of May to October indicating water surplus for possible recharge into groundwater regime during these months. The monthly PET ranges from 119.3 to 177 mm.

Geomorphology and Soil Types

Geographically the district can be divided into three distinct units viz. the coastal plains, the midlands and the eastern highland regions. The coastal plains with an elevation ranging between 0-6 m amsl occur as narrow belt of alluvial deposits parallel to the coast. To the east of coastal belt is the midland region with altitude ranging from 6-80m amsl. The midland area is characterised by rugged topography formed by small hillocks separated by deep cut valleys. The midland regions show a general slope towards the western coast. To its east is the high land region. Major parts of the catchment of river Kallada and Ithikara fall within this unit. This unit occupies the maximum area of the district. The Western Ghat fringes is bounded by 300 to 600 m contours.

There are five major soil types encountered in the district. They are Lateritic, Brown Hydromorphic, Greyish Onattukara, Riverine and Coastal Alluvium and Forest Loam. Lateritic soil is the most predominant soil type of the district and it occurs in the midland and hilly areas and it is derived from laterites. Brown hydromorphic soil is confined to the valleys between undulating topography in the midlands and in the low lying areas of the coastal strip.

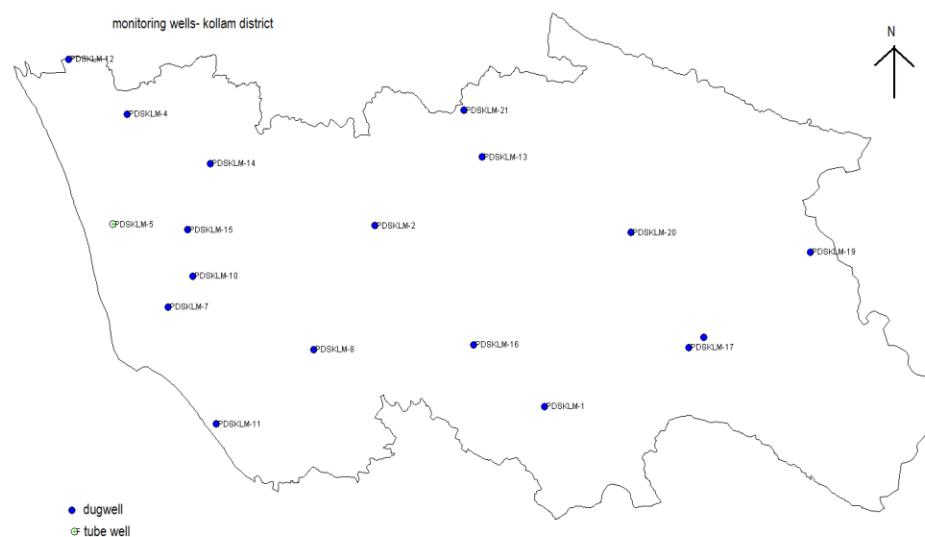


Figure 12: Location map selected wells in Kollam district

Ground Water Quality Analyses

Ground water occurs in the porous granular formations such as alluvium, laterite, the Tertiary sediments and weathered and decomposed crystalline rocks as well as in the fissures, joints and fractures in the fresh crystalline rocks. Water quality monitoring was done at 114 sampling sites during the pre-monsoon (2008) season. At many of the places, the pH values showed variations between 3.5 and 8.3, i.e., from highly acidic to highly alkaline. The areas having acidic nature are in Vilakudy which recorded a low value of 3.5, followed by Kizhakumbhagam (3.60), Sasthamkotta (4.00), Anchalammodu (4.00), Kadakkal (4.10), Veliyam (4.50), Pallimukku (4.50), etc. Electrical Conductivity showed large values at Vilakudy (1320 $\mu\text{S}/\text{cm}$), Eravipuram (899 $\mu\text{S}/\text{cm}$), Ochira (831 $\mu\text{S}/\text{cm}$) and Aavaneeswaram (803 $\mu\text{S}/\text{cm}$). Sodium was

present in excess at the samples from Vilakudy (117.60 mg/l). High Iron concentrations were observed at Kummil (6.85 mg/l), Edappallikota (6.20), Mukhathala (5.81 mg/l) and Aloor (4.69 mg/l). In Kollam district, the interesting part is that most of the data showed a similarity to historical data which indicates that the concentration remained same during the present observation period.

Table 12a: Statistical analysis of selected parameters during Post-monsoon 2008.

Kollam pre-monsoon 2008					
parameters	No.	minimum	Maximum	mean	St. Deviation
pH	114	3.5	8.3	6.29	0.97
EC	114	52	1320	269.55	226.32
TH	114	18.6	260.4	62.35	46.90
Cl	114	0.9	176	27.80	25.82
Na	114	3	117.6	21.32	18.53
Fe	114	0.01	6.85	0.53	0.95

Table 12b: Statistical correlation of selected parameters during Post-monsoon 2008.

Kollam post-monsoon 2008					
parameters	No.	minimum	Maximum	mean	St. Deviation
pH	37	4.13	8.2	6.83	0.69
EC	37	39	750	248.32	169.85
TH	37	4.3	214	58.33	45.89
Cl	37	3	79	27.76	20.19
Na	37	1.6	71.5	21.19	16.81
Fe	37	0.01	10.16	0.83	1.80

In the post-monsoon period, the pH value showed a slight improvement (from a minimum of 3.5 to 4.13), however, the mean value showed an increase in pH from 6.29 to 6.83. Electrical conductivity, total hardness, chloride and sodium concentrations showed a marked reduction. The iron concentration indicated a steep increase at certain patches and the mean value increased to 0.83. Tables 12a & 12b show the ranges of various parameters in the year 2008 pre-monsoon and post monsoon respectively.

PH

The pH values of the samples collected from selected locations of Kollam district varied from 3.40 to 8.20 during pre-monsoon and 4 to 8 during post-monsoon of 2008. It is quite interesting to note that major part of the study area falls under acidic groups. During the post-monsoon, situation improved much. In the western and eastern part of the district water was neutral to alkaline. During the post-monsoon, acidic water was found only in the south-western part of

the district. In the year 2010, limited analysis were carried out based on investigations for pollution prone areas, the results of the analysis shows that pH varies from 6.75 to 8.15 during pre-monsoon and 4.1 to 6.3 during post-monsoon. This clearly indicate that the modifications and runoff waters plays significant role in pH variation. The seasonal variation of pH in waters during 2008 & 2010 are given in Figures 12a & 12b.

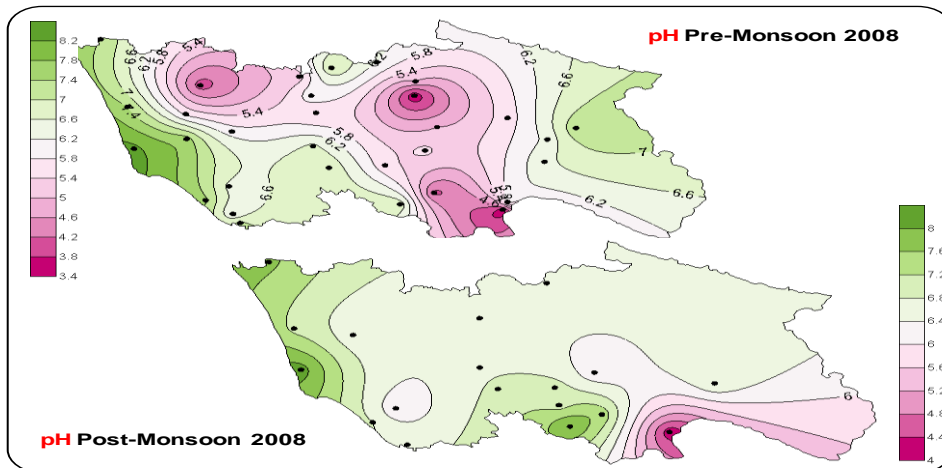


Figure 12a: Spatial variation of pH in Groundwater of Kollam district (Year:2010)

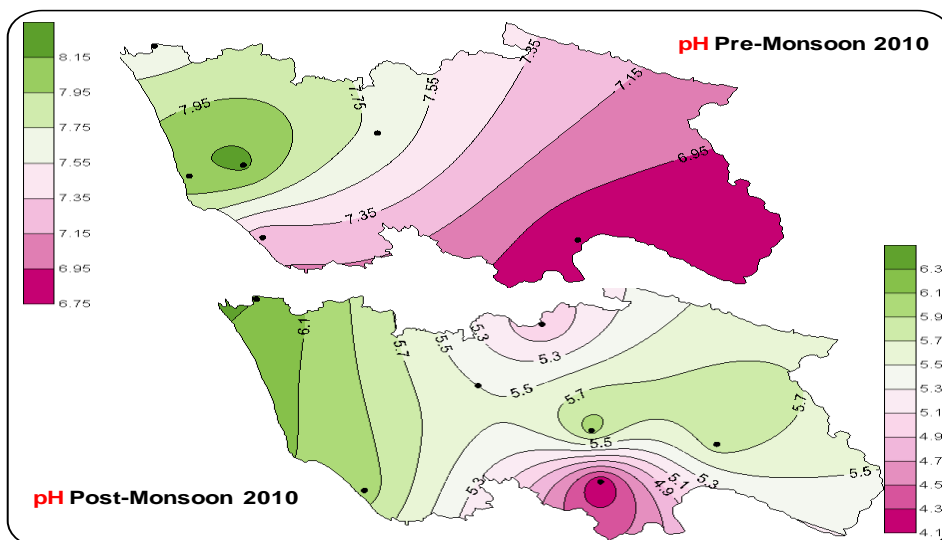


Figure 12b: Spatial variation of pH in Groundwater of Kollam district (Year:2010)

Electrical conductivity

Electrical conductivity of the samples varied from less than 50 micro-siemens/cm to 1350 micro-siemens/cm during pre-monsoon and less than 100 micro-siemen/cm to 700 micro-siemen/cm in the post-monsoon in the year 2008. However, it is noticed that highest EC was found in almost in a central part of the district whereas in all other parts of the districts it is

within the permissible limits. An observation taken during 2010 for limited number of wells showed a different picture. The EC values varied from 50 micro-siemen/cm to 1300 microsiemen/cm during pre-monsoon and 160 microsiemen/cm to 720 micro-siemen/cm during post-monsoon. However, the higher values observed are quite localized in nature. Figure 12c & 12d show the variation of Electrical conductivity during 2008 & 2010.

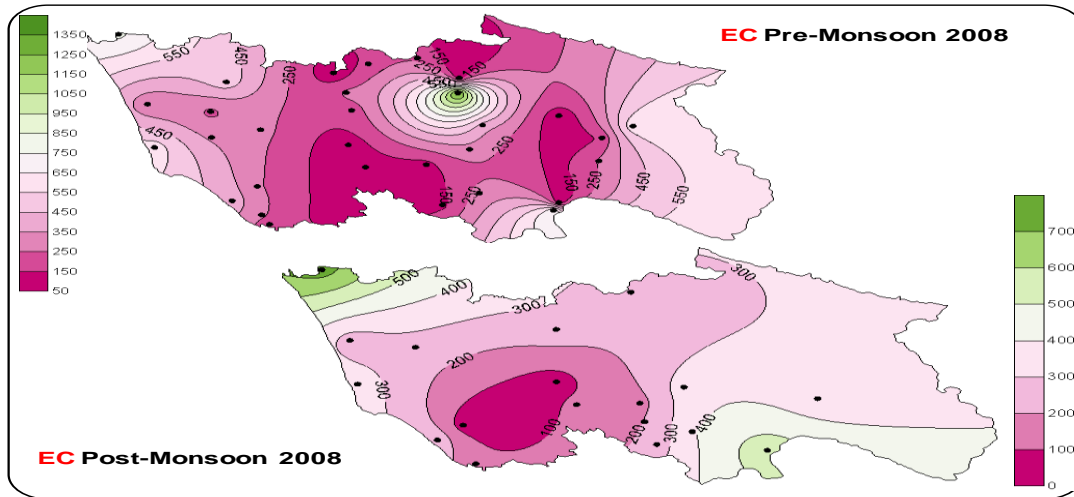


Figure 12c: Spatial variation of EC in Groundwater of Kollam district (Year:2008)

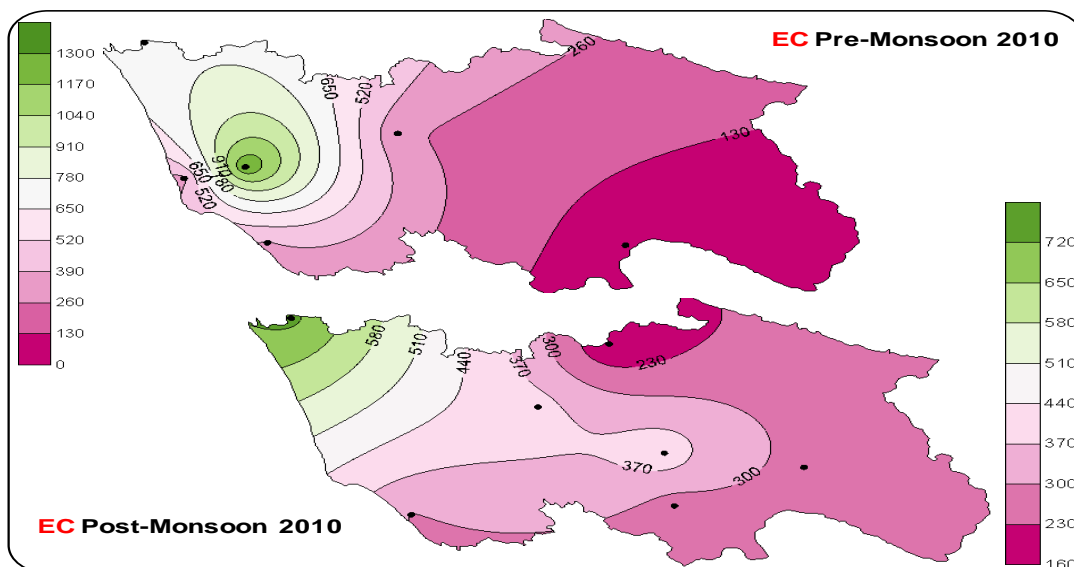


Figure 12d: Spatial variation of EC in Groundwater of Kollam district (Year:2010)

Total Dissolved Solids

The distribution of TDS in groundwater of Kollam district was quite proportional to EC. In few localities TDS is slightly higher than the standard values. The concentration of TDS varied from less than 80 mg/l to 800 mg/l during pre-monsoon 2010 were analysed and found that the values are within the permissible limits. The maximum concentration observed during pre-monsoon was 480 mg/l. It varied between 80 mg/l to 480 mg/l during pre-monsoon and 80

mg/l to 440 mg/l during the post-monsoon in the year 2010. However, in majority of the locations TDS was below 400 mg/l. The seasonal variation of TDS during 2010 is depicted in Figure 12e.

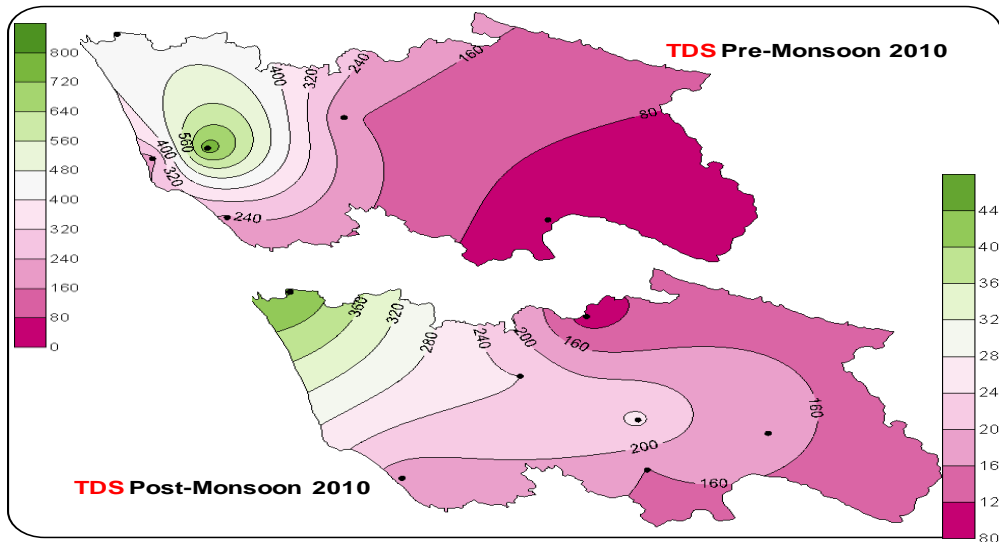


Figure 12d: Spatial variation of TDS in Groundwater of Kollam district (Year:2010)

Total Alkalinity

In the study area, it is found that the alkalinity varied between less than 10 mg/l to a maximum of 370 mg/l during pre-monsoon and 17 mg/l to 170 mg/l during the post-monsoon of 2010. Higher values of alkalinity were noticed in the western part of the district and it is local in nature. It is noticed that the presence of carbonate is quite negligible in almost all locations. Therefore, the total alkalinity is mainly due to bicarbonates. The distribution of bicarbonates and Total alkalinity are shown figures 12e & 12f.

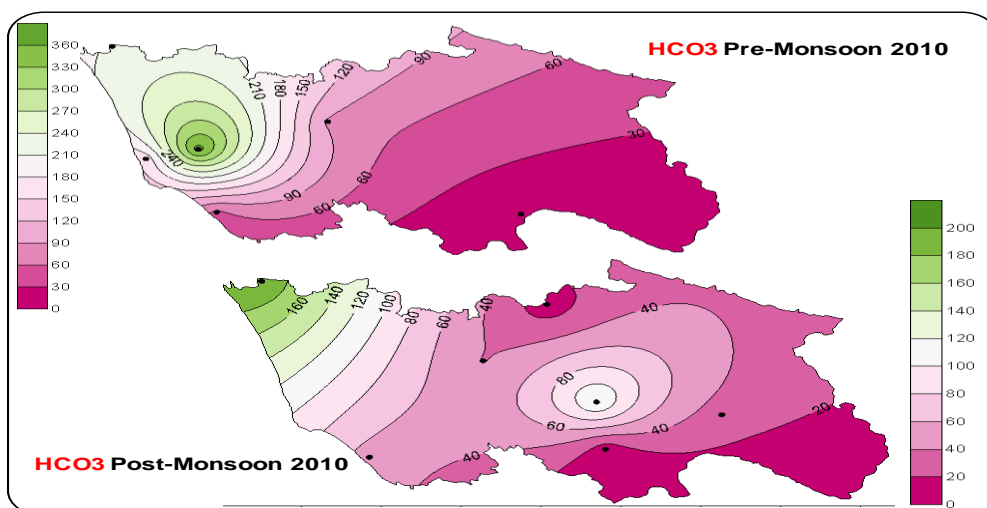


Figure 12e. Spatial variation of HCO₃ in Groundwater of Kollam district (Year:2010)

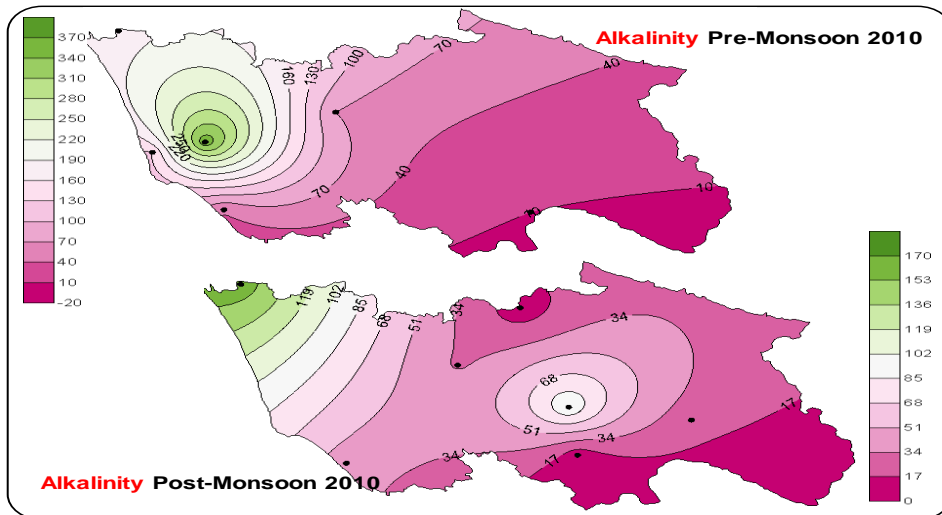


Figure 12f: Spatial variation of TDS in Groundwater of Kollam district (Year:2010)

Chlorides

The chloride content in the water samples varied from 18 mg/l to a maximum of 180 mg/l during pre-monsoon and in the post-monsoon, it is between 34 mg/l and 94 mg/l. The observed chloride concentration is well within the desirable ranges. Figures 12g shows the spatial distribution of chloride in Kollam district.

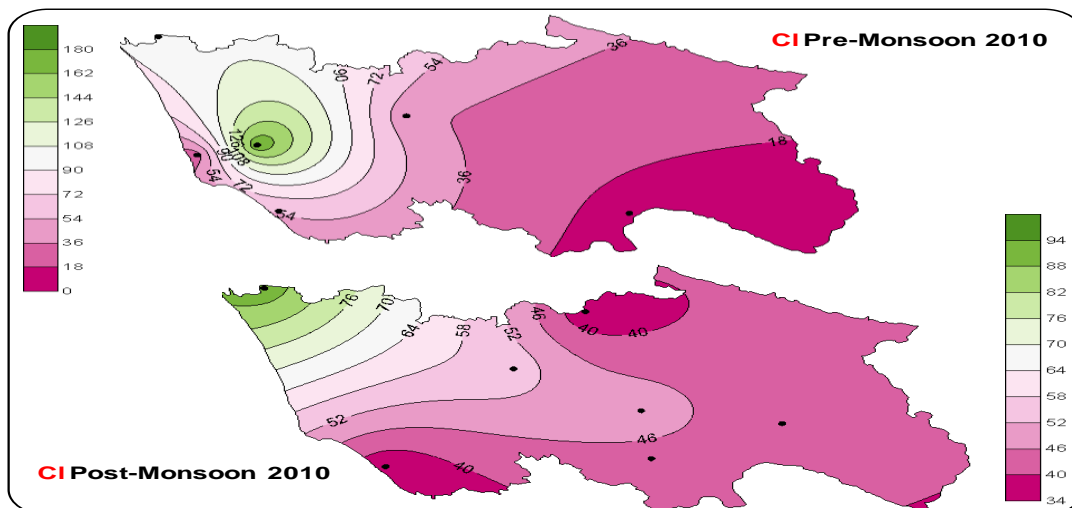


Figure 12g: Spatial variation of Chlorides in Groundwater of Kollam district (Year:2010)

Fluoride

The maximum concentration of fluoride observed was 0.27 mg/l during pre-monsoon in the western border, near to the coast. The presence of fluorides is negligibly small in the district. It is found that the concentration fluoride much less than the required quantity in the groundwater. During post-monsoon, the fluoride content is almost negligible in percentage. Figure 12h shows the variation of fluorides in Kollam district.

