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Hydrochemical Characteristics of Groundwater for Domestic and Irrigation Purposes in Periyakulam Taluk of Theni District, Tamil Nadu

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Abstract

Study was carried out in Periyakulam taluk of Theni district in Tamil Nadu, India with an objective of understanding the suitability of local groundwater quality for domestic and irrigation purposes. Thirty groundwater samples were collected in premonsoon (August 2011) and postmonsoon (February 2012) and analysed for physical and chemical parameters. Groundwater in this area was found to be within desirable Bureau of Indian Standards for drinking water except certain location hardness and Fluoride exceeds the permissible limit (more than 1.5 mg/l). The presence of fluoride above the permissible level have created a serious threat to rural population dental fluorosis have appeared alarming rate in certain regions. Hydrochemical groundwater evaluations revealed that most of the groundwater belongs to the Ca-HCO_3 type and mixed Ca-Mg-Cl type. Base-exchange indices classified 83% of the groundwater sources as the Na^+-SO_4^{2-} and 73% belong to Na^+-HCO_3^- type pre and postmonsoon. The meteoric genesis indices demonstrated that 73% of groundwater sources belong to a deep meteoric water percolation type before monsoon and 76% belong to a shallow meteoric water type in after monsoon season. Groundwater in this area was assessed for irrigation purposes on the basis of salinity indices, chloronity indices, sodicity indices, sodium percentage, and residual sodium carbonate classification. Most of the groundwater samples were suitable for irrigation except in a few locations.

Keywords: Physicochemical characteristics, domestic and irrigation suitability periyakulam taluk.

Introduction

The quality of water is vital concern for mankind since it is directly linked with human health. Groundwater is highly valued because it constitutes the major drinking and irrigation water source in most of the parts of India. In recent decades, exploitation of groundwater has increased greatly, particularly for agricultural purpose, because large parts of the country have little access to rainfall due to frequent failures of monsoon. Presently, 85% of the water requirement for domestic use in rural areas, 55% for irrigation and over 50% for industrial and urban uses is met from groundwater[8].Groundwater irrigation started with only 6.5 Mha in 1950-51[5], which was increased to 46.5 Mha in 2000-2001[17] meeting about 70% of the irrigation water requirements of the country. This clearly indicates the growing pressure on groundwater resources. There is growing concern on the deterioration of groundwater quality due to geogenic and anthropogenic activities [4]. The quality of groundwater in a region is a function of physical, chemical and biological parameters. Groundwater quality is as important as the quantity. Poor quality of water adversely affects the plant growth and human health [9,19,20,21]. It decreases agricultural production; reduce agrarian economy, retards improvement in the living conditions of rural people. Potable water is the water that is free from disease producing chemical substances and microorganisms that are dangerous to health, majority of the rural people do not have accesses to potable water for domestic use. Several regions in India have encountered degradation in groundwater quality too, due to increase of population growth and rapid urbanization [3,14]. The present study carried out with the aim of understanding the groundwater quality and its suitability for domestic and irrigation purpose. Groundwater is usually as direct use in rural water supply without proper treatment and for agricultural practice most of the year. Groundwater may also contaminated due weathering of rock and agrochemicals used for irrigation in this area. However, no studies have been carried out in the with respect to drinking and irrigation purpose so far in the rural area of Periyakulam taluk. The present study, which was carried out in premonsoon (August 2011) and Postmonsoon (Febrary 2012), from the area are selected for the present study.

Study Area: The study has been carried out in Periyakulam Taluk is situated in Theni district southwest of Tamil Nadu. It is located 482 Km south of Chennai city and covers an area of 390.03 km^2. The taluk is situated between the latitudes 9°53'N to 10°14'N and longitudes 77°17'E and 78°45'E. It