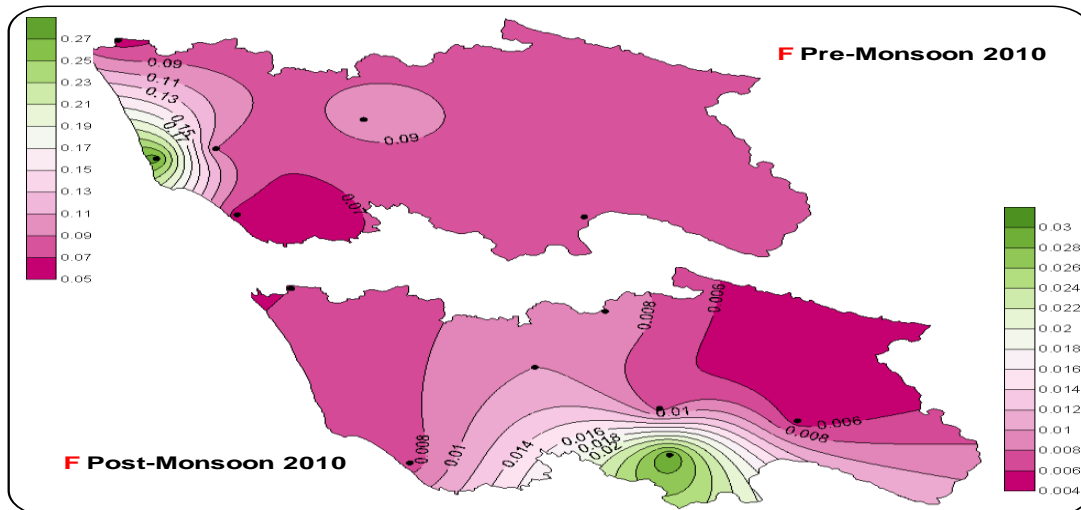


Figure 12h: Spatial variation of Fluorides in Groundwater of Kollam district (Year:2010)

Sulphates

The sulphate concentration ranged from 2 mg/l to 52 mg/l during pre-monsoon and in the post-monsoon, it varied between 4 mg/l and 49 mg/l. It is found that the variations of sulphates are quite minimal and the concentration observed is much below the desirable ranges of sulphates. Figure 12i shows the variation of sulphates in Kollam district.

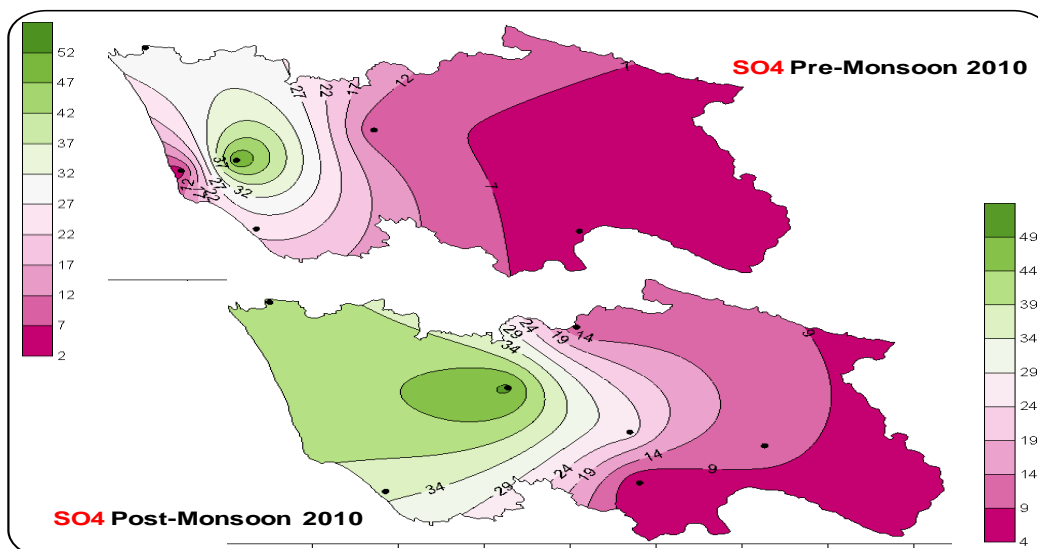


Figure 12i: Spatial variation of Sulphates in Groundwater of Kollam district (Year:2010)

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.7 mg/l to 7 mg/l during pre-monsoon and in the post monsoon it ranges between 1 mg/l and 7.4 mg/l. Figure 12j shows the variation of nitrates in Kollam district in the year 2010.

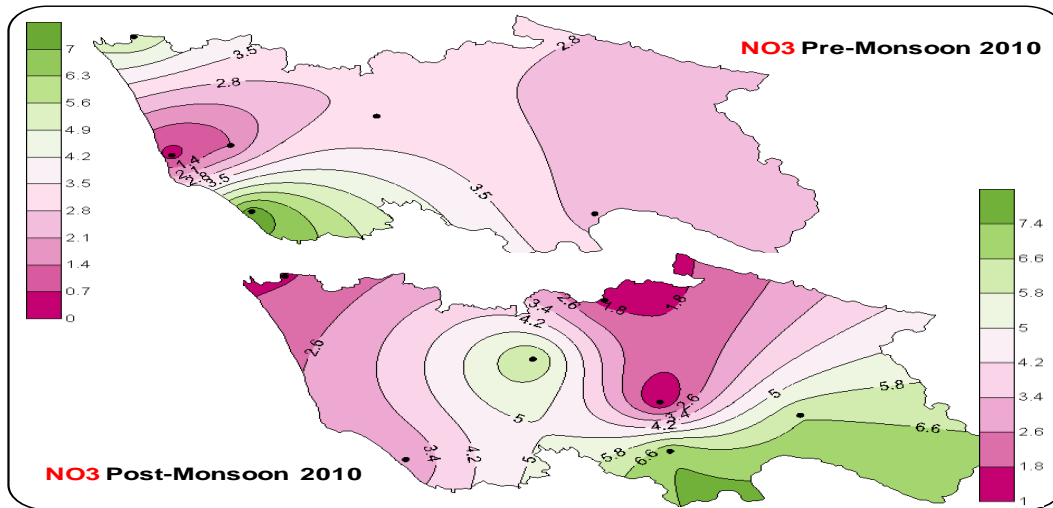


Figure 12j: Spatial variation of NO3 in Groundwater of Kollam district (Year:2010)

Total Hardness

Total hardness of the water samples varied from less than 40 mg/l to 440 mg/l during pre-monsoon and in the post-monsoon, it varied between 30 mg/l to 190 mg/l in the year 2010. Total hardness showed a considerably higher concentration during pre-monsoon and in the post-monsoon it showed a decline. The seasonal variation of total hardness is represented in Figure 12k.

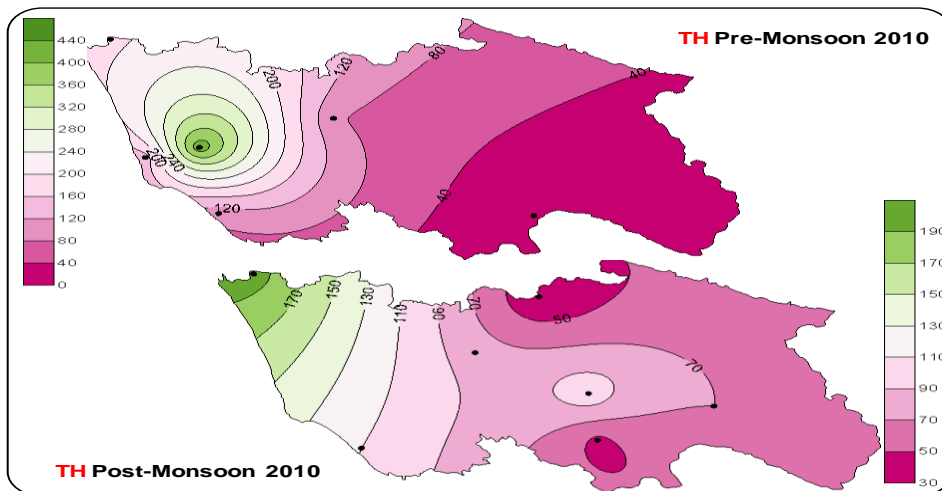


Figure 12k: Spatial variation of TH in Groundwater of Kollam district (Year:2010)

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figures 12l and 12m). It is observed that both calcium and magnesium concentrations are much below the permissible limit. Calcium concentration varies from 9 mg/l to 135 mg/l during pre-monsoon and less than 6 mg/l to 46 mg/l in the post-monsoon. The magnesium concentration varies

from less than 2 mg/l to 18 mg/l in the pre-monsoon and during post-monsoon it varies from less than 3 mg/l to 21 mg/l.

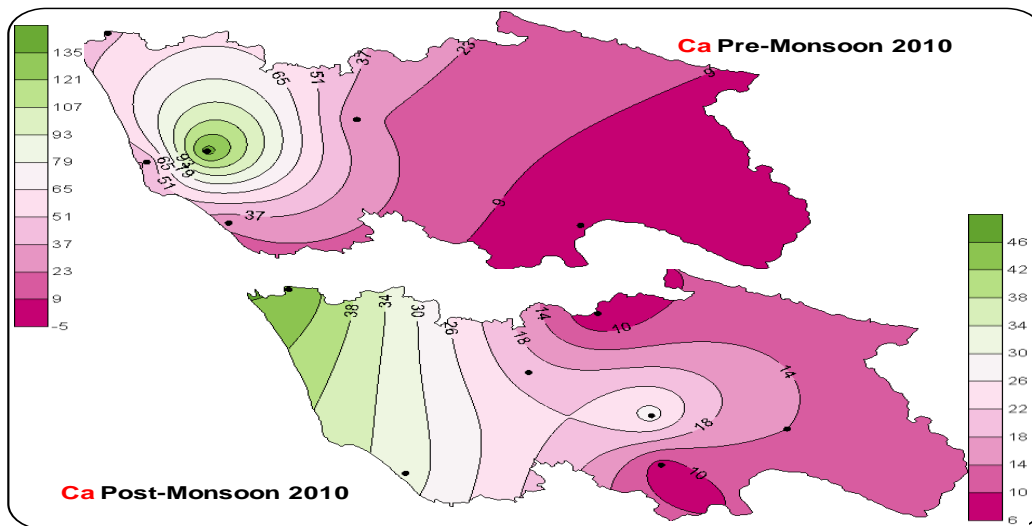


Figure 12l: Spatial variation of Ca in Groundwater of Kollam district (Year:2010)

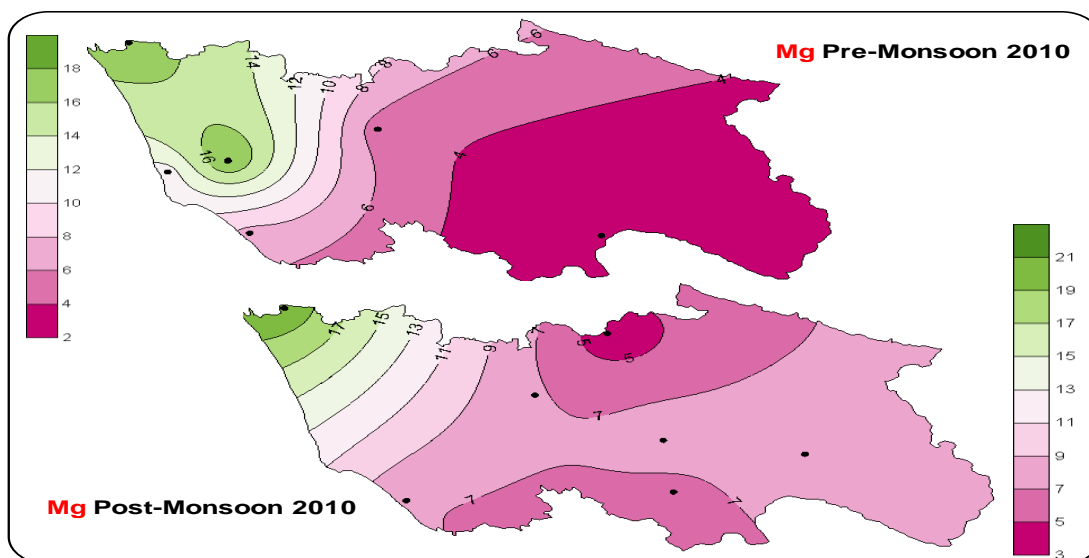


Figure 12m: Spatial variation of Mg in Groundwater of Kollam district (Year:2010)

Sodium and Potassium

Analysis of sodium concentration in the ground water samples were carried out in the year 2008 and 2010. The result of 2010 is shown in figures 12n & 12o. The observed concentration of sodium varied from less than 12 mg/l to 120 mg/l during pre-monsoon and in the post-monsoon it ranges from 6 mg/l to 60 mg/l. In 2010, it showed a lower concentration, i.e. 5 mg/l to 95 mg/l in pre-monsoon and 16 mg/l to 58 mg/l in the post-monsoon. The concentration of potassium varied from 2.5 mg/l to 15.5 mg/l during pre-monsoon and 3 mg/l to 25 mg/l in the

post-monsoon. The seasonal variation of potassium concentration is represented in figure 12p.

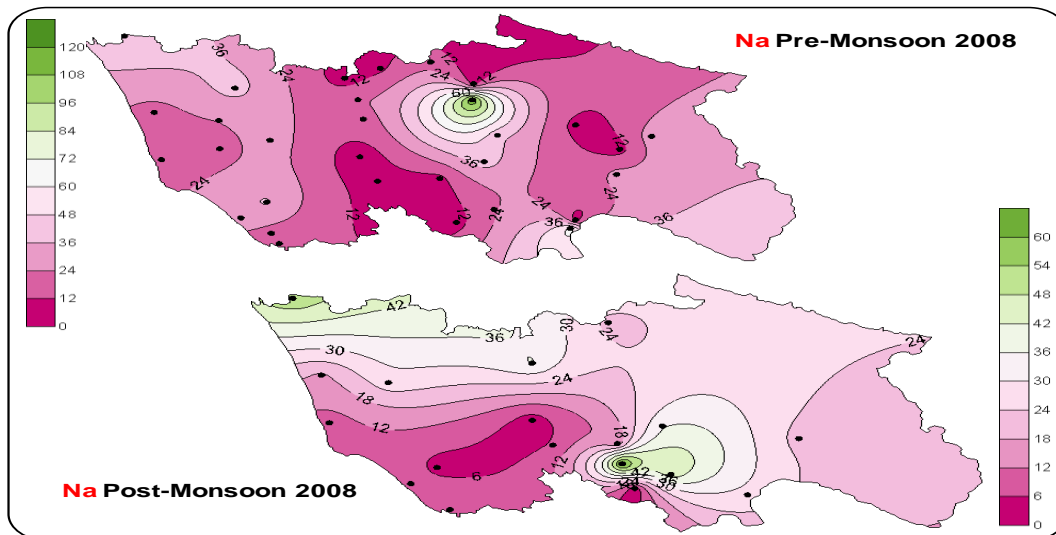


Figure 12n: Spatial variation of Na in Groundwater of Kollam district (Year:2008)

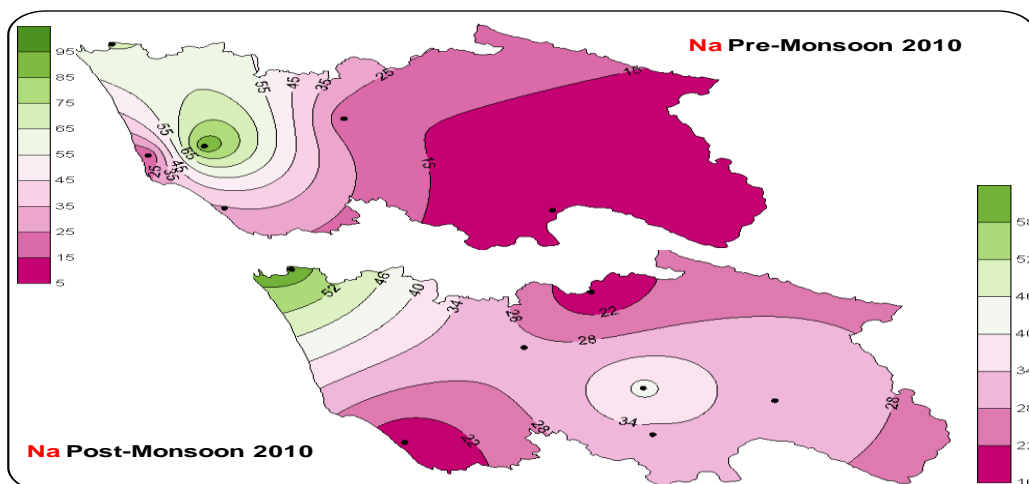


Figure 12o: Spatial variation of Na in Groundwater of Kollam district (Year:2010)

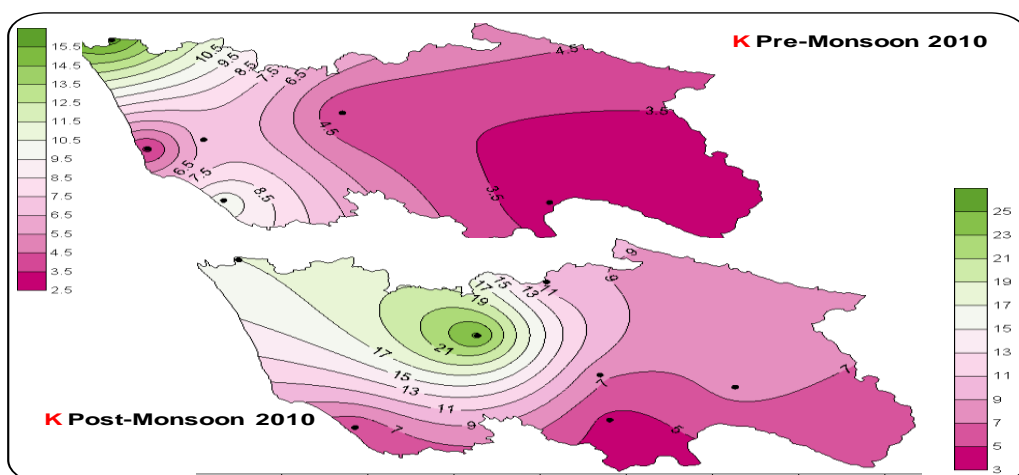


Figure 12p: Spatial variation of Potassium in Groundwater of Kollam district (Year:2010)

Iron

The maximum concentration of iron in the study area during pre-monsoon of 2010 was found to be 1.8 mg/l which is higher than the desirable ranges. In 2008, the concentration varied between 0.2 mg/l to 1.8 mg/l during pre-monsoon and 0.1 mg/l to 2.3 mg/l in the post-monsoon. In 2010, the concentration is much less and it varies from 0.025 mg/l to 0.145 mg/l in the pre-monsoon and 0.1 mg/l to 0.74 mg/l in the post-monsoon. The figures 12q and 12r shows the variation of iron in the district.

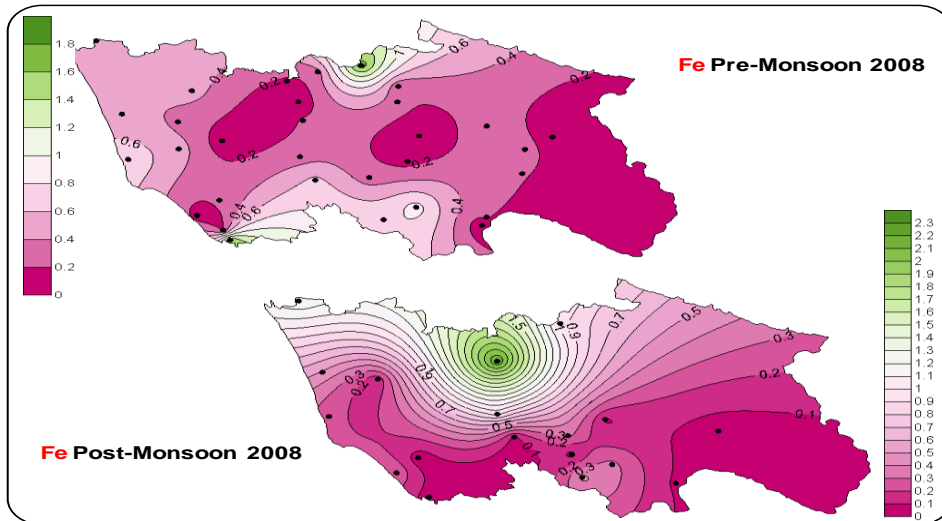


Figure 12q: Spatial variation of Iron in Groundwater of Kollam district (Year:2008)

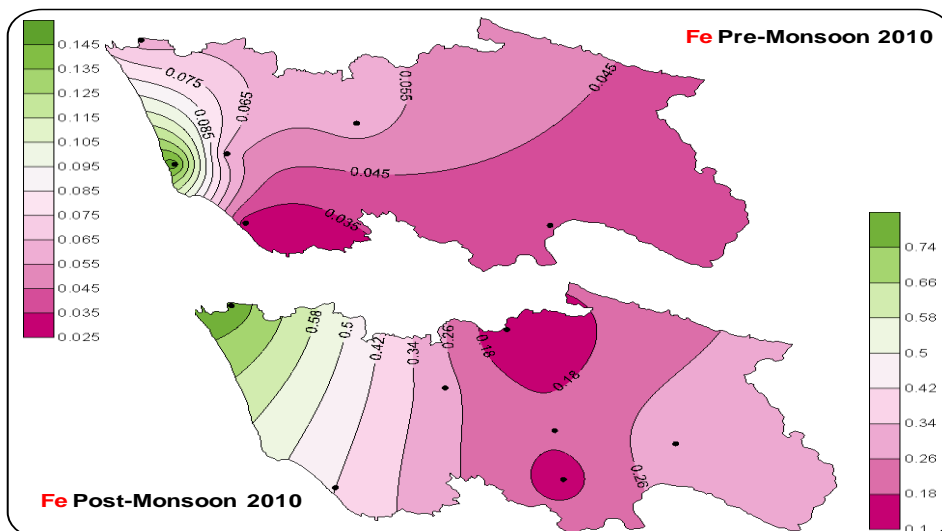


Figure 12r: Spatial variation of Iron in Groundwater of Kollam district (Year:2010)

Groundwater Classification

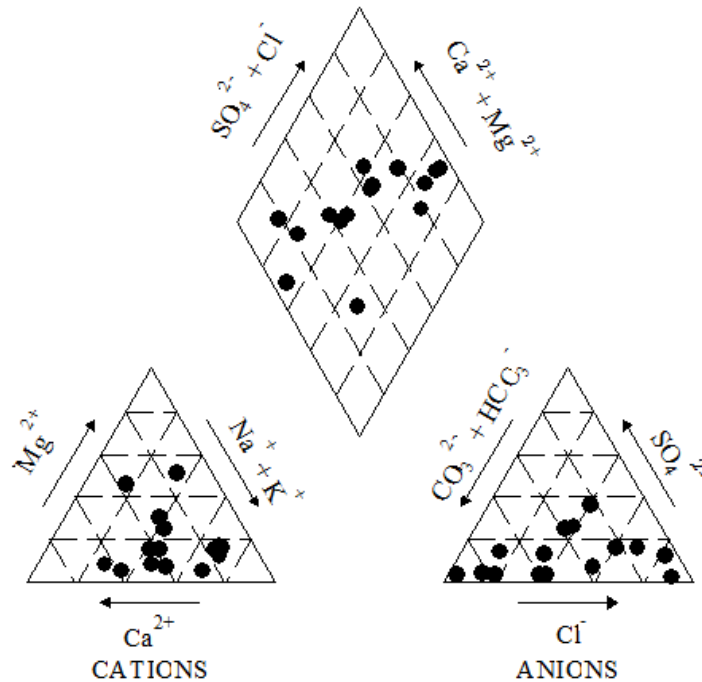


Figure 12s: Piper's diagram of Kollam District (pre-monsoon 2008)

The pre-monsoon samples of Kollam region 40% exhibit carbonate hardness exceeding 50% and 33.33% showed non-carbonate alkali exceeding 50%. 20% of the samples showed Strong acids exceed weak acids followed by 9% of neutral condition, i.e. no one cation-anion pair exceeds 50%.

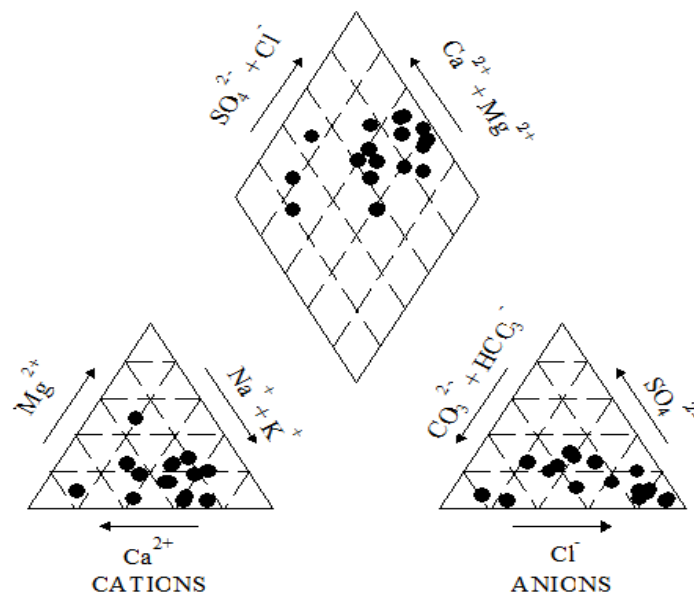


Figure 12t: Piper's diagram of Kollam District (post-monsoon 2008)

During the post-monsoon, 47% of the samples fall under area 4 indicating strong acids exceed weak acids. 35% showed the domination of alkalis and strong acids. This also indicates the presence of brines and ocean water in the region. The third category identified in this analysis is the presence of carbonate hardness exceeds 50%.

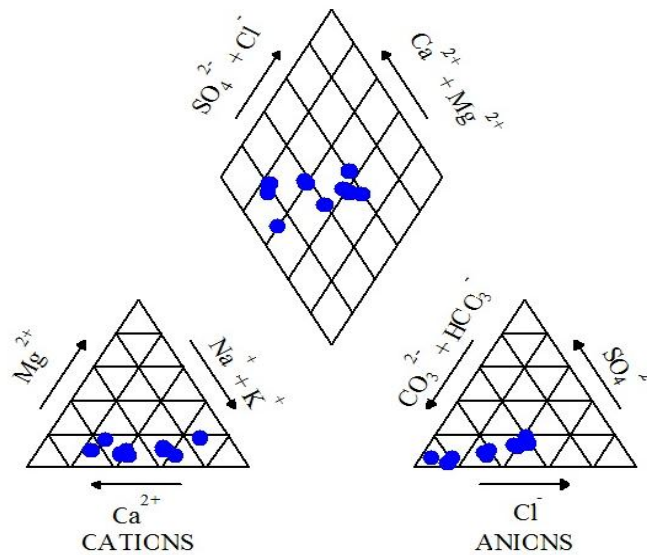


Figure 12u: Piper's diagram of Kollam District (pre-monsoon 2010)

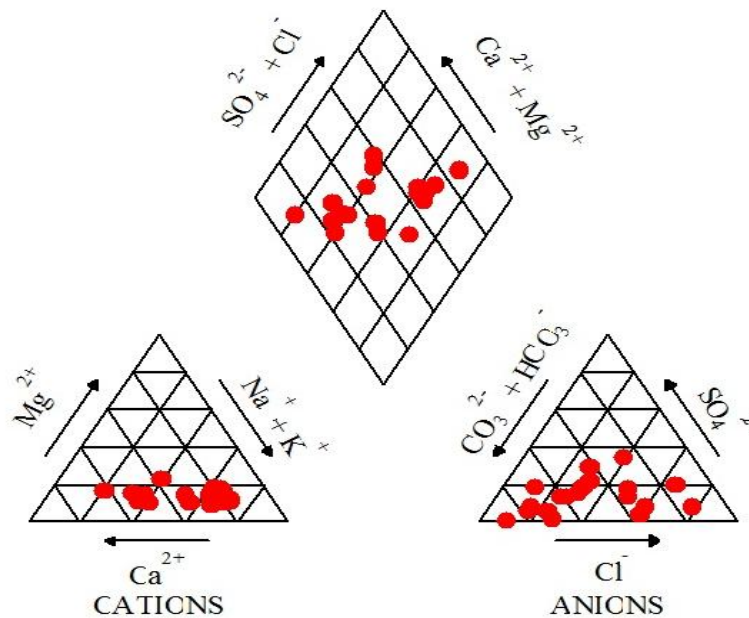


Figure 12v: Piper's diagram of Kollam District (post-monsoon 2010)

Figures 12w & 12x show that area 5 (40%) and area 7 (33.33%) are the most dominating ones in Kollam during Pre-monsoon season. Temporary hardness is very common in the district.

Another major category found is the presence of alkali metals which exceeds alkaline earth's and strong acidic anions exceed weak acidic anions. Such water normally create salinity problems both in irrigation and drinking uses. During the post-monsoon, it is observed that area 7 (47%) and 6 (355) were the dominating ones. The said observation showed that the water changed from temporary hardness during the post-monsoon season due to various chemical reactions. Further, water falls under Na- Cl type & Na- SO₄ type. This indicates the influence of coastal waters on the ground water.

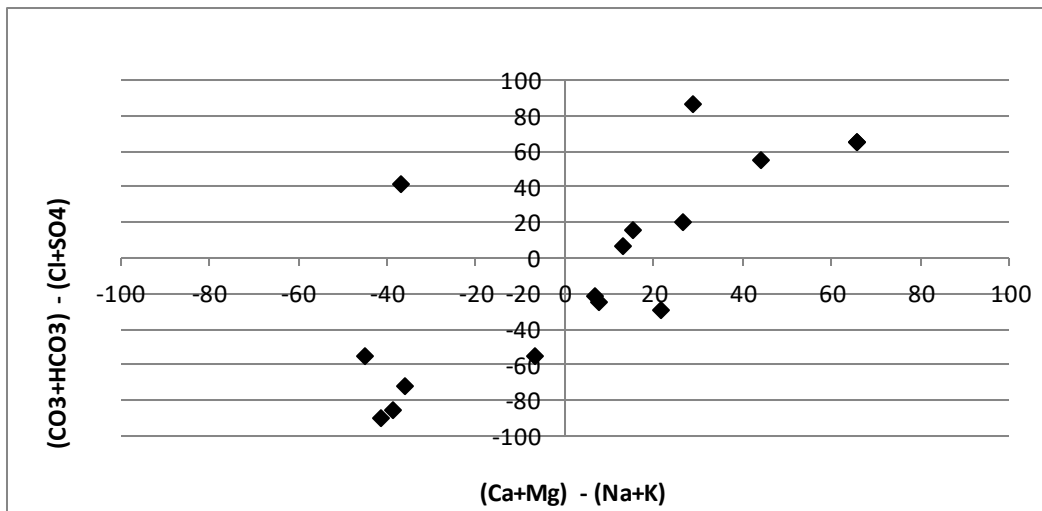


Figure 12w: Chadha's diagram of Kollam district (Pre-monsoon, 2006)

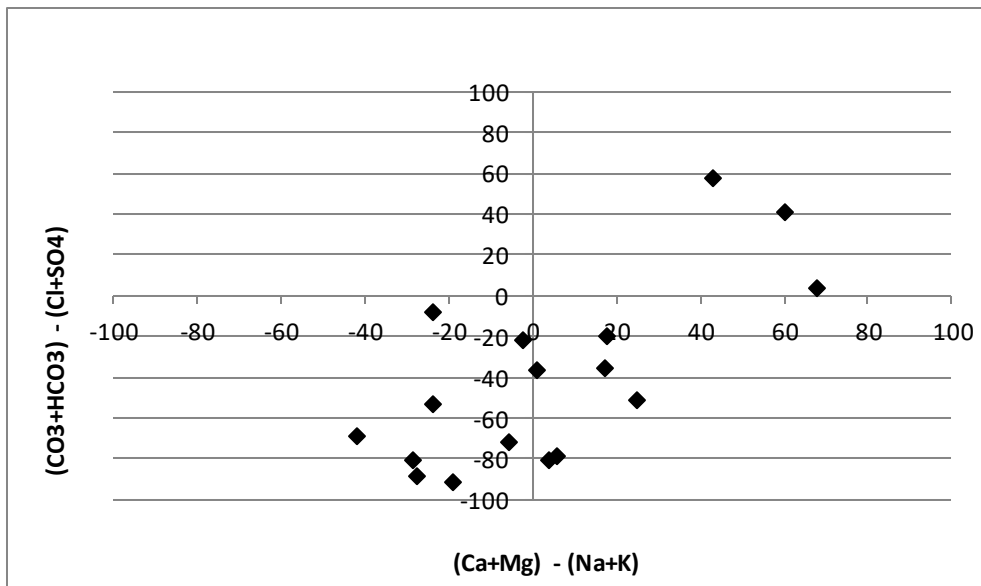


Figure 12x: Chadha's diagram of Kollam district (Post-monsoon, 2006)

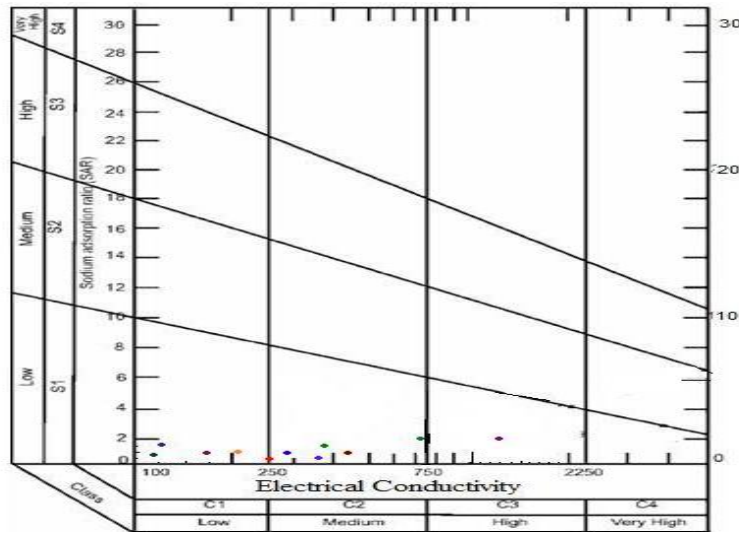


Figure 12y: USSL Classification of groundwater of Kollam District (pre-monsoon 2010)

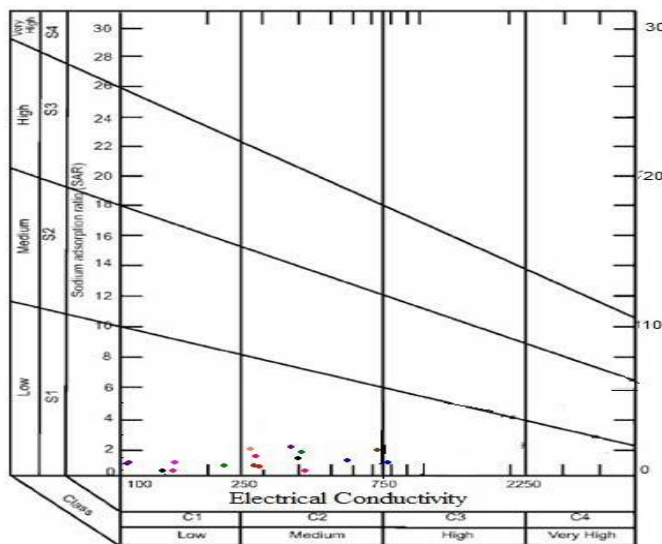


Figure 12y:USSL Classification of groundwater of Kollam District (post-monsoon 2010)

Statistical Analysis of Groundwater quality data of 2008

Table 12c:Correlation between various parameters during pre-monsoon 2008

Parameters	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	0.213	1				
TH	0.545	0.804	1			
Cl	0.024	0.878	0.554	1		
Na	0.092	0.532	0.311	0.545	1	
Fe	0.003	0.142	0.216	0.185	0.017	1

Table 12d:Correlation between various parameters during post-monsoon 2008

	pH	EC	TH	Cl	Na	Fe
pH	1					
EC	0.109	1				
TH	0.313	0.555	1			
Cl	-0.205	0.853	0.299	1		
Na	-0.131	0.862	0.327	0.909	1	
Fe	-0.048	-0.142	-0.076	-0.078	-0.133	1

13.0 GROUNDWATER QUALITY OF PATTANAMTHITTA DISTRICT

Groundwater samples were collected during the year 2008 and 2009 from 68 stations and were subjected to laboratory analyses. The water quality parameters were within desirable limits for most of the stations. However, pH was found to be less than 7 in many of the stations. Adur and Pandalam samples recorded a minimum value of 4.00. The pH value for Mallappalli was 4.10, 4.60 for Vallicode and 4.70 for Pathanamthitta. Kuttoor recorded a moderately high value of 325.50 mg/l for Total Hardness. Iron concentration showed high values at Enathimangalam (6.66 mg/l), Naranamoozhi (3.5 mg/l), Konni (3.28 mg/l) and Pathanamthitta (2.79 mg/l).

pH

In the year, 2010 only limited number of samples were collected based on field investigations and previous results. The pH values of the samples varied from 6.80 to 8.6 during pre-monsoon and 6.9 to 8.3 during post-monsoon in the year 2010. The quality shows a wide variation ranging between slightly acidic to highly alkaline in nature. Water is found to be suitable for drinking during all the seasons. Figure shows the variation of pH during the year 2010. Figure 13a shows the variation of pH during 2010.

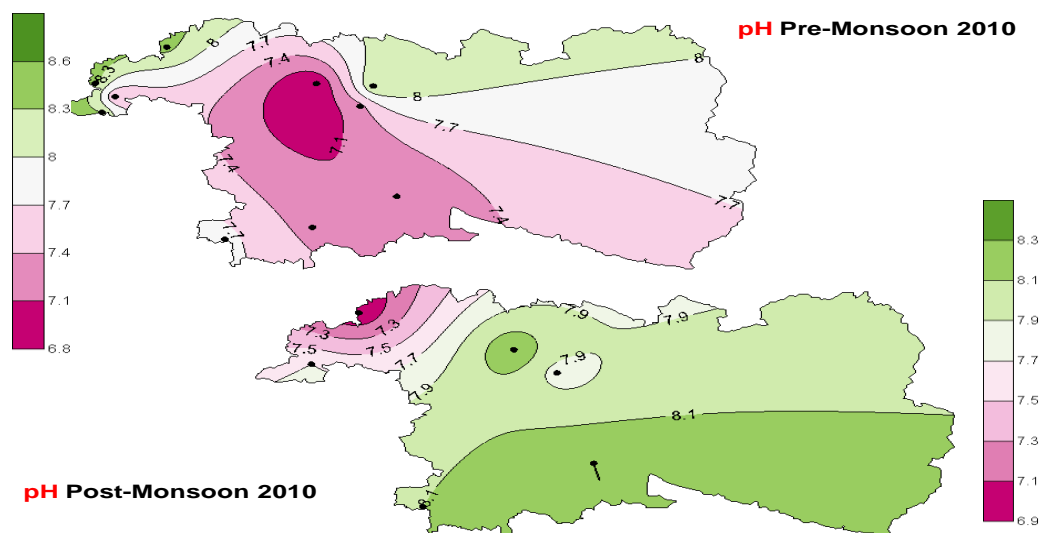


Figure 13a: Spatial distribution of pH in Pathanamthitta district during 2010

Electrical conductivity

Electrical conductivity of the samples varied from 60.0 micro-siemens/cm to 460 micro-siemens/cm during pre-monsoon, 70 micro-siemens/cm to 350 micro-siemens/cm during the post-monsoon of 2010. EC values are well within the desirable limits based on BIS. Figure 13b shows the variation of Electrical conductivity during 2010.

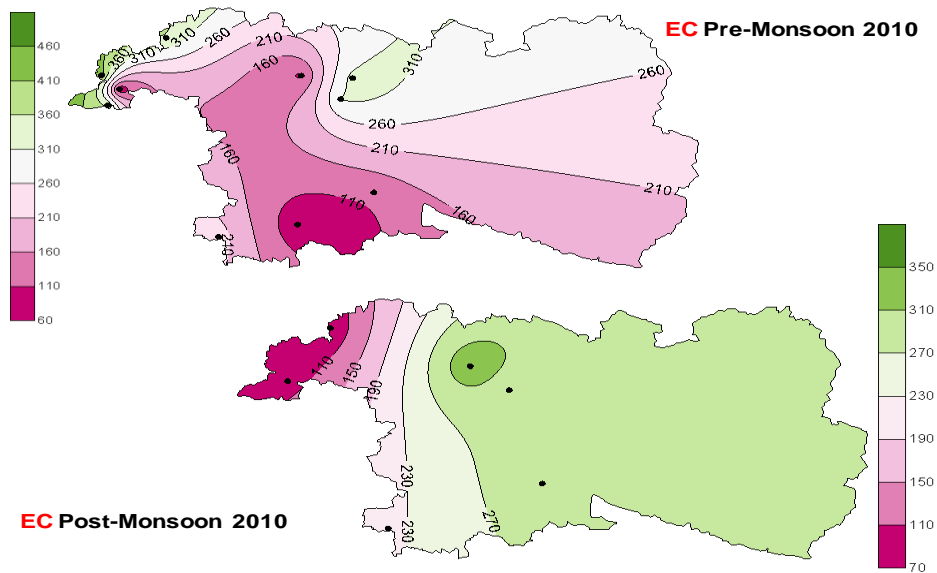


Figure 13b: Spatial distribution of EC in Pathanamthitta district during 2010

Total Dissolved Solids

When total dissolved solids in water is more than 500 mg/l, palatability decreases and may cause gastrointestinal irritation (Park and Park, 1998). The Total Dissolved Solids observed in the Pathanamthitta district varied between 40 mg/l and 250 mg/l during pre-monsoon 2010 and during post-monsoon varied from 40 mg/l to 190 mg/l during 2010. The seasonal variation of TDS in water samples is depicted in Figure 13c.

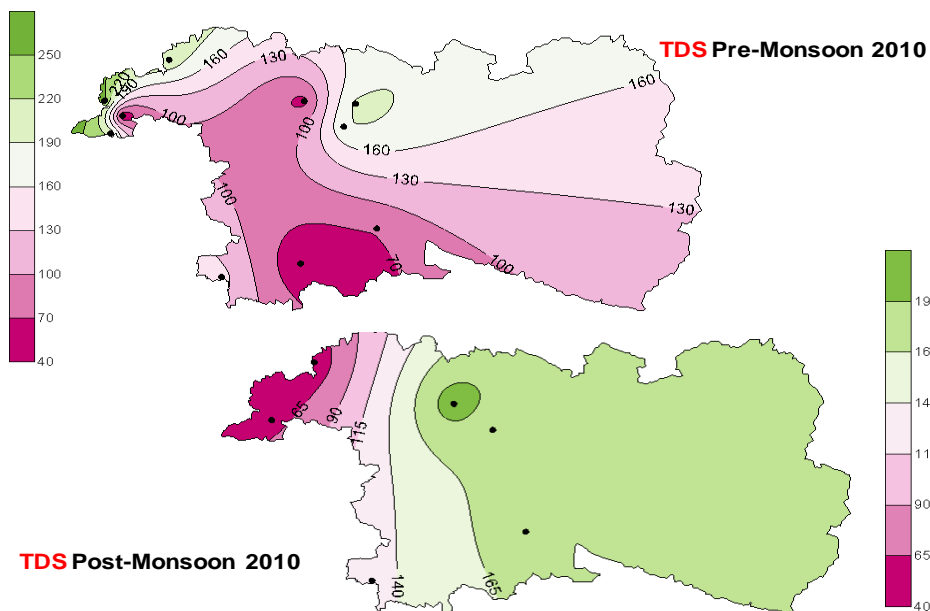


Figure 13c: Spatial distribution of TDS in Pathanamthitta district during 2010

Total Alkalinity

In the study area, it is found that carbonates are absent in almost all selected locations. Therefore, the total alkalinity is represented by bicarbonates. The bicarbonates vary between 15 mg/l to slightly more than 165 mg/l during the pre-monsoon of 2010. In the post-monsoon, it showed a decline and varied from 5 mg/l to 125 mg/l. The total alkalinity of the water samples were found to be within the permissible limit for all the samples as per BIS (1991). The seasonal variation of bicarbonates is shown in figure 13d.

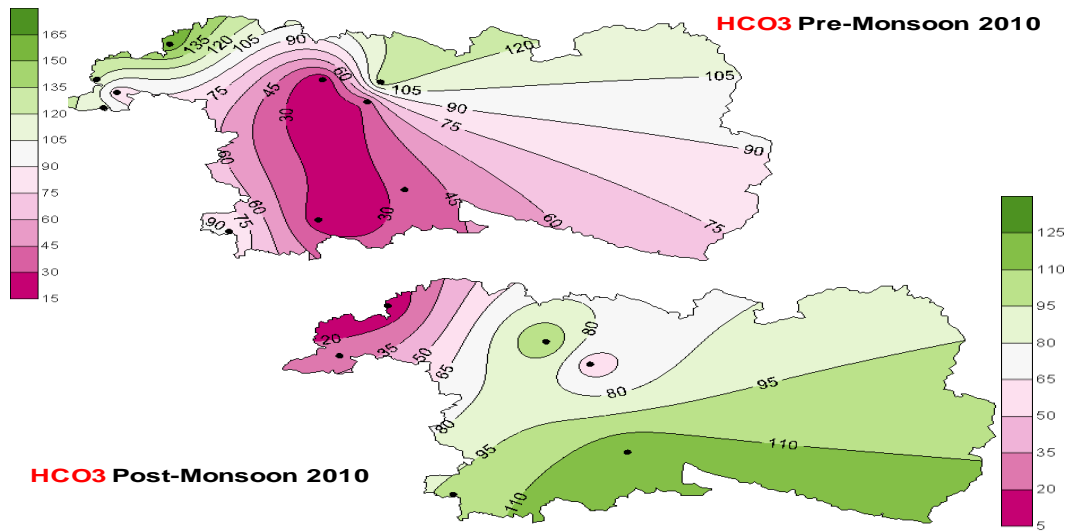


Figure 13d: Spatial distribution of Bicarbonates in Pathanamthitta district during 2010

Chlorides

In majority of the locations, the maximum chloride content in the water samples varied from 6 mg/l to 42 mg/l during 2010 pre-monsoon and during post-monsoon 13.5 mg/l to 23.5 mg/l. Therefore the chloride content is well within the desirable ranges. Figure 13e shows the variation of chlorides during 2010.

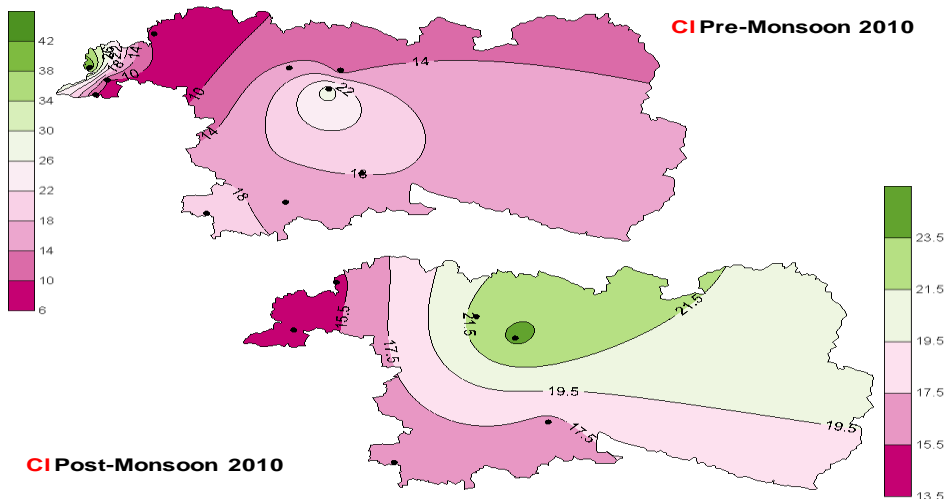


Figure 13e: Spatial distribution of Chlorides in Pathanamthitta district 2010

Sulphates

The sulphate concentration ranged from 1.0 mg/l to 19 mg/l during pre-monsoon and in the post-monsoon, the concentration varied between 2 mg/l to 11.6 mg/l. The comparatively higher rainfall occurred in the year 2010 may be the reason for reduction in sulphate concentration. Figure 13f shows the variation of sulphates during 2010.

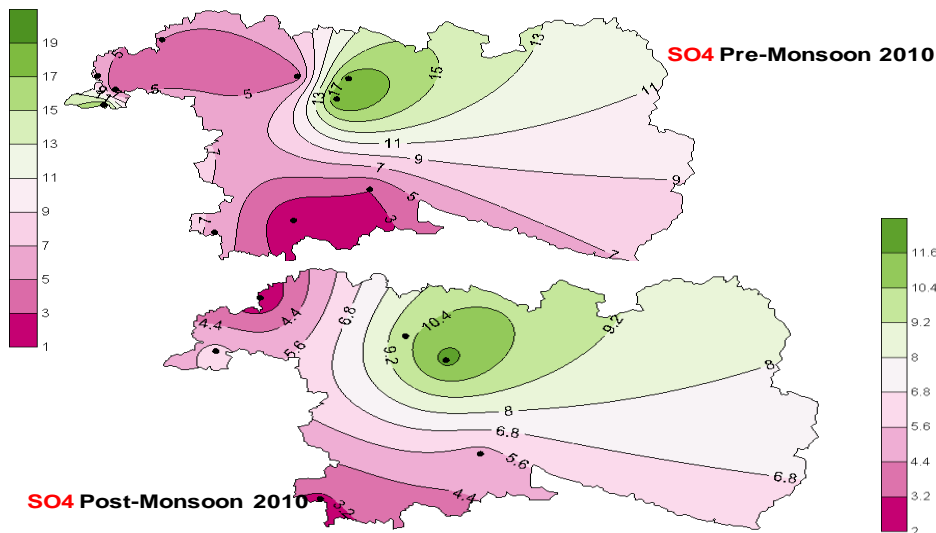


Figure 13f: Variation of Sulphates in Pathanamthitta district during pre and post monsoon of 2010

Nitrates

Analysis carried out during the study period shown that the Nitrate concentration varies from 0.9 mg/l to 13.5 mg/l and in the post monsoon it showed a slight decline varying from increase to m 1.1 mg/l to 11 mg/l. Therefore, the agriculture as well as plantation activities bring more nitrate concentration in the central part of the district in comparison to other parts. This necessitates the monitoring of wells which is quite necessary in these areas. Figure 13g shows the variation of nitrates during 2010.

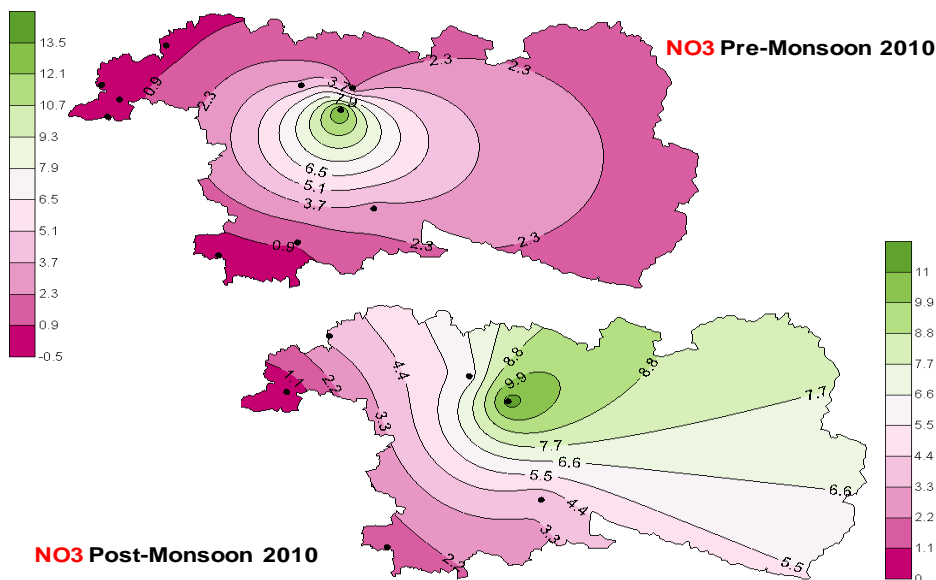


Figure 13g: Spatial distribution of Nitrates in Pathanamthitta district during 2010

Total Hardness

Analysis of ground water samples were carried out during 2008 to 2010. Total hardness of the water samples varied from 15 mg/l to 135 mg/l during pre-monsoon and 15 mg/l to 120 mg/l during post-monsoon. This clearly indicates that the water is free from hardness and well suited for all purposes. Figure 13h shows the variation of nitrates during 2010.

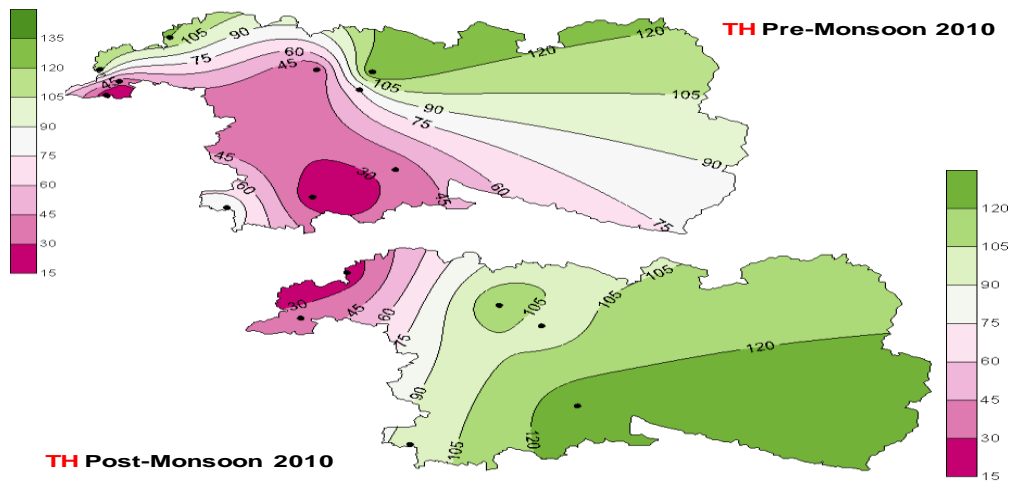


Figure 13h: Spatial distribution of TH in Pathanamthitta district during 2010

Calcium and Magnesium

The distribution of calcium and magnesium is shown in the figure below (figures 13i & 13j). It is observed that both calcium and magnesium concentrations are much below the permissible limit. The concentration of calcium varies between 5 mg/l and 75 mg/l during pre-monsoon and in the post monsoon it varies from 2 mg/l to 34 mg/l. There is a considerable decline in calcium concentration from pre-monsoon to post-monsoon season. The magnesium concentration varies from 0.5 mg/l to 12.5 mg/l during both pre-monsoon and post-monsoon seasons. This clearly indicates that the source of magnesium could be due to source rocks whereas calcium may be from rocks as well as through runoff waters.

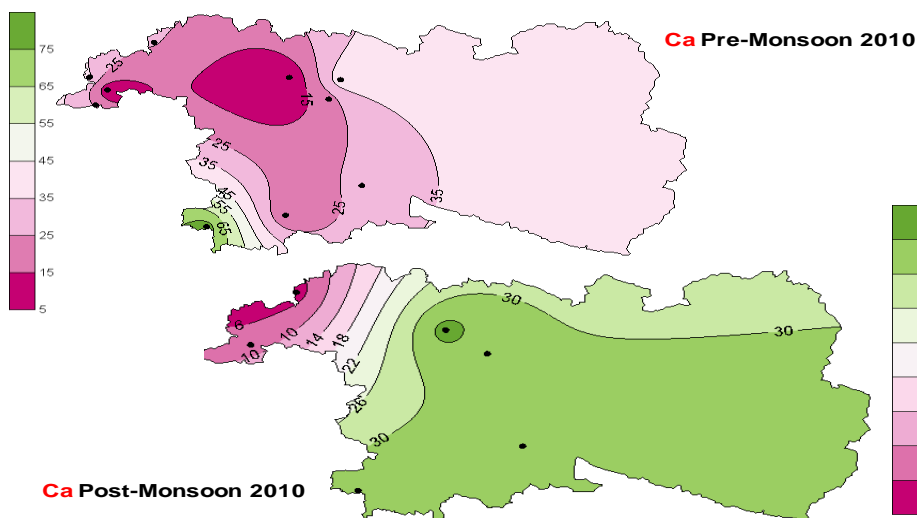


Figure 13i: Spatial distribution of Ca in Pathanamthitta district during 2010

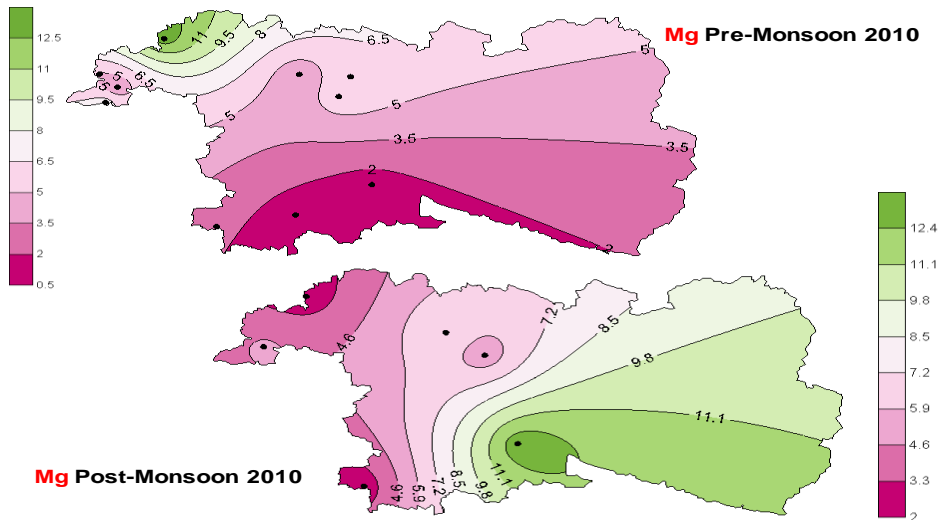


Figure 13j: Variation of Mg in Pathanamthitta district during Pre and post monsoon of 2010

Sodium and Potassium

Analysis of sodium concentration in the ground water samples from 2008 to 2010, shows that there is no significant change in the content during the study period. The observed concentration is below the permissible ranges. Similar observation was found in the case of potassium. The concentration of sodium varies between 5.0 mg/l to 40 mg/l, during pre-monsoon and 6 mg/l to 21 mg/l during post-monsoon of 2010. The potassium concentration varied from 0.5 mg/l to 10.4 mg/l during the pre-monsoon of and 1 mg/l to 2 mg/l during post-monsoon 2010. The seasonal variation of sodium and potassium concentration is represented in figures 13k and 13l.

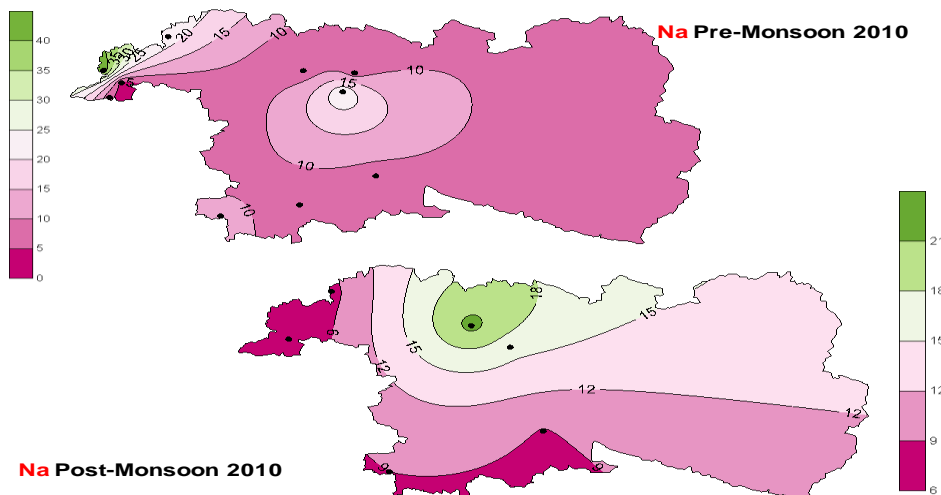


Figure 13k: Spatial distribution of Na in Pathanamthitta district during 2010

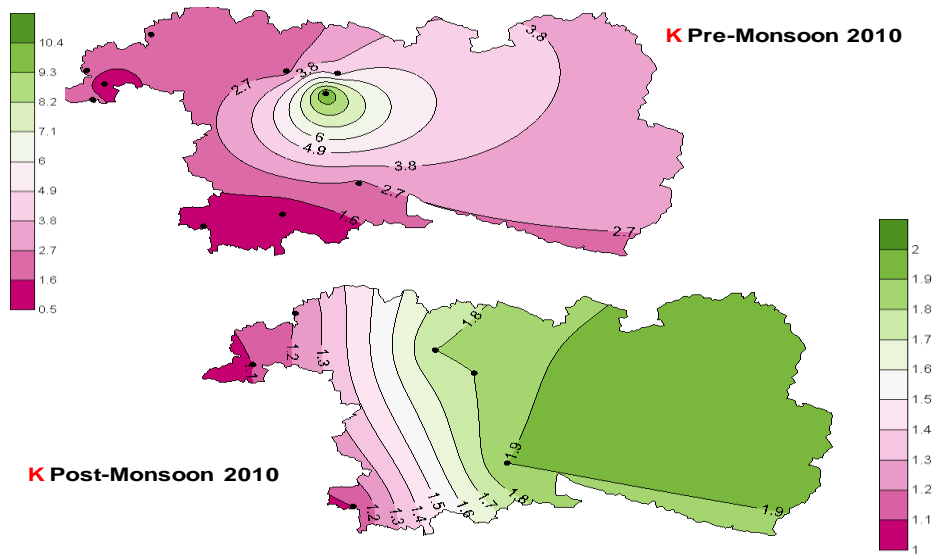


Figure 13l: Spatial distribution of K in Pathanamthitta district during 2010

Iron

The concentration of iron in 2010, varies from 0.05 mg/l to 1.03 mg/l in the pre-monsoon and 0.012 mg/l to 0.024 mg/l in the post-monsoon. During pre-monsoon the concentration of iron is higher than the permissible limits where as in the post-monsoon it is much below the desirable ranges. Therefore, it is evident that the higher concentration of iron could be due to in-situ exposures of iron rich rocks. The figure 13m shows the variation of iron in the district.

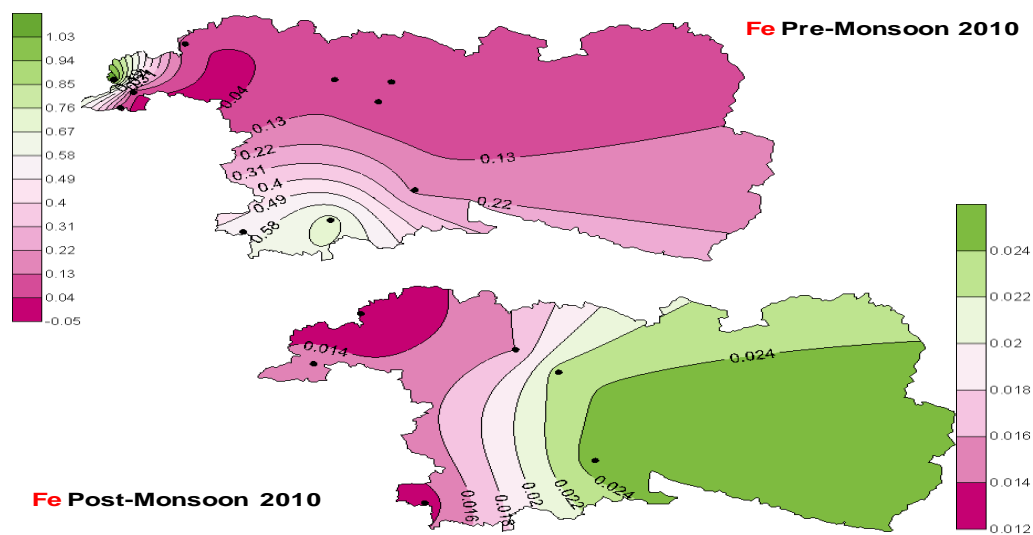


Figure 13m: Spatial distribution of Iron in Pathanamthitta district during 2010

Groundwater Classification

Groundwater classification is shown with the help of Piper's diagram (figures 13n and 13o). Irrigation suitability is also presented in figures 13p and 13q.

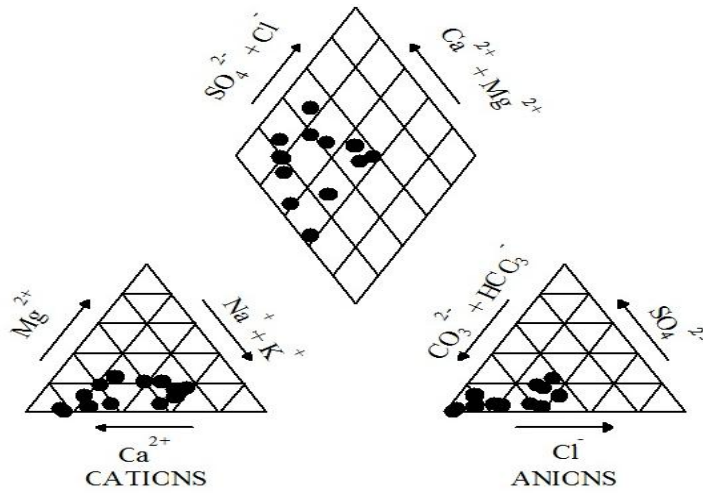


Figure 13n: Piper's diagram of pathananlthitta District Pre-monsoon 2010)

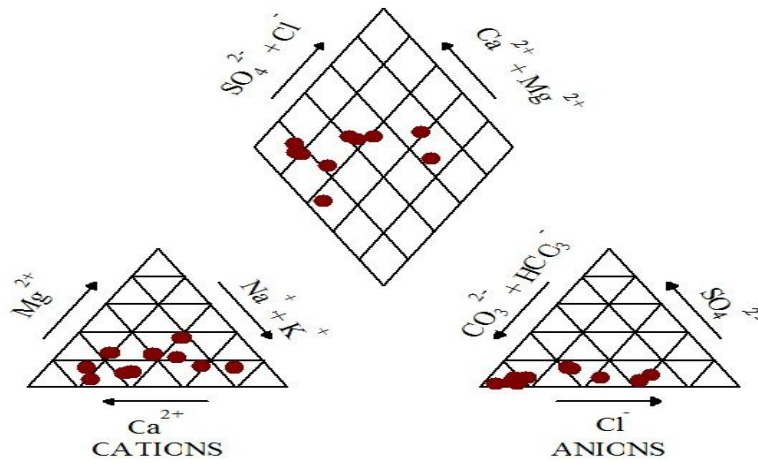


Figure 13o: Piper's diagram of pathananlthitta District (Post-monsoon 2010)

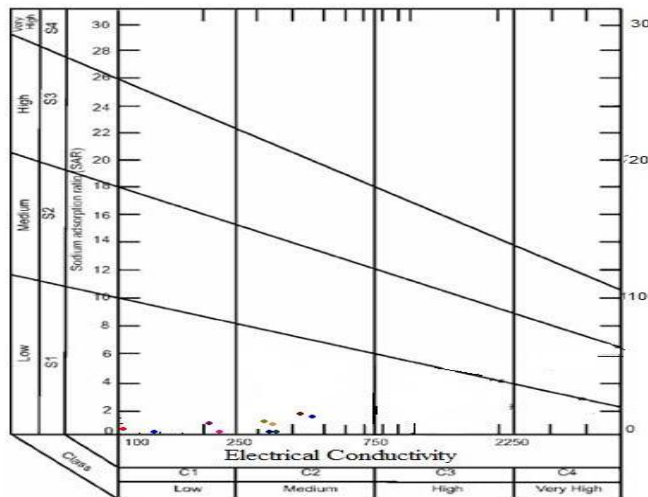


Figure 13p: USSL Classification of Groundwater(Pre-monsoon 2010)

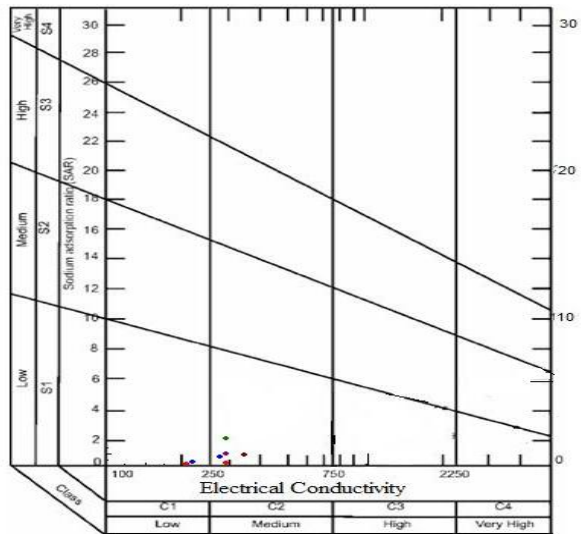


Figure 13c: USSL Classification of Groundwater (Post-monsoon 2010)

14. GROUNDWATER QUALITY OF THIRUVANANTHAPURAM DISTRICT

pH

The pH values of the samples collected from Thruvananthapuram district, varied from 3.80 to 8.6 during pre-monsoon and 4 to 8 during post-monsoon in the year 2008. Water was found to be acidic to neutral in the eastern and northern part of the district. Monitoring was continued during 2010. The results indicate that there is a considerable improvement in the pH which varied between 6.1 and 7.9 in the pre-monsoon and 5.5 to 8.3 during post-monsoon. The alkaline water was observed in an isolated case which could be due to local geology and climatic conditions. The acidic nature of the water can be attributed to carbon dioxide that is incorporated into the ground water by bacterial oxidation (Mathews and Pekdeger, 1981). The seasonal variation of pH in waters during 2008 and 2010 are given in figures 14a and 14b.

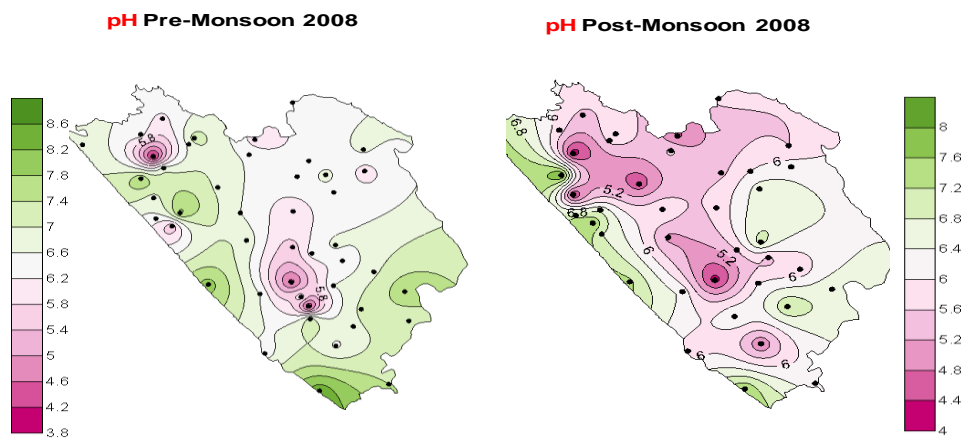


Figure 14a: Spatial distribution of pH during 2008

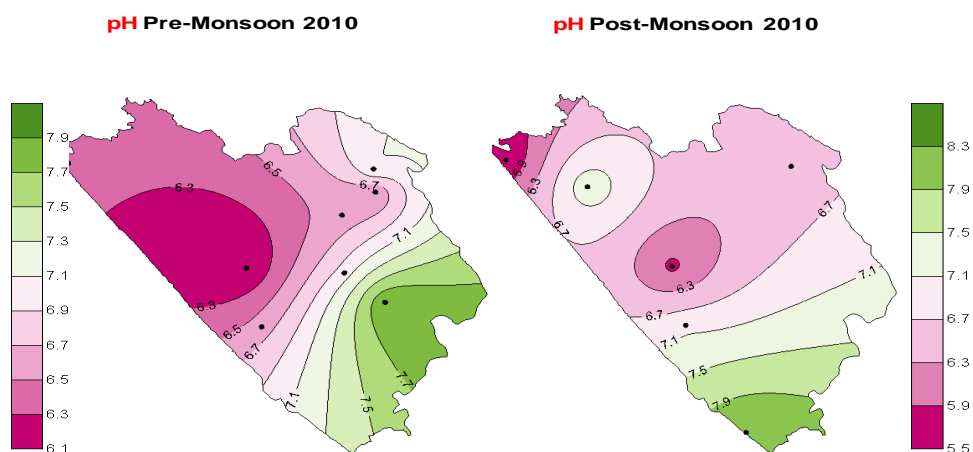


Figure 14b: Spatial distribution of pH during 2010

Electrical conductivity

Electrical conductivity of the samples varied from less than 200 micro-siemens/cm to 3800 micro-siemens/cm during pre-monsoon, and less than 400 microsiemen/cm to 3600 microsiemen/cm during the post-monsoon of 2008. In 2010, EC value showed a drastic reduction, reducing it to 280 microsiemen/cm during pre-monsoon and 1800 microsiemen/cm during post-monsoon. This kind of sudden change in the electrical conductivity could be due to the higher recharge occurred during the previous year. In the post-monsoon, due to the mixing of runoff water due to poor well maintenance could be one of the reasons for such a change. Figures 14c and 14d represents the spatial variation of Electrical conductivity in Thiruvananthapuram district.

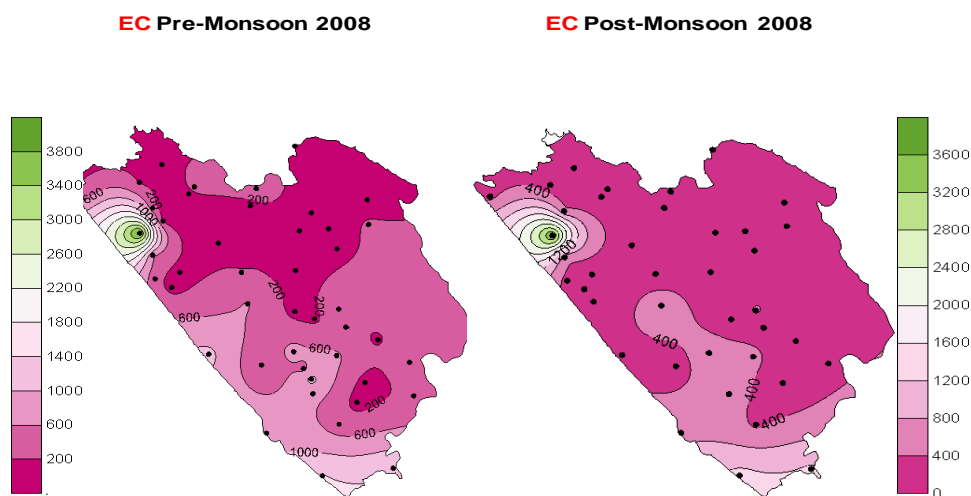


Figure 14c: Spatial Distribution of Electrical conductivity during 2010

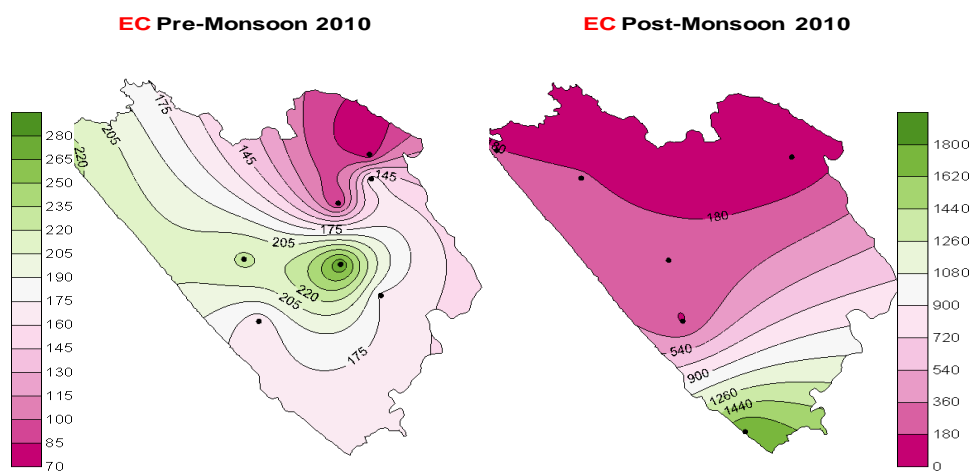


Figure 14d: Spatial Distribution of Total hardness during 2010

Total Dissolved Solids

Drinking water quality is affected by the presence of soluble salts. Total dissolved solid is an indication of the general water quality conditions of the water. When total dissolved solids in water is more than 500 mg/l, palatability decreases and may cause gastrointestinal irritation. Total Dissolved Solids varies between 40 mg/l and 170 mg/l during pre-monsoon and from

less than 100 mg/l to 1100 mg/l during post-monsoon. The seasonal variation of TDS in groundwater samples of Thruvananthapuram district is depicted in figure 14e.

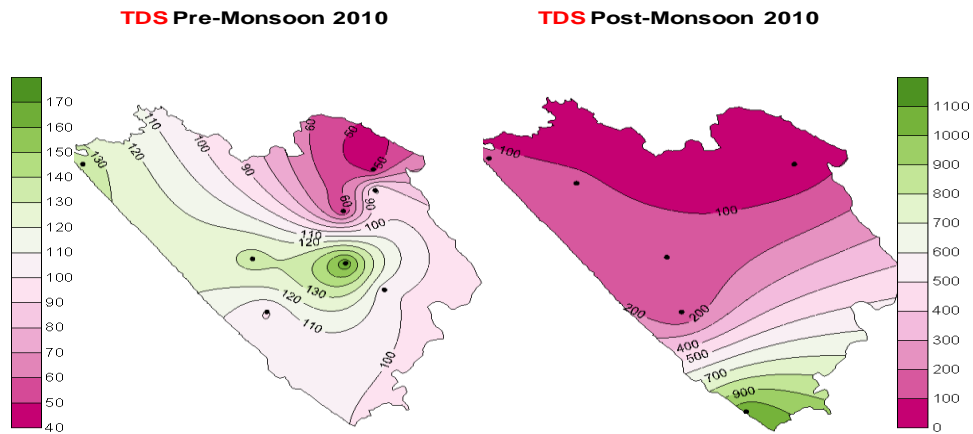


Figure 14e: Spatial Distribution of TDS during 2010

Chlorides

The maximum chloride content in the water samples varied from 10 mg/l to 520 mg/l during 2008 pre-monsoon, 20 mg/l to 650 mg/l during post-monsoon 2008. Further observation taken during 2010 showed a decline in chloride concentration varying between 6mg/l to 66mg/l in the pre-monsoon and less than 20mg/l to 420mg/l in the post-monsoon. The higher chloride concentration in the post-monsoon could be due to the mixing of waste waters with the groundwaters of shallow aquifers. Figures

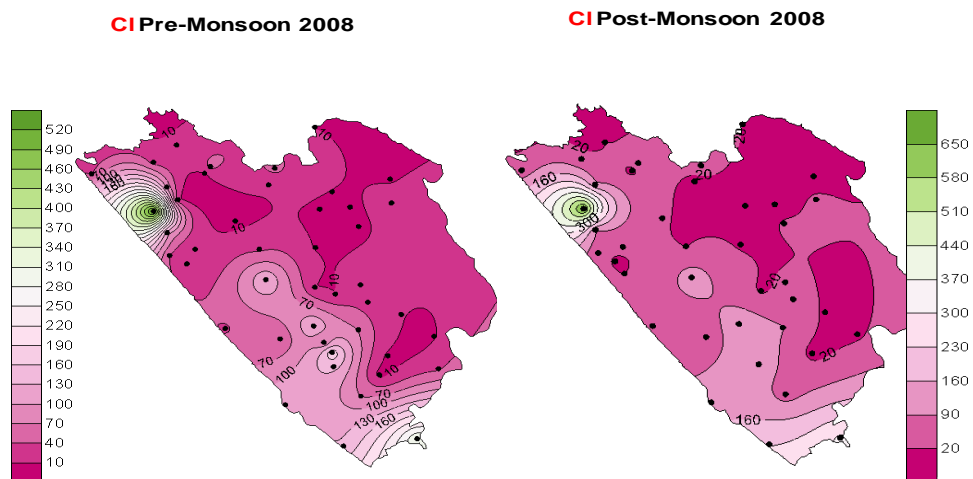


Figure 14f: Spatial distribution of Chlorides during 2008

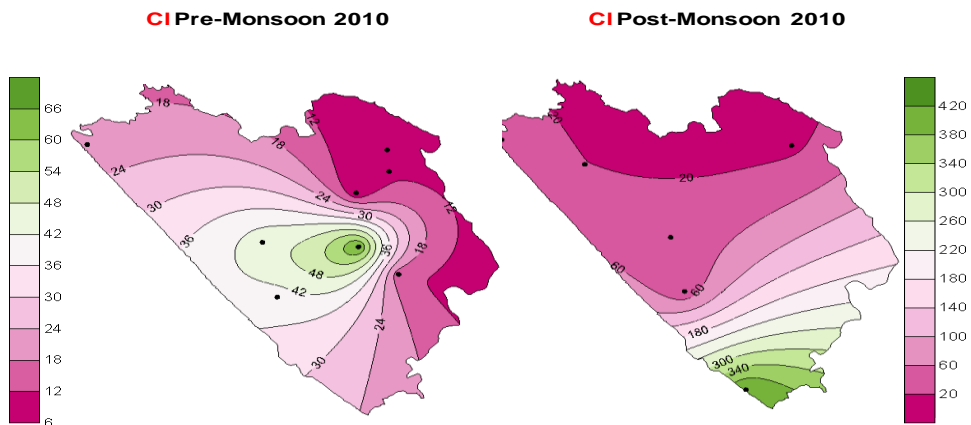


Figure 14g: Spatial Distribution of Chlorides during 2010

Total Alkalinity

In the study area, in the year 2010, Total Alkalinity, varied from 10 mg/l to 82 mg/l and from less than 20 mg/l to 260 mg/l during post-monsoon. The bicarbonate concentration varies between 10 mg/l to 73 mg/l during pre-monsoon and from less than 15 mg/l to 225 mg/l in the post-monsoon seasons of 2010. Figures 14h & 14i shows the distribution of total alkalinity and bicarbonates in the study area.

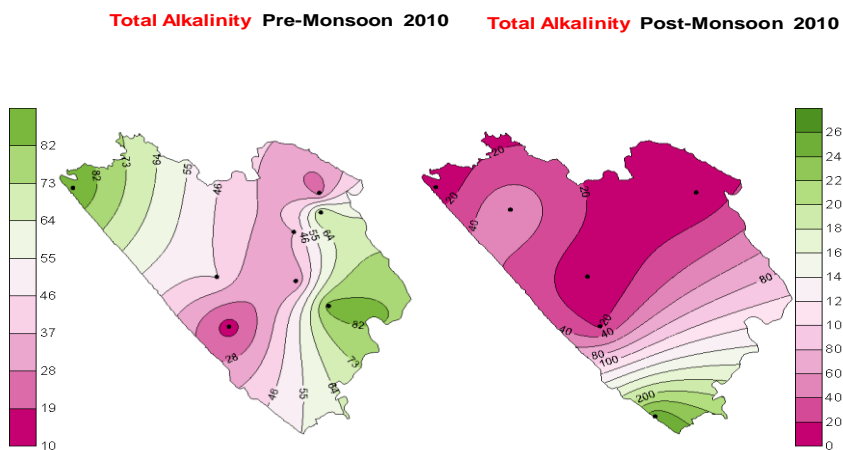


Figure 14h: Spatial Distribution of Total Alkalinity during 2010

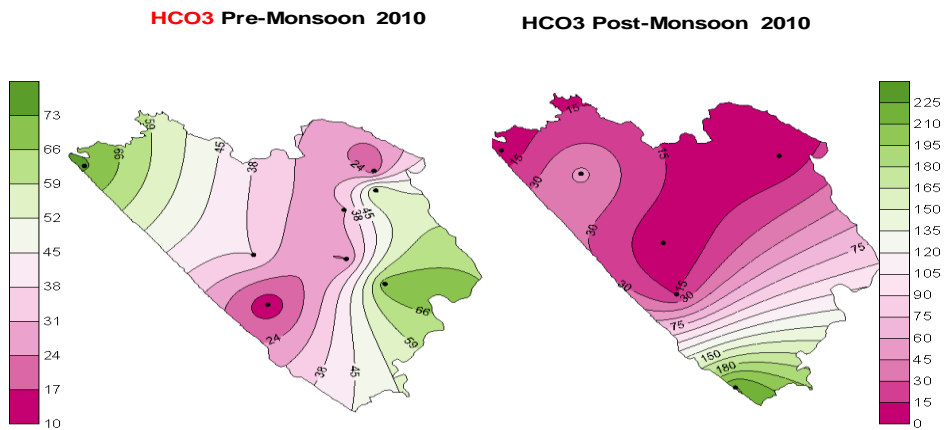


Figure 14i: Spatial distribution of bicarbonates during 2010

Sulphates

The sulphate concentration ranged from 2.0 mg/l to 16 mg/l during pre-monsoon and from less than 3 mg/l to 53 mg/l in the post-monsoon during 2010. It is noticed that the concentration of sulphate was much lesser than the prescribed desirable ranges. Figure 14j shows the spatial distribution of sulphates in the district.

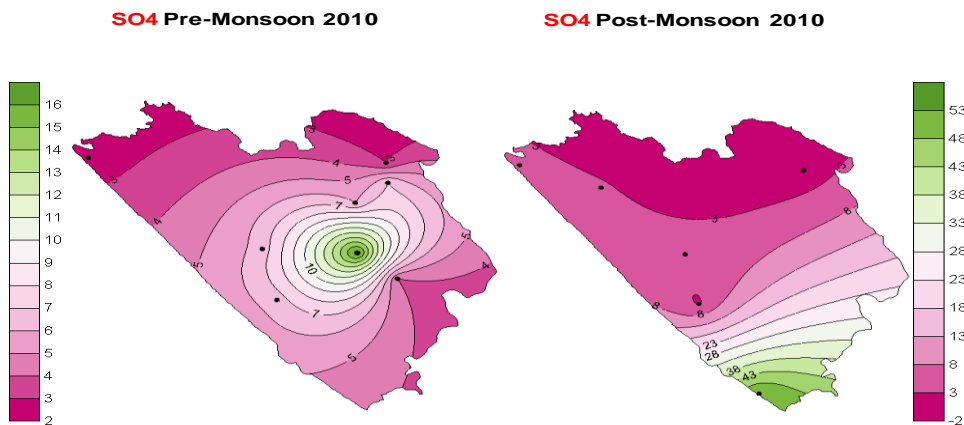


Figure 14j: Spatial Distribution of Total hardness during 2009

Nitrates

The seasonal distribution of Nitrates in the study area seems to be quite negligible. The highest value observed was only 3.6 mg/l during pre-monsoon and 6.6 mg/l in the post-monsoon. Nitrates are the indicators of groundwater pollution in most of the cases, however, the concentration of nitrate is much lower than the prescribed limit of 45 mg/l.

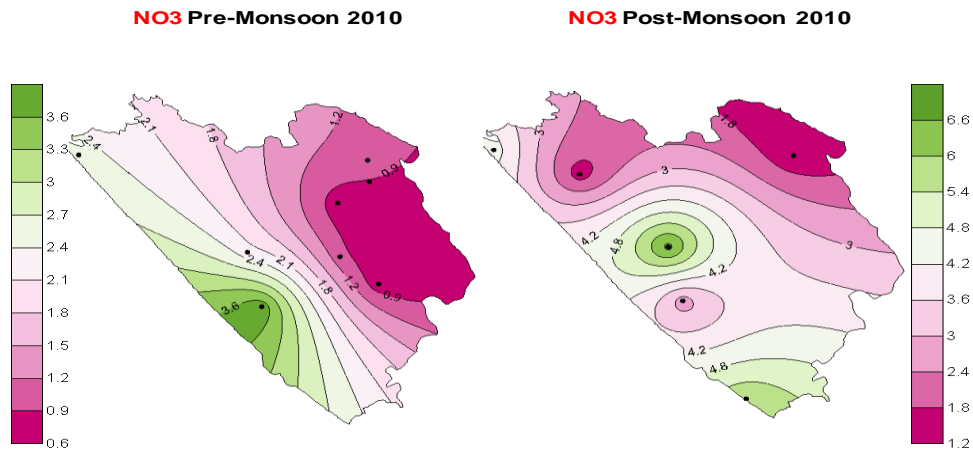


Figure 14k: Spatial Distribution of Total hardness during 2009

Total Hardness

Total hardness of the water samples varied from less than 50 mg/l to 750 mg/l during pre-monsoon and a maximum of 650 mg/l was noticed in the post-monsoon 2008. In the year 2010, Total hardness showed a significant decrease during pre-monsoon 69 mg/l) and it reduced to 330 mg/l in the post-monsoon of 2010. The seasonal variation of total hardness is represented in figures 14l and 14m. Total hardness showed a very high positive correlation with magnesium suggesting a magnesium contributed hardness.

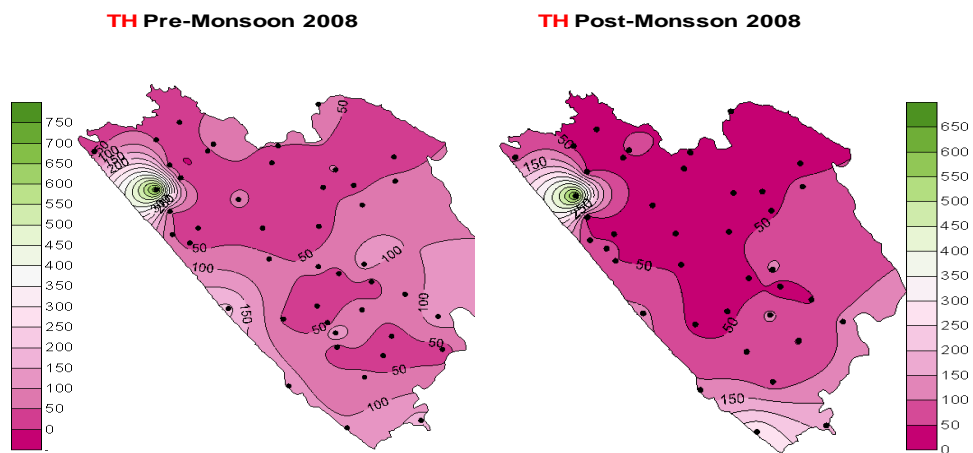


Figure 14l: Spatial Distribution of Total hardness during 2008

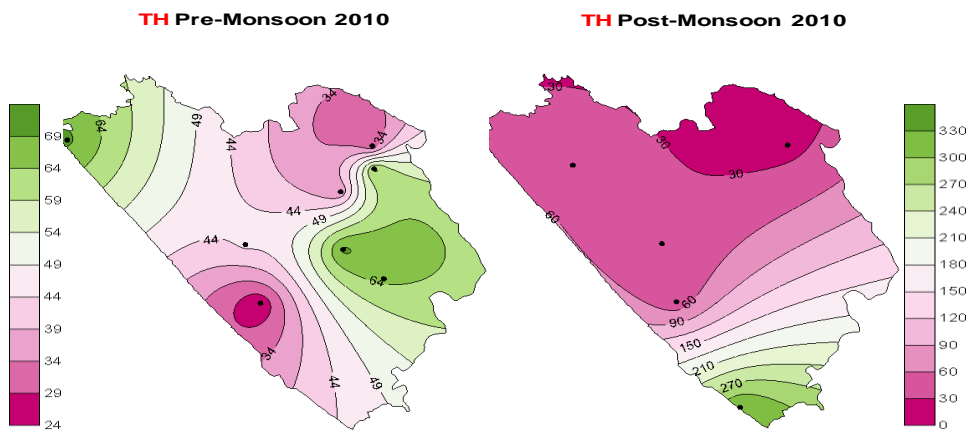


Figure 14m: Spatial Distribution of Total hardness during 2010

Calcium and Magnesium

The distribution of calcium and magnesium in the year 2010, is shown in the figure below (figures 14n & 14o). It is observed that both calcium and magnesium concentrations are much below the permissible limit. The concentration of calcium varies between 4 mg/l and 24 mg/l during pre-monsoon and in the post monsoon it varies from less than 3 mg/l to 90 mg/l. It is also noticed that the proportion of magnesium concentration is relatively higher than the normally expected.

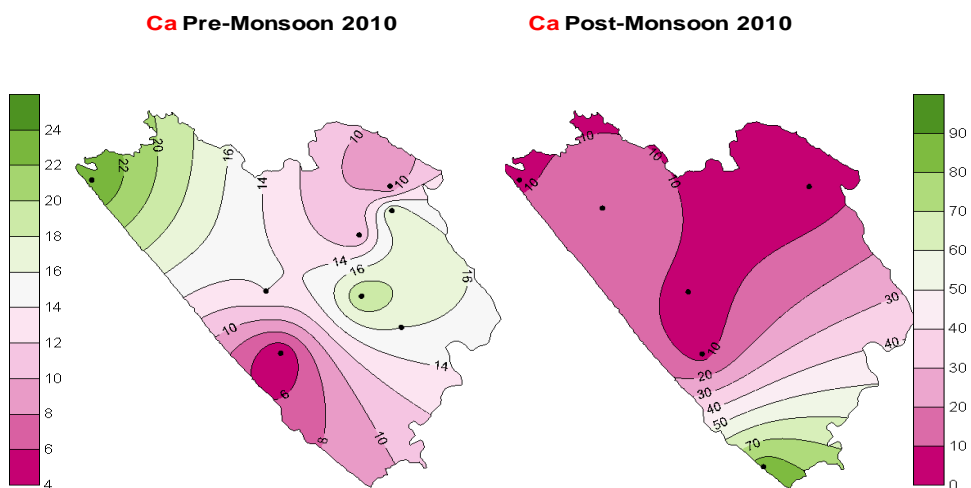


Figure 14n: Spatial Distribution of calcium during 2010

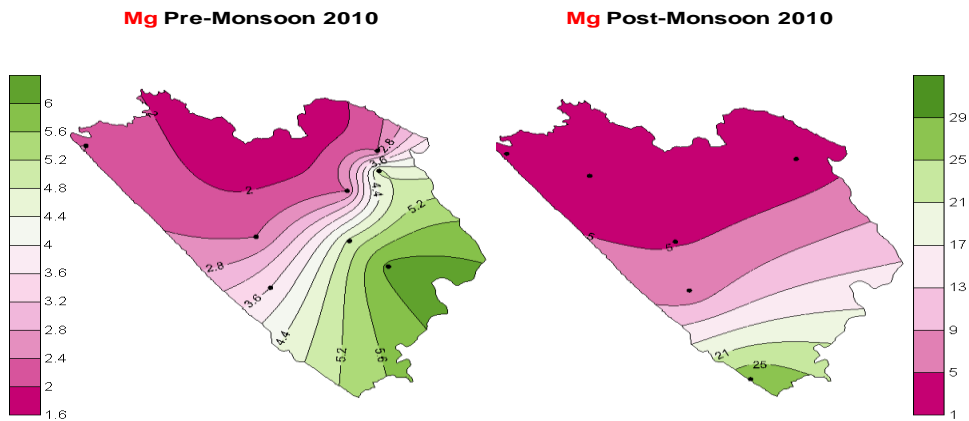


Figure 14o: Spatial Distribution of Magnesium during 2010

Sodium and Potassium

Analysis of sodium concentration in the ground water samples from 2008 to 2010, shows that there is a significant change in sodium content from 2008 to 2010. The observed concentration varies from less than 20 mg/l to 380 mg/l during pre-monsoon and 520 mg/l in the post-monsoon of 2008. However, in the year 2010, it ranges between 1 mg/l to 28 mg/l and 10 mg/l to 230 mg/l during post-monsoon. The potassium concentration varied from 0.2 mg/l to 5.7 mg/l during the pre-monsoon of and 1.5 mg/l to 10.5 mg/l during post-monsoon 2010. The seasonal variation of sodium and potassium concentration is represented in figures 14p, 14q and 14r.

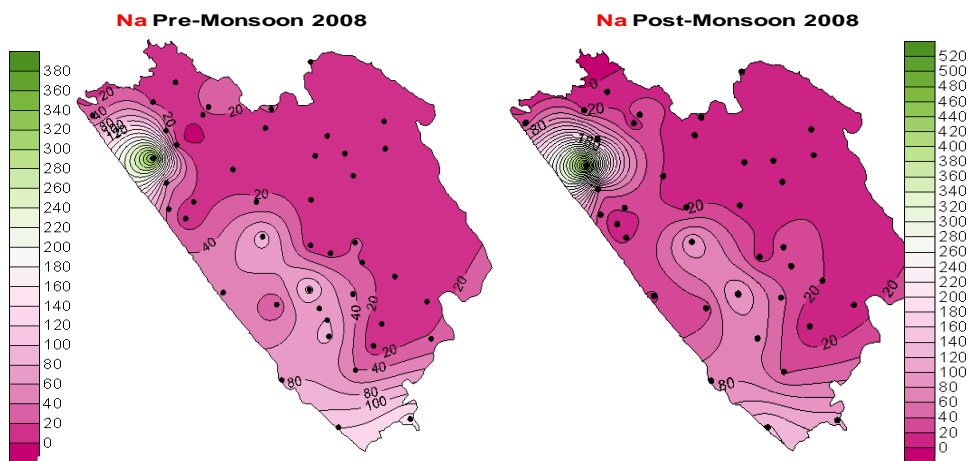


Figure 14p: Spatial Distribution of Total hardness during 2008

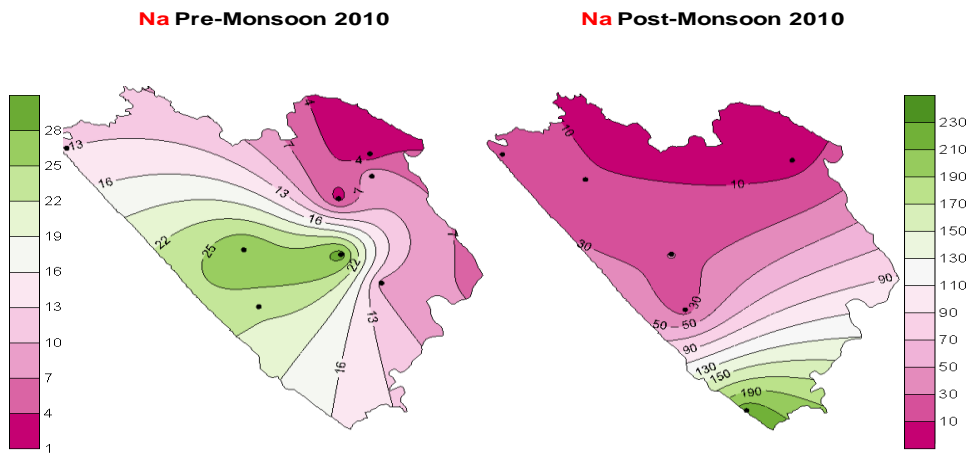


Figure 14q: Spatial Distribution of Sodium during 2010

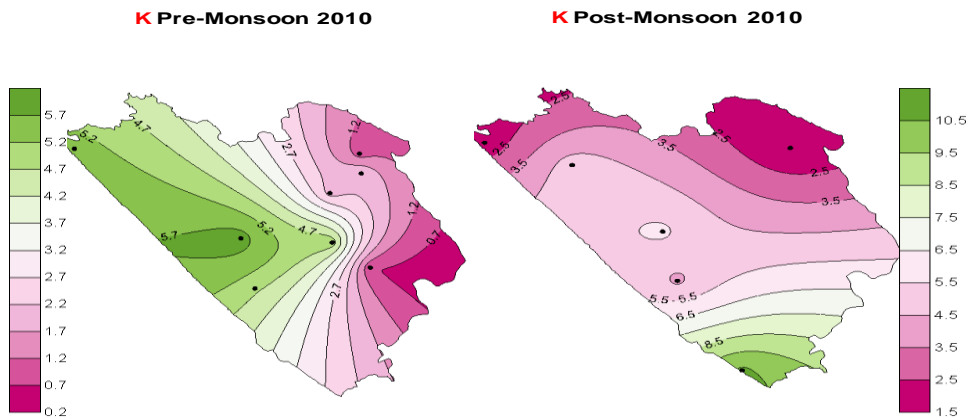


Figure 14r: Spatial Distribution of Total hardness during 2010

Iron

The concentration of iron in 2008, varies from 0.01 mg/l to 11 mg/l in the pre-monsoon and 0.05 mg/l to 8.5 mg/l in the post-monsoon. It is found that both during pre-monsoon and post-monsoon concentration was higher than the permissible limits. Therefore, it is evident that the higher concentration of iron could be due to in-situ exposures of iron rich rocks. The figure 14s shows the variation of iron in the district.

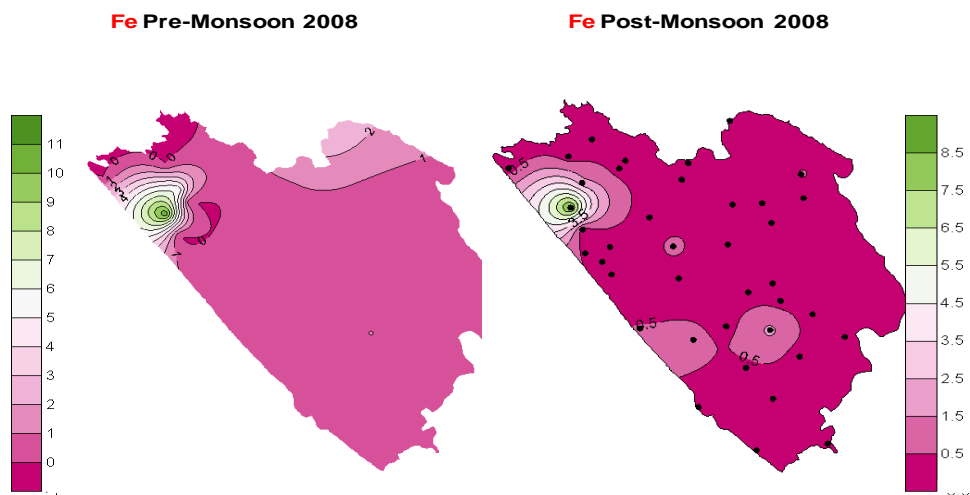


Figure 14s: Spatial Distribution of Iron during 2008

Groundwater Classification

Classification of groundwater of Thiruvananthapuram district is shown in figures 14t and 14u. Irrigation suitability of groundwater is shown in figures 14v and 14w.

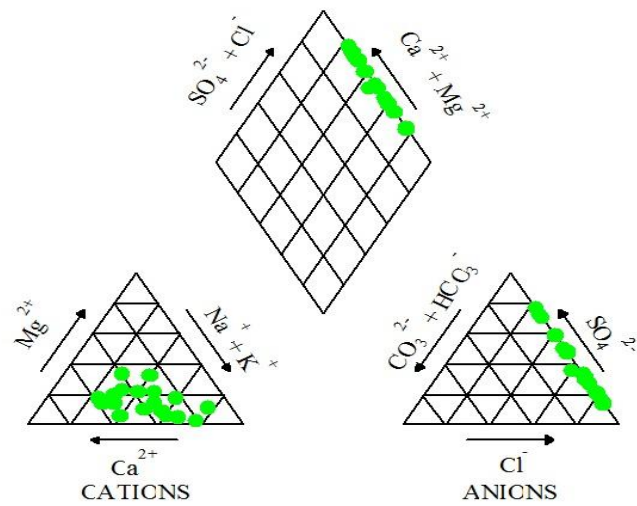


Figure 14t: Piper's diagram of Thiruvananthapuram District (pre-monsoon 2010)

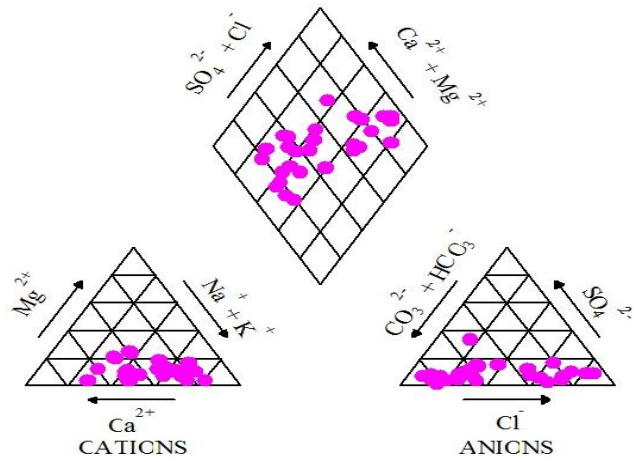


Figure 14u: Piper's diagram of Thiruvanthapuram District (post-monsoon 2010)

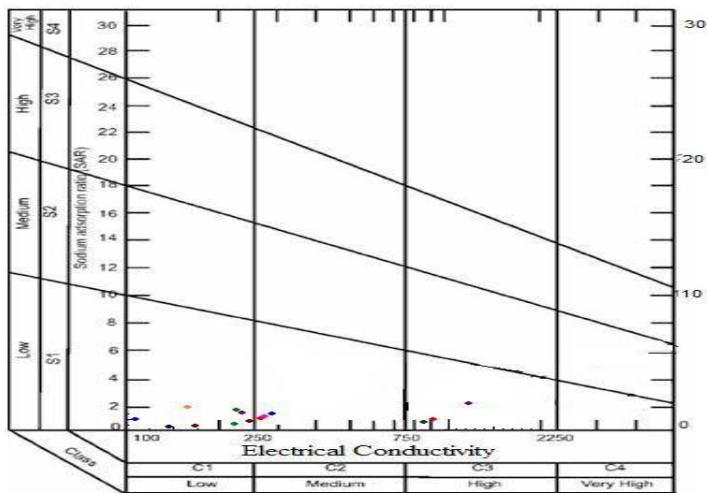


Figure 14v: USSL Classification of Groundwater(pre-monsoon,2010)

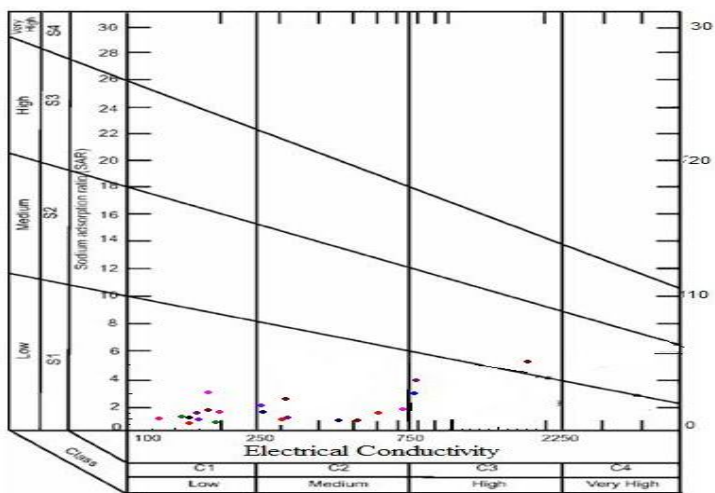


Figure 14w: USSL Classification of Groundwater (pre-monsoon 2010)

STATION/ WELL NUMBER	POSTMONSOON 2010	PREMONSOON 2010
ALAPUZHA		
ALPNHP18	290.6029879	179.1311158
QALPF1	19.35952381	35.3101774
QALPF10	41.14341737	49.45149393
QALPF9	38.01503268	68.82766106
QALPO13	26.7802521	34.04369748
QALPO15	49.77507003	38.29362745
QALPO16	52.93814192	37.08174603
QALPO21	2333.540079	36.16685341
QALPO4	42.87310924	31.45646592
QALPO40	68.47422969	53.48211951
QALPO42	53.27492997	34.0659057
QALPO46A	31.44355742	45.93496732
QALPO47	59.29383754	69.93011204
QALPO51A	84.11956116	36.21603641
QALPO52	36.39467787	41.10583567
QALPO54	59.53123249	31.44862278
QALPO57A	92.06101774	383.2575163
QALPO9	40.76437908	44.47180205
QALPO30		36.18828198
QALPF6		26.0996732
QALPO18		34.41283847
ERNAKULAM		
GWE 76	26.37683007	16.44329132
GWE-77	19.99864986	127.3915873
GWE78	20.16147059	19.93671335
QEKMB1	17.88388422	18.35620915

QEKMB12	550.2909804	556.1968254
QEKMB13	32.22429038	102.9734454
QEKMB17	75.97430906	43.30263772
QEKMB4	18.36104108	30.51375817
QEKMB6	55.69117647	55.18678805
QEKMB8	16.54823529	178.5792764
QEKMO15	59.25280112	38.35370215
QEKMO20	27.86484594	18.14678805
QEKMO26	18.44071429	16.71752568
QEKMO3	18.13564426	28.81735761
QEKMO38	16.96518207	16.84913165
QEKMO5	16.6900887	19.55662465
QEKMO50	16.86257703	27.75093371
QEKMO9	14.74921569	16.27211951
QEKMT1	171.9448459	542.2884921
QEKMO48		21.84056489
QEKMO58		77.4057423
IDDUKI		
IDKB-03	20.41076797	32.23611765
IDKB-05	17.15416433	84.02577171
IDKO-01	17.70479458	17.38048739
IDKO-03	28.24605275	16.04313772
IDKO-05	17.07573296	14.20656583
IDKO-08	25.53321662	19.26494725
IDKO-09	28.32815126	24.15167974
IDKO-13	22.6861648	20.40538749
IDKO-14	16.97367647	29.54278571
IDKO-16	28.7920028	14.54460317
IDKO-18	19.65348273	14.80634174
IDKO-20	15.08236695	13.26018487

IDKO-22	27.20018674	30.28302568
IDKO-24	23.21677965	20.42714472
IDKO-25	20.89108777	16.23975724
IDKO-28	45.59912698	15.30251634
IDKO-30	19.97761905	22.4854902
IDKO-39	50.02022876	17.77069094
IDKO-40	23.35779178	14.8677535
IDKO-43	16.44783147	
KANNUR		
QKNR-B 218	50.39032866	45.95019888
QKNR-B 224	47.17566947	84.13698833
QKNR-MOW187	37.18084967	
QKNR-MOW188	31.80510738	27.24953782
QKNR-MOW189	20.85225397	39.56151027
QKNR-MOW190	23.42744538	41.59974837
QKNR-POW-C1	33.16393884	40.04018814
QKNR-POW-C11	28.27545191	33.96853875
QKNR-POW-C13	24.17891176	28.53259337
QKNR-POW-C16	114.3875196	51.39505649
QKNR-POW-C17	24.16838982	41.25597339
QKNR-POW-C19	24.01977871	30.51668394
QKNR-POW-C2	24.97517927	26.8215943
QKNR-POW-C21	0.379339639	27.41532866
QKNR-POW-C22	26.97737535	14.69925303
QKNR-POW-C5	39.09961765	83.64021242
QKNR-POW-C6	24.73985341	70.7396732
QKNR-POW-C7	33.85342857	45.32396825
QKNR-POW-C8	32.89088235	26.1969944
QKNRB 238	43.58976284	37.62156676

QKNRB 239	39.94707003	58.42847526
QKNRB 240	114.5611872	48.45753548
QKNRB 241	75.16463072	55.29773156
QKNRB 242	107.3148329	203.2457288
QKNRB 243	41.56535014	108.0585878
QKNRB 244	62.61204108	145.8648525
QKNR-B 219		42.48112698
QKNR-B 220		58.12184967
QKNR-B 221		64.31192437
QKNR-B 222		63.6524211
QKNR-B 223		61.43528665
QKNR-B 225		63.93671522
QKNR-B 226		59.88537815
QKNR-B 227		40.18130486
QKNR-B 228		73.63556396
QKNR-B 229		37.71374463
QKNR-B 230		58.56820075
QKNR-B 234		64.1643436
QKNR-B 235		36.55751914
QKNR-B 236		72.28174463
QKNRB 238		37.62156676
QKNRB 239		58.42847526
QKNRB 240		48.45753548
QKNRB 241		55.29773156
QKNRB 242		203.2457288
QKNRB 243		108.0585878
QKNRB 244		145.8648525
QKNR-MOW171		35.28446499
QKNR-MOW172		42.62502568

QKNR-MOW173		21.57167414
QKNR-MOW180		42.93703408
QKNR-MOW181		41.89938562
QKNR-MOW182		30.04442344
QKNR-MOW183		38.52833567
QKNR-MOW184		39.28395658
QKNR-MOW186		108.6838119
QKNR-OW1		70.15911951
QKNR-OW2		59.84415966
QKNR-OW3		36.28386041
QKNR-OW4		39.1045929
QKNR-OW5		32.54777498
QKNR-OW6		144.8907437
QKNR-OW7		102.95007
QKNR-OW8		101.1753338
KASARGODE		
QKGDO-8	31.38095425	
QKGDO11	24.58794585	
QKGDO12	23.58633473	52.5900747
QKSDB 258	100.8475453	66.09372689
QKSDB225	36.65142063	63.16676004
QKSDB238	37.02421569	121.8330369
QKSDB239	50.6906662	141.0377171
QKSDB244	306.2195098	397.160789
QKSDB246	39.95005415	45.02953968
QKSDB248	41.98333883	347.9047624
QKSDB249	42.03335151	164.5213898
QKSDB250	422.8628495	73.84524697
QKSDB251	78.83172917	53.92509057

QKSDB252	67.08663989	100.3770747
QKSDB253	31.16985484	71.596176
QKSDB254	455.8667499	49.22848553
QKSDB256	126.8941706	36.84492624
QKSDO 1	252.2399319	110.3370401
QKSDO 14	544.9897996	250.5640289
QKSDO 15	156.9645775	65.34853408
QKSDO 16	213.7498412	40.27997386
QKSDO10	184.6265378	31.46804855
QKSDO18	169.4833264	28.63397526
QKSDO192	159.9444293	50.3619141
QKSDO193		30.39679739
QKSDO194	211.0711209	33.41132586
QKSDO196	183.2898941	60.99264239
QKSDO199	138.8696202	30.05514239
QKSDO202	139.4029856	48.4049183
QKSDO206	115.0186128	36.32969188
QKSDO207	128.0549616	30.90661531
QKSDO208	121.3000303	47.99504202
QKSDO209	1195.161449	48.3975
QKSDO210	344.9437437	34.4085901
QKSDO211	23.09104053	425.063408
QKSDO212	61.08540781	78.08034547
QKSDO217	243.4719277	40.94601074
QKSDO25	453.172707	115.2350327
QKSDO5	678.4795353	41.47329412
QKSDO9	155.0813881	89.37447246
KOLLAM		
PDSKLM-1	194.1950277	23.52983193

PDSKLM-10	1155.198415	73.69327731
PDSKLM-11	518.6166403	30.04577498
PDSKLM-12	970.0996386	46.2910831
PDSKLM-13	421.6471445	19.25084034
PDSKLM-14	148.7897122	17.99892624
PDSKLM-15	167.2092184	23.13538749
PDSKLM-16	165.19522	20.81792717
PDSKLM-17	250.3769671	30.52609711
PDSKLM-18	421.9158769	20.87474323
PDSKLM-19	456.4718224	15.47619048
PDSKLM-2	366.8955352	33.1609944
PDSKLM-20 PDSKLM-21	12.64073818 143.8599423	17.52595705 17.81932306
PDSKLM-3	313.0231263	28.91339869
PDSKLM-4	371.0671412	38.74019608
PDSKLM-5	10620.39736	39.63975257
PDSKLM-6	111.483486	63.87908497
PDSKLM-7	9307.718055	33.168324
PDSKLM-8	813.7659005	22.31064426
PDSKLM-9	423.6371247	22.07453315
KOTTAYAM		
PDS-02	957.7552529	
PDS-03	8377.338406	61.75088702
PDS-05	2970.25099	30.70840336
PDS-06	5795.505105	43.09005602
PDS-1	627.1010353	51.28316993
PDS-13	302.7710125	18.48193277
PDS-18	1147.112726	51.14056956
PDS-20	8025.333564	56.09752568
PDS-26	324.9637291	19.64159664

PDS-30	960.859565	21.26531279
PDS-31	369.1150725	16.90268441
PDS-32	2738.098734	
PDS-7	1331.97012	38.95072362
PDS-OW-01	492.1391168	33.99281046
PDS-OW-03	175.0418356	13.30847339
PDS-OW-04	467.9600332	18.88996265
PDS-OW-05	439.3986022	17.01237162
PDS-OW-07	760.9252513	47.30546218
PDS-OW-10	840.6418638	17.26783847
PDS-OW-11	252.953224	22.07542017
PDS-OW-13	583.5500352	25.22442577
PDS-OW-15	375.2763003	33.94274043
PDS-OW-17	767.6194519	16.91664332
PDS-OW-18	606.7917875	
PDS-OW-19	1898.174204	14.33092904
PDS-OW-2	1311.175221	18.65978058
PDS-OW-21	314.840586	19.84054155
PDS-OW-22	486.4499808	15.76247432
PDS-OW-8	255.1776405	18.46036415
PDS-OW_6	639.1792278	22.43559757
KOZHIKODE		
PDSKDD 01	238.1475161	38.94669094
PDSKDD 02	222.4499789	28.25972362
PDSKDD 03	1051.852707	212.576119
PDSKDD 04	200.6621349	85.35855556
PDSKDD 05	415.2925454	38.64588702
PDSKDD 06	3037.263606	121.7285453

PDSKKD 07	161.098904	28.01038842
PDSKKD 08	965.1381384	81.6307521
PDSKKD 09	255.474565	94.44798646
PDSKKD 10	6207.488838	259.0699608
PDSKKD 11	264.3928823	69.11323156
PDSKKD 12	169.5825426	33.49879879
PDSKKD 13	980.9743998	211.3513604
PDSKKD 14	3673.556719	121.7364916
PDSKKD 15	254.2766398	203.8384052
PDSKKD 16	412.182269	31.52021942
PDSKKD 17	347.4078607	44.97192297
PDSKKD 18	147.6539132	21.6898338
PDSKKD 19	3021.492839	83.67239029
PDSKKD 20	4303.571761	37.00072222
PDSKKD 21	275.1419844	25.60683193
PDSKKD 22	198.401359	27.10617647
PDSKKD 23	396.1988045	27.38640803
PDSKKD 24	888.8562361	20.34633894
MALLAPUAR AM		
MPM PDS BW-1	152.0787722	35.55118487
MPM PDS BW-2	170.6985171	109.9276611
MPM PDS BW-3	1237.706347	40.61585434
MPM PDS BW-4	11894.58224	129.472028
MPM PDS OW-1	304.1330664	22.41759477
MPM PDS OW-10	78.55196738	40.49517087
MPM PDS OW-11	258.594049	32.34710317
MPM PDS OW-12	2771.482983	52.2678338
MPM PDS OW-13	263.8200058	173.2383754
MPM PDS OW-13A	109.9452035	249.9212885

MPM PDS OW-14	44.38406327	24.13314006
MPM PDS OW-15	63.74463723	30.31052661
MPM PDS OW-16	387.0644192	32.97195892
MPM PDS OW-17	3320.294758	246.9103511
MPM PDS OW-18 MPM PDS OW-19	1289.541803 163.7503172	142.3540336 302.2412465
MPM PDS OW-2	458.2676052	29.98930906
MPM PDS OW-20	6490.142862	304.7018207
MPM PDS OW-3	43.71192371	28.32397386
MPM PDS OW-4	103.3271667	27.55066527
MPM PDS OW-5	174.6943566	24.18396685
MPM PDS OW-6	82.04504916	23.75755415
MPM PDS OW-7	247.5340852	21.94069374
MPM PDS OW-8	244.9633361	21.67653221
MPM PDS OW-9	62.30204454	62.30204454
PALLAKAD		
PKD Q B1	1044.255365	257.055112
PKD Q B10	1586.516263	32.2149113
PKD Q B2	205.6802455	56.85804855
PKD Q B3	357.0472483	115.8818161
PKD Q B4	1906.537966	
PKD Q B5	133.5632342	44.20294118
PKD Q B6	490.3057582	71.41594304
PKD Q B7	920.3320934	96.26004669
PKD Q B8		83.31043417
PKD Q B9	682.4892514	70.3636788
PKD Q O 10	2723.455592	24.56865079
PKD Q O1	1462.24477	83.09105976
PKD Q O11	339.139618	27.17429505

PKD Q O12	136.0569575	18.60356209
PKD Q O13	1320.773864	103.1836648
PKD Q O14 PKD Q O15	84.40998188 268.9034503	43.88141923 39.16894958
PKD Q O16	90.09326221	42.00986928
PKD Q O17	2401.159177	19.71380486
PKD Q O18	4388.222319	27.55979458
PKD Q O19	141.3173065	36.93686275
PKD Q O2	1793.580294	39.0888282
PKD Q O3	354.4733784	64.85595238
PKD Q O4	127.7354561	76.2547619
PKD Q O5	122.5762893	99.79477124
PKD Q O6	345.0080972	87.7262605
PKD Q O7	112.6733921	64.22434641
PKD Q O8	134.6352472	103.0348039
PKD Q O9	3500.223238	39.67035014
PKD Q O20		80.32602708
PATHANMITH A		
QPTA17	700.5974625	21.45168067
QPTA18	25.01850113	74.45980392
QPTA28	168.7405119	54.75252101
QPTA43	242.5359697	17.73377684
QPTA47	146.0691437	30.02478992
QPTA48	15.22147526	15.62296919
QPTA56	19.03135607	33.43069094
QPTA57	438.6105179	16.3269141
QPTA60	17.61139672	24.82161531
QPTA67	28.5007909	30.34990663
QPTA68	136.7836052	22.05079365

QPTA70	23.85020185	12.90821662
QPTA71	21.41417587	23.01622316
QPTA72	113.0749259	27.57215219
QPTA73	289.3307409	92.66617647
QPTA74	22.99374966	45.35546218
QPTA75	15.10124128	44.72315593
QPTA76	1319.142031	49.29470121
QPTA77	1169.59476	30.79467787
QPTA78	74.81186357	13.49845938
QPTA79	333.3690147	34.51078431
THIRUVANTA PURAM		
QTVM - 02	476.6275743	15.76527544
QTVM - 03	105.0379538	57.4235761
QTVM - 10	129.6665859	20.97985528
QTVM - 12	438.9919289	82.38944911
QTVM - 19	90.15621766	28.43849206
QTVM - 22	1353.382477	22.38991597
QTVM - 27	21.47995084	27.07469655
QTVM - 40	144.475234	21.7747479
QTVM - 68	192.3858782	19.41965453
QTVM - 69	98.38399874	15.76073763
QTVM - 74	17.05455567	20.14430439
QTVM - 77	46.5780524	44.628338
QTVM - 81	28.05337672	35.79696545
QTVM - 82	447.6141685	76.77474323
QTVM - 83	49.05857802	61.85298786
QTVM - 84	14.20710771	20.49670868
QTVM - 85	16.27252018	17.51820728

QTVM - 86		5986.166853	26.92983193
QTVM - 87		293.6845183	23.0094071
QTVM - B07		44.97627039	45.15877218
QTVM - B08		280.0995925	27.50396825
QTVM - B09		58.51051574	24.8047619
QTVM - B10		308.8124238	17.73244631
QTVM - B11		194.3941135	21.90485528
QTVM - B12		223.2073365	21.65070028
QTVM - B13		57.41479843	25.1950747
QTVM - B14		56.40991514	255.238422
QTVM - B15		1436.674068	37.19670868
QTVM - B16		94.91291234	30.06062092
QTVM - B17		62.48789477	94.20653595
THRISSUR		POSTMONSOON 2008	
QTSRB44	TSR1 17	126.4858009	23.94532213
QTSRB48	TSR1 18	288.8504762	22.77618581
QTSRB63	TSR1 18O W	207.0366234	188.2971849
QTSRB76	TSR1 18O W	69.96718615	38.73065359
QTSRB77	TSR1 23	78.99549784	42.99267507
QTSRB78	TSR1 23O W	53.32294372	78.06697479
QTSRO26	TSR1 24	45.73220779	61.99817927
QTSRO43	TSR1 24O W	126.5729004	31.74903828

QTSRO62	TSR1 25	203.1097835	22.39206349
QTSRB47	TSR1 34	83.12839827	22.9440943
QTSRO19	TSR1 34O W	67.08606061	23.36269841
QTSRO2	TSR1 38	50.31991342	12.81257236
QTSRO23	TSR1 38O W	73.94813853	13.60901494
QTSRO3	TSR1 40	71.06536797	17.04170868
QTSRO36	TSR1 40O W	105.6528139	20.04102241
QTSRO38	TSR1 42	43.46744589	15.86656863
QTSRO39	TSR1 44	91.24718615	28.93553221
QTSRO50	TSR1 45	68.72164502	23.86345472
QTSRB34	TSR1 46	114.1149784	19.15713819
QTSRB37	TSRO W1	138.0915152	16.58276377
QTSRB55	TSRO W13	70.1438961	55.56337535
QTSRB64	TSRO W14	119.8689177	20.22977591
QTSRO12	TSRO W15	110.8694372	27.45190943
QTSRO24	TSRO W17	99.7565368	27.48626984
QTSRO67	TSRO W22	348.7336797	23.41359477
QTSRO8	TSRO W25	75.16891775	64.08948179

QTSRO9	TSRO W27	79.52735931	36.05028478
QTSRT66	TSRO W28	222.4285714	16.39592437
QTSRB79	TSRO W32	102.2948052	16.52518207
QTSRO14	TSRO W33	134.7741991	39.74319328
QTSRO25	TSRO W34	57.33004329	77.07364613
QTSRO54	TSRO W35	91.6234632	115.8590336
QTSRO80	TSRO W36	149.3171429	20.31247899
QTSRO1	TSRO W37	75.94510823	80.82945378
	TSRO W38		53.55032213
	TSRO W6		19.97591036
	TSRO W7		52.07892157
WAYANAD		POSTMONSOON 2010	
WYDPDSQ1		180.9643119	54.36446592
WYDPDSQ10		438.870121	31.09212138
WYDPDSQ11		166.3383066	54.0667591
WYDPDSQ12		161.4913756	25.50916387
WYDPDSQ13		380.1266538	55.70548413
WYDPDSQ14		525.2882777	72.20905976
WYDPDSQ15		370.114064	37.39683427
WYDPDSQ16		312.886753	32.98368534
WYDPDSQ17		224.7381524	91.86546685
WYDPDSQ18		530.8776092	63.84456629
WYDPDSQ2		229.8785901	37.52179832
WYDPDSQ3		11356.44179	328.6627544

WYDPDSQ4	204.3629255	68.70417927
WYDPDSQ5	228.0114481	61.25796872
WYDPDSQ6	162.5464332	43.13045331
WYDPDSQ7	193.0178125	31.03408683
WYDPDSQ8	192.4611497	42.5432507
WYDPDSQ9	215.8234305	24.19601167

STATION/ WELL NUMBER	POSTMONSOON 2010	PREMONSOON 2010
ALAPUZHA		
KASARGODE		
QKGDO-8	31.38095425	
QKGDO11	24.58794585	
QKGDO12	23.58633473	52.5900747
QKSDB 258	100.8475453	66.09372689
QKSDB225	36.65142063	63.16676004
QKSDB238	37.02421569	121.8330369
QKSDB239	50.6906662	141.0377171
QKSDB244	306.2195098	397.160789
QKSDB246	39.95005415	45.02953968
QKSDB248	41.98333883	347.9047624
QKSDB249	42.03335151	164.5213898
QKSDB250	422.8628495	73.84524697
QKSDB251	78.83172917	53.92509057
QKSDB252	67.08663989	100.3770747
QKSDB253	31.16985484	71.596176
QKSDB254	455.8667499	49.22848553
QKSDB256	126.8941706	36.84492624
QKSDO 1	252.2399319	110.3370401

QKSDO 14	544.9897996	250.5640289
QKSDO 15	156.9645775	65.34853408
QKSDO 16	213.7498412	40.27997386
QKSDO10	184.6265378	31.46804855
QKSDO18	169.4833264	28.63397526
QKSDO192	159.9444293	50.3619141
QKSDO193		30.39679739
QKSDO194	211.0711209	33.41132586
QKSDO196	183.2898941	60.99264239
QKSDO199	138.8696202	30.05514239
QKSDO202	139.4029856	48.4049183
QKSDO206	115.0186128	36.32969188
QKSDO207	128.0549616	30.90661531
QKSDO208	121.3000303	47.99504202
QKSDO209	1195.161449	48.3975
QKSDO210	344.9437437	34.4085901
QKSDO211	23.09104053	425.063408
QKSDO212	61.08540781	78.08034547
QKSDO217	243.4719277	40.94601074
QKSDO25	453.172707	115.2350327
QKSDO5	678.4795353	41.47329412
QKSDO9	155.0813881	89.37447246
QEKMO48		21.84056489
QEKMO58		77.4057423
KANNUR		
QKNR-B 218	50.39032866	45.95019888
QKNR-B 224	47.17566947	84.13698833
QKNR-MOW187	37.18084967	
QKNR-MOW188	31.80510738	27.24953782

QKNR-MOW189	20.85225397	39.56151027
QKNR-MOW190	23.42744538	41.59974837
QKNR-POW-C1	33.16393884	40.04018814
QKNR-POW-C11	28.27545191	33.96853875
QKNR-POW-C13	24.17891176	28.53259337
QKNR-POW-C16	114.3875196	51.39505649
QKNR-POW-C17	24.16838982	41.25597339
QKNR-POW-C19	24.01977871	30.51668394
QKNR-POW-C2 QKNR-POW-C21	24.97517927 0.379339639	26.8215943 27.41532866
QKNR-POW-C22	26.97737535	14.69925303
QKNR-POW-C5	39.09961765	83.64021242
QKNR-POW-C6	24.73985341	70.7396732
QKNR-POW-C7	33.85342857	45.32396825
QKNR-POW-C8	32.89088235	26.1969944
QKNRB 238	43.58976284	37.62156676
QKNRB 239	39.94707003	58.42847526
QKNRB 240	114.5611872	48.45753548
QKNRB 241	75.16463072	55.29773156
QKNRB 242	107.3148329	203.2457288
QKNRB 243	41.56535014	108.0585878
QKNRB 244	62.61204108	145.8648525
QKNR-B 219		42.48112698
QKNR-B 220		58.12184967
QKNR-B 221		64.31192437
QKNR-B 222		63.6524211
QKNR-B 223		61.43528665
QKNR-B 225		63.93671522
QKNR-B 226		59.88537815

QKNR-B 227		40.18130486
QKNR-B 228		73.63556396
QKNR-B 229		37.71374463
QKNR-B 230		58.56820075
QKNR-B 234		64.1643436
QKNR-B 235		36.55751914
QKNR-B 236		72.28174463
QKNRB 238		37.62156676
QKNRB 239		58.42847526
QKNRB 240		48.45753548
QKNRB 241		55.29773156
QKNRB 242		203.2457288
QKNRB 243		108.0585878
QKNRB 244		145.8648525
QKNR-MOW171		35.28446499
QKNR-MOW172		42.62502568
QKNR-MOW173		21.57167414
QKNR-MOW180		42.93703408
QKNR-MOW181		41.89938562
QKNR-MOW182		30.04442344
QKNR-MOW183		38.52833567
QKNR-MOW184		39.28395658
QKNR-MOW186		108.6838119
QKNR-OW1		70.15911951
QKNR-OW2		59.84415966
QKNR-OW3		36.28386041
QKNR-OW4		39.1045929
QKNR-OW5		32.54777498
QKNR-OW6		144.8907437

QKNR-OW7		102.95007
QKNR-OW8		101.1753338
IDDUKI		
IDKB-03	20.41076797	32.23611765
IDKB-05	17.15416433	84.02577171
IDKO-01	17.70479458	17.38048739
IDKO-03	28.24605275	16.04313772
IDKO-05	17.07573296	14.20656583
IDKO-08	25.53321662	19.26494725
IDKO-09	28.32815126	24.15167974
IDKO-13	22.6861648	20.40538749
IDKO-14	16.97367647	29.54278571
IDKO-16	28.7920028	14.54460317
IDKO-18	19.65348273	14.80634174
IDKO-20	15.08236695	13.26018487
IDKO-22	27.20018674	30.28302568
IDKO-24	23.21677965	20.42714472
IDKO-25	20.89108777	16.23975724
IDKO-28	45.59912698	15.30251634
IDKO-30	19.97761905	22.4854902
IDKO-39	50.02022876	17.77069094
IDKO-40	23.35779178	14.8677535
IDKO-43	16.44783147	
KANNUR		
QKNR-B 218	50.39032866	45.95019888
QKNR-B 224	47.17566947	84.13698833
QKNR-MOW187	37.18084967	
QKNR-MOW188	31.80510738	27.24953782
QKNR-MOW189	20.85225397	39.56151027

QKNR-MOW190	23.42744538	41.59974837
QKNR-POW-C1	33.16393884	40.04018814
QKNR-POW-C11	28.27545191	33.96853875
QKNR-POW-C13	24.17891176	28.53259337
QKNR-POW-C16	114.3875196	51.39505649
QKNR-POW-C17	24.16838982	41.25597339
QKNR-POW-C19	24.01977871	30.51668394
QKNR-POW-C2 QKNR-POW-C21	24.97517927 0.379339639	26.8215943 27.41532866
QKNR-POW-C22	26.97737535	14.69925303
QKNR-POW-C5	39.09961765	83.64021242
QKNR-POW-C6	24.73985341	70.7396732
QKNR-POW-C7	33.85342857	45.32396825
QKNR-POW-C8	32.89088235	26.1969944
QKNRB 238	43.58976284	37.62156676
QKNRB 239	39.94707003	58.42847526
QKNRB 240	114.5611872	48.45753548
QKNRB 241	75.16463072	55.29773156
QKNRB 242	107.3148329	203.2457288
QKNRB 243	41.56535014	108.0585878
QKNRB 244	62.61204108	145.8648525
QKNR-B 219		42.48112698
QKNR-B 220		58.12184967
QKNR-B 221		64.31192437
QKNR-B 222		63.6524211
QKNR-B 223		61.43528665
QKNR-B 225		63.93671522
QKNR-B 226		59.88537815
QKNR-B 227		40.18130486

QKNR-B 228		73.63556396
QKNR-B 229		37.71374463
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QKNR-B 234		64.1643436
QKNR-B 235		36.55751914
QKNR-B 236		72.28174463
QKNRB 238		37.62156676
QKNRB 239		58.42847526
QKNRB 240		48.45753548
QKNRB 241		55.29773156
QKNRB 242		203.2457288
QKNRB 243		108.0585878
QKNRB 244		145.8648525
QKNR-MOW171		35.28446499
QKNR-MOW172		42.62502568
QKNR-MOW173		21.57167414
QKNR-MOW180		42.93703408
QKNR-MOW181		41.89938562
QKNR-MOW182		30.04442344
QKNR-MOW183		38.52833567
QKNR-MOW184		39.28395658
QKNR-MOW186		108.6838119
QKNR-OW1		70.15911951
QKNR-OW2		59.84415966
QKNR-OW3		36.28386041
QKNR-OW4		39.1045929
QKNR-OW5		32.54777498
QKNR-OW6		144.8907437
QKNR-OW7		102.95007

QKNR-OW8		101.1753338
KASARGODE		
QKGDO-8 QKGDO11	31.38095425 24.58794585	
QKGDO12	23.58633473	52.5900747
QKSDB 258	100.8475453	66.09372689
QKSDB225	36.65142063	63.16676004
QKSDB238	37.02421569	121.8330369
QKSDB239	50.6906662	141.0377171
QKSDB244	306.2195098	397.160789
QKSDB246	39.95005415	45.02953968
QKSDB248	41.98333883	347.9047624
QKSDB249	42.03335151	164.5213898
QKSDB250	422.8628495	73.84524697
QKSDB251	78.83172917	53.92509057
QKSDB252	67.08663989	100.3770747
QKSDB253	31.16985484	71.596176
QKSDB254	455.8667499	49.22848553
QKSDB256	126.8941706	36.84492624
QKSDO 1	252.2399319	110.3370401
QKSDO 14	544.9897996	250.5640289
QKSDO 15	156.9645775	65.34853408
QKSDO 16	213.7498412	40.27997386
QKSDO10	184.6265378	31.46804855
QKSDO18	169.4833264	28.63397526
QKSDO192	159.9444293	50.3619141
QKSDO193		30.39679739
QKSDO194	211.0711209	33.41132586
QKSDO196	183.2898941	60.99264239

QKSDO199	138.8696202	30.05514239
QKSDO202	139.4029856	48.4049183
QKSDO206	115.0186128	36.32969188
QKSDO207	128.0549616	30.90661531
QKSDO208	121.3000303	47.99504202
QKSDO209	1195.161449	48.3975
QKSDO210	344.9437437	34.4085901
QKSDO211	23.09104053	425.063408
QKSDO212	61.08540781	78.08034547
QKSDO217	243.4719277	40.94601074
QKSDO25	453.172707	115.2350327
QKSDO5	678.4795353	41.47329412
QKSDO9	155.0813881	89.37447246
KOLLAM		
PDSKLM-1	194.1950277	23.52983193
PDSKLM-10	1155.198415	73.69327731
PDSKLM-11	518.6166403	30.04577498
PDSKLM-12	970.0996386	46.2910831
PDSKLM-13	421.6471445	19.25084034
PDSKLM-14	148.7897122	17.99892624
PDSKLM-15	167.2092184	23.13538749
PDSKLM-16	165.19522	20.81792717
PDSKLM-17	250.3769671	30.52609711
PDSKLM-18	421.9158769	20.87474323
PDSKLM-19	456.4718224	15.47619048
PDSKLM-2	366.8955352	33.1609944
PDSKLM-20 PDSKLM-21	12.64073818 143.8599423	17.52595705 17.81932306
PDSKLM-3	313.0231263	28.91339869
PDSKLM-4	371.0671412	38.74019608

PDSKLM-5	10620.39736	39.63975257
PDSKLM-6	111.483486	63.87908497
PDSKLM-7	9307.718055	33.168324
PDSKLM-8	813.7659005	22.31064426
PDSKLM-9	423.6371247	22.07453315
KOTTAYAM		
PDS-02	957.7552529	
PDS-03	8377.338406	61.75088702
PDS-05	2970.25099	30.70840336
PDS-06	5795.505105	43.09005602
PDS-1	627.1010353	51.28316993
PDS-13	302.7710125	18.48193277
PDS-18	1147.112726	51.14056956
PDS-20	8025.333564	56.09752568
PDS-26	324.9637291	19.64159664
PDS-30	960.859565	21.26531279
PDS-31	369.1150725	16.90268441
PDS-32	2738.098734	
PDS-7	1331.97012	38.95072362
PDS-OW-01	492.1391168	33.99281046
PDS-OW-03	175.0418356	13.30847339
PDS-OW-04	467.9600332	18.88996265
PDS-OW-05	439.3986022	17.01237162
PDS-OW-07	760.9252513	47.30546218
PDS-OW-10	840.6418638	17.26783847
PDS-OW-11	252.953224	22.07542017
PDS-OW-13	583.5500352	25.22442577
PDS-OW-15	375.2763003	33.94274043

PDS-OW-17	767.6194519	16.91664332
PDS-OW-18	606.7917875	
PDS-OW-19	1898.174204	14.33092904
PDS-OW-2	1311.175221	18.65978058
PDS-OW-21	314.840586	19.84054155
PDS-OW-22	486.4499808	15.76247432
PDS-OW-8	255.1776405	18.46036415
PDS-OW_6	639.1792278	22.43559757
KOZHIKODE		
PDSKGD 01	238.1475161	38.94669094
PDSKGD 02	222.4499789	28.25972362
PDSKGD 03	1051.852707	212.576119
PDSKGD 04	200.6621349	85.35855556
PDSKGD 05	415.2925454	38.64588702
PDSKGD 06	3037.263606	121.7285453
PDSKGD 07	161.098904	28.01038842
PDSKGD 08	965.1381384	81.6307521
PDSKGD 09	255.474565	94.44798646
PDSKGD 10	6207.488838	259.0699608
PDSKGD 11	264.3928823	69.11323156
PDSKGD 12	169.5825426	33.49879879
PDSKGD 13	980.9743998	211.3513604
PDSKGD 14	3673.556719	121.7364916
PDSKGD 15	254.2766398	203.8384052
PDSKGD 16	412.182269	31.52021942
PDSKGD 17	347.4078607	44.97192297
PDSKGD 18	147.6539132	21.6898338
PDSKGD 19	3021.492839	83.67239029
PDSKGD 20	4303.571761	37.00072222
PDSKGD 21	275.1419844	25.60683193

PDSKKD 22	198.401359	27.10617647
PDSKKD 23	396.1988045	27.38640803
PDSKKD 24	888.8562361	20.34633894
MALLAPUAR AM		
MPM PDS BW-1	152.0787722	35.55118487
MPM PDS BW-2	170.6985171	109.9276611
MPM PDS BW-3	1237.706347	40.61585434
MPM PDS BW-4	11894.58224	129.472028
MPM PDS OW-1	304.1330664	22.41759477
MPM PDS OW-10	78.55196738	40.49517087
MPM PDS OW-11	258.594049	32.34710317
MPM PDS OW-12	2771.482983	52.2678338
MPM PDS OW-13	263.8200058	173.2383754
MPM PDS OW-13A	109.9452035	249.9212885
MPM PDS OW-14	44.38406327	24.13314006
MPM PDS OW-15	63.74463723	30.31052661
MPM PDS OW-16	387.0644192	32.97195892
MPM PDS OW-17	3320.294758	246.9103511
MPM PDS OW-18	1289.541803	142.3540336
MPM PDS OW-19	163.7503172	302.2412465
MPM PDS OW-2	458.2676052	29.98930906
MPM PDS OW-20	6490.142862	304.7018207
MPM PDS OW-3	43.71192371	28.32397386
MPM PDS OW-4	103.3271667	27.55066527
MPM PDS OW-5	174.6943566	24.18396685
MPM PDS OW-6	82.04504916	23.75755415
MPM PDS OW-7	247.5340852	21.94069374
MPM PDS OW-8	244.9633361	21.67653221

MPM PDS OW-9	62.30204454	62.30204454
PALLAKAD		
PKD Q B1	1044.255365	257.055112
PKD Q B10	1586.516263	32.2149113
PKD Q B2	205.6802455	56.85804855
PKD Q B3	357.0472483	115.8818161
PKD Q B4	1906.537966	
PKD Q B5	133.5632342	44.20294118
PKD Q B6	490.3057582	71.41594304
PKD Q B7	920.3320934	96.26004669
PKD Q B8		83.31043417
PKD Q B9	682.4892514	70.3636788
PKD Q O 10	2723.455592	24.56865079
PKD Q O1	1462.24477	83.09105976
PKD Q O11	339.139618	27.17429505
PKD Q O12	136.0569575	18.60356209
PKD Q O13	1320.773864	103.1836648
PKD Q O14	84.40998188	43.88141923
PKD Q O15	268.9034503	39.16894958
PKD Q O16	90.09326221	42.00986928
PKD Q O17	2401.159177	19.71380486
PKD Q O18	4388.222319	27.55979458
PKD Q O19	141.3173065	36.93686275
PKD Q O2	1793.580294	39.0888282
PKD Q O3	354.4733784	64.85595238
PKD Q O4	127.7354561	76.2547619
PKD Q O5	122.5762893	99.79477124
PKD Q O6	345.0080972	87.7262605
PKD Q O7	112.6733921	64.22434641
PKD Q O8	134.6352472	103.0348039

PKD Q 09	3500.223238	39.67035014
PKD Q 020		80.32602708
PATHANMITH A		
QPTA17	700.5974625	21.45168067
QPTA18	25.01850113	74.45980392
QPTA28	168.7405119	54.75252101
QPTA43	242.5359697	17.73377684
QPTA47	146.0691437	30.02478992
QPTA48	15.22147526	15.62296919
QPTA56	19.03135607	33.43069094
QPTA57	438.6105179	16.3269141
QPTA60	17.61139672	24.82161531
QPTA67	28.5007909	30.34990663
QPTA68	136.7836052	22.05079365
QPTA70 QPTA71	23.85020185 21.41417587	12.90821662 23.01622316
QPTA72	113.0749259	27.57215219
QPTA73	289.3307409	92.66617647
QPTA74	22.99374966	45.35546218
QPTA75	15.10124128	44.72315593
QPTA76	1319.142031	49.29470121
QPTA77	1169.59476	30.79467787
QPTA78	74.81186357	13.49845938
QPTA79	333.3690147	34.51078431
THIRUVANTA PURAM		
QTVM - 02	476.6275743	15.76527544
QTVM - 03	105.0379538	57.4235761
QTVM - 10	129.6665859	20.97985528

QTVM - 12	438.9919289	82.38944911
QTVM - 19	90.15621766	28.43849206
QTVM - 22	1353.382477	22.38991597
QTVM - 27	21.47995084	27.07469655
QTVM - 40	144.475234	21.7747479
QTVM - 68	192.3858782	19.41965453
QTVM - 69	98.38399874	15.76073763
QTVM - 74	17.05455567	20.14430439
QTVM - 77	46.5780524	44.628338
QTVM - 81	28.05337672	35.79696545
QTVM - 82	447.6141685	76.77474323
QTVM - 83	49.05857802	61.85298786
QTVM - 84	14.20710771	20.49670868
QTVM - 85	16.27252018	17.51820728
QTVM - 86	5986.166853	26.92983193
QTVM - 87	293.6845183	23.0094071
QTVM - B07	44.97627039	45.15877218
QTVM - B08	280.0995925	27.50396825
QTVM - B09	58.51051574	24.8047619
QTVM - B10	308.8124238	17.73244631
QTVM - B11	194.3941135	21.90485528
QTVM - B12	223.2073365	21.65070028
QTVM - B13	57.41479843	25.1950747
QTVM - B14	56.40991514	255.238422
QTVM - B15	1436.674068	37.19670868
QTVM - B16	94.91291234	30.06062092
QTVM - B17	62.48789477	94.20653595
THRISSUR	POSTMONSOON 2008	

QTSRB44	TSR1 17	126.4858009	23.94532213
QTSRB48	TSR1 18	288.8504762	22.77618581
QTSRB63	TSR1 18O W	207.0366234	188.2971849
QTSRB76	TSR1 18O W	69.96718615	38.73065359
QTSRB77	TSR1 23	78.99549784	42.99267507
QTSRB78	TSR1 23O W	53.32294372	78.06697479
QTSRO26	TSR1 24	45.73220779	61.99817927
QTSRO43	TSR1 24O W	126.5729004	31.74903828
QTSRO62	TSR1 25	203.1097835	22.39206349
QTSRB47	TSR1 34	83.12839827	22.9440943
QTSRO19	TSR1 34O W	67.08606061	23.36269841
QTSRO2	TSR1 38	50.31991342	12.81257236
QTSRO23	TSR1 38O W	73.94813853	13.60901494
QTSRO3	TSR1 40	71.06536797	17.04170868
QTSRO36	TSR1 40O W	105.6528139	20.04102241
QTSRO38	TSR1 42	43.46744589	15.86656863
QTSRO39	TSR1 44	91.24718615	28.93553221

QTSRO50	TSR1 45	68.72164502	23.86345472
QTSRB34	TSR1 46	114.1149784	19.15713819
QTSRB37	TSRO W1	138.0915152	16.58276377
QTSRB55	TSRO W13	70.1438961	55.56337535
QTSRB64	TSRO W14	119.8689177	20.22977591
QTSRO12	TSRO W15	110.8694372	27.45190943
QTSRO24	TSRO W17	99.7565368	27.48626984
QTSRO67	TSRO W22	348.7336797	23.41359477
QTSRO8	TSRO W25	75.16891775	64.08948179
QTSRO9	TSRO W27	79.52735931	36.05028478
QTSRT66	TSRO W28	222.4285714	16.39592437
QTSRB79	TSRO W32	102.2948052	16.52518207
QTSRO14	TSRO W33	134.7741991	39.74319328
QTSRO25	TSRO W34	57.33004329	77.07364613
QTSRO54	TSRO W35	91.6234632	115.8590336
QTSRO80	TSRO W36	149.3171429	20.31247899
QTSRO1	TSRO W37	75.94510823	80.82945378
	TSRO W38		53.55032213
	TSRO W6		19.97591036

	TSRO W7		52.07892157
WAYANAD		POSTMONSOON 2010	
WYDPDSQ1		180.9643119	54.36446592
WYDPDSQ10		438.870121	31.09212138
WYDPDSQ11		166.3383066	54.0667591
WYDPDSQ12		161.4913756	25.50916387
WYDPDSQ13		380.1266538	55.70548413
WYDPDSQ14		525.2882777	72.20905976
WYDPDSQ15		370.114064	37.39683427
WYDPDSQ16		312.886753	32.98368534
WYDPDSQ17		224.7381524	91.86546685
WYDPDSQ18		530.8776092	63.84456629
WYDPDSQ2		229.8785901	37.52179832
WYDPDSQ3		11356.44179	328.6627544
WYDPDSQ4		204.3629255	68.70417927
WYDPDSQ5		228.0114481	61.25796872
WYDPDSQ6		162.5464332	43.13045331
WYDPDSQ7		193.0178125	31.03408683
WYDPDSQ8		192.4611497	42.5432507
WYDPDSQ9		215.8234305	24.19601167

Modelling of Solute Transport

Application of SWIM Model

SWIM is an acronym that stands for Soil Water Infiltration and Movement. It is a software package developed within the CSIRO Division of Soils for simulating infiltration, evapotranspiration, and redistribution. The first version (SWIMv1) was published in 1990 (Ross, 1990b)*. Version 2 of the model (identified as SWIMv2.0), which combines water movement with transient solute transport and which accommodates a variety of soil property descriptions and more flexible boundary conditions, was completed in 1992. The latest version, SWIMv2.1, is described here.

SWIMv2 is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, soil evaporation, deep drainage and leaching. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g., precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model.

The model deals with a one-dimensional soil profile. For a vertical soil profile, this means that it may be vertically inhomogeneous, but must be horizontally uniform. This assumption has two consequences of importance in many common simulations. There is only one hydraulic conductivity function for each layer, so that any macropore, or bypass flow can only be accounted for in a limited way. Secondly, the calculated solute concentrations apply to the whole soil layer, which means that there is no concentration gradient from the bulk soil to near the root surface. The presence of such a concentration gradient may in reality affect the soil osmotic potential and hence water and solute uptake. The overall purpose of the model is to address issues relating to the soil water and solute balance. As such it is a research tool that can be integrated in laboratory and field studies concerned with soil water and solute transport.

Soil Water Infiltration and Movement (SWIM) Model

SWIMv2.1 is based on a numerical solution of the Richards equation and the advection-dispersion equation. In the present study, the model has been applied to simulate the movement of solute in the unsaturated zone. The physical system and the associated flows addressed by the model are shown schematically in Fig 2. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g. precipitation, evaporative demand, solute input) was supplied in order to run the model (Verburg et al., 1996). The governing partial differential equation (Richards equation) applicable for one-dimensional flow in the unsaturated zone can be written as:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} K \left[\frac{\partial \Psi}{\partial x} + \frac{dz}{dx} \right] + S$$

where,

- θ = volumetric water content (cm^3/cm^3)
- t = time (h)
- x = distance into the soil (cm soil)
- K = Hydraulic conductivity ($\text{cm}^2 \text{ water}/\text{cm soil}/\text{h}$)
- Ψ = matric potential (cm water)
- z = gravitational potential (cm); and
- S = Sink strength ($\text{cm}^3 \text{ water}/\text{cm}^3 \text{ soil}/\text{h}$)

where, θ and Ψ related by the water retention curve and K is related to θ by the hydraulic conductivity function. This so-called mixed θ and Ψ form of the Richard's equation is solved numerically with the Newton-Raphson iterative method (Campbell, 1985). For the purpose of numerically solving the equation (4), the soil profile is represented by a series of nodes (depth-wise); the number and spacing (for example, 10 cm, 20 cm ...) of which are determined by the user in the input file. Smaller depth increments lead to more accurate solutions (Ross and Bristow, 1990). The first node defined by the user is always taken as the soil surface or top boundary. Therefore, the equation (4) can then be discretised on a space-time grid.

Solute transport phenomena are explained by the equation given below.

$$\frac{\partial(\theta c)}{\partial t} + \frac{\partial(\rho s)}{\partial t} = \frac{\partial}{\partial x} \left[\theta D \frac{\partial c}{\partial x} \right] - \frac{\partial(qc)}{\partial x} + \phi$$

where,

c	=	solute concentration in solution (μmol or μg solutes/ cm^3 water)
s	=	adsorbed concentration ($\mu\text{mol/g}$ soil or $\mu\text{g/g}$ soil)
ρ	=	soil bulk density (g/cm^3)
q	=	water flux density (cm/h)
D	=	combined dispersion and diffusion coefficient (cm^2/h)
ϕ	=	source/sink term ($\mu\text{mol/cm}^3/\text{h}$ or $\mu\text{g/cm}^3/\text{h}$)

Currently, SWIMv2.1 can only account for one solute at a time. The choice of units for solute concentration, c, is flexible. Any units can be used as long as they are expressed in an amount/ cm^3 soil. Units of s, ϕ , and k changes accordingly, as well as the units of **Slos**.

Values for the diffusion coefficient in water (**d0**) can be found in several literature sources (e.g., Robinson and Stokes, 1965; Lehrman, 1979; Weast and Astle 1980; Kemper, 1986; Sadeghi et al., 1988). The diffusion coefficient depends on the temperature, the concentration of the solute, and on the ions that the solute consists of. For example, if chloride moves as CaCl_2 , it has a diffusion coefficient of approximately $0.045 \text{ cm}^2/\text{h}$, whereas if it moves as KCl the appropriate value is about $0.071 \text{ cm}^2/\text{h}$ (25°C , approx. $1.0 \mu\text{mol/cm}^3$ ($=0.001\text{M}$)). If there is a mixed electrolyte, the diffusion coefficient is determined by a contribution for each. Nye (1966) has outlined an approach to calculate the appropriate diffusion coefficient in that case (see e.g., Bond and Phillips, 1990a). If the cation and anion fronts move separately (e.g., Bond and Smiles, 1988; Bond and Phillips, 1990b), then the appropriate diffusion coefficient for the anion may be that in combination with the resident cation, rather than with the incoming cation. Note, however, that SWIMv2.1 currently does not handle separate fronts.

Solute initial and boundary conditions

Solute can be added to the system in a variety of ways:

- as part of initialisation: solute concentrations (in solution) are specified for each node (**csi(i)**). If there is adsorption ($k \neq 0$), then the initial amount of adsorbed solute is “created” using the specified adsorption isotherm.
- in rainfall or irrigation: cumulative solute additions (in amounts rather than concentrations) are given in the input file (**nts** time-addition pairs). These solute are assumed to be mixed with the rainfall/irrigation. The units of the amounts needed to be consistent with the unit of solute concentration used. E.g. if, over a certain time period, 0.32 cm of irrigation water is applied to the soil surface ($0.32 \text{ cm}^3 \text{ water/cm}^2$ surface area) with a solute concentration of $50 \mu\text{mol solute/cm}^3$ water, then the amount of solute added (to be specified in input file) is $16 \mu\text{mol solute/cm}^2$ surface area.
- as part of cultivation: in this case the solute is added “dry” to the surface. It will enter the soil with infiltrating water at a concentration of **slsci** or disappear with surface runoff water at a concentration of **slscr** (**slsci** and **slscr** are specified in the input file).
- by production in the profile:
- by artificial “creation” of solute when there is a constant potential top and/or bottom boundary condition for water flow (**itbc = 1** or **ibbc = 1**): the solute concentration at these boundaries is kept constant and in order to achieve this solute may be “created”.

At the top boundary the solute concentration is held at the specified initial value (**csi(0)**), while for the bottom boundary it is specified separately in the input file as **csi(n)**.

Parameters Considered

Root radius (rad)	=	0.09cm
Root conductance (groot)	=	$1.1 \cdot 10^{-7}$
Minimum Xylem potential (psimin)	=	-15,000 cm

Root depth constant (xc)	= 30 cm
Maximum root length density (rldmax)	= 3 cm/cm ³

Limitations of the Model

1. Only one-dimensional flow is considered. Lateral equilibrium is, therefore, assumed. Net lateral surface runoff is treated as a sink terms at the surface.
2. Macropores and bypass flow are only taken into account of in a limited way.
3. The soil matrix is assumed rigid, so that SWIMv2.1 is not strictly applicable to swelling soils.
4. Soil air flow is ignored.
5. Vapour flow within the soil can be included as part of the conductivity term, but only in response to matric potential gradients.
6. Temperature effects on water movement are ignored.
7. Osmotic effects are ignored, except in water uptake and soil evaporation.
8. Wetting front instability or fingering is not taken into account.

KANNUR

pH of the groundwater during the pre-monsoon (2008) varied between 6.4 and 7.6. Maximum was observed at Urathur which is an eastern border of the district. In the post-monsoon , maximum was noticed at Mathil (8.1) near the coastal region. The analysis carried out during 2010 shows significant change in pH with a maximum value of 8.4 at Chemberi during pre-monsoon and 8.8 at Kottiyoor (post-monsoon). These changes could be attributed to local variation of water levels as well as due to the addition of domestic sewages. Electrical conductivity observed was within the permissible limits. In the year 2008, during pre-monsoon, a maximum of 700 microsiemens /cm was observed at Thalassery near the coast and during post-monsoon 560 microsiemen/cm was observed. In the year 2010, EC value, touched 1000 microsiemen/cm at Mathil (during pre-monsoon) and in the post-monsoon, a decline was noticed with a maximum value of 310 microsiemens/cm (at Taliparambu). Carbonate distribution does not show much variation from 2008 to 2010. However, considerable quantity of carbonate is found in groundwater. A maximum of 15 mg/l was noticed in Chemberi during pre-monsoon of 2010 and 7.4 mg/l was noticed during post-monsoon. Bicarbonate was quite high near the coast (Mathil 280 mg/l) in the pre-monsoon and in the post-monsoon 105 mg/l was noticed at Karivellur. The reason is well known as there is an influence of seawater into the coastal water bodies. The maximum chloride concentration observed during the pre-monsoon season of 2008 was 82 mg/l (Panoor) and 70 mg/l during post-monsoon. In the year 2010, maximum concentration was 170 mg/l at Mathil (pre-monsoon) and 42 mg/l during post-monsoon.

Fluoride concentration in Kannur district was found to be much higher than the permissible limits. During pre-monsoon 2010, it was 1.8 mg/l and in the post-monsoon it reduced to 1.19 mg/l which is not ideal for drinking purposes. Concentration of sulphates are quite nominal. A maximum of 37 mg/l was noticed at Madayil (Pre-monsoon, 2010) and 6 mg/l (post-monsoon

2010) at Taliparambu. Nitrates varies between 0- 8 mg/l during pre-monsoon (2010) and 0-3.8 mg/l during post-monsoon. Total dissolved solids show a maximum concentration of 570 mg/l at Mathil, which is slightly higher than the desirable limits during pre-monsoon and 180 mg/l at Taliparambu. Total hardness exceeded the desirable limits during the post-monsoon of 2008 and 2010. The reason is obvious that there is a large influx of sediments entering the groundwater due to overland flow. All major cations concentration is found to be within the permissible limits. However, Iron concentration exceeded much above the permissible limits.

Table 9b: Correlation between various ions during Post-monsoon 2008

	pH	EC	TH	Cl	Na
pH	1				
EC	0.196	1			
TH	0.398	0.641	1		
Cl	-0.147	0.781	0.156	1	
Na	0.115	0.785	0.199	0.761	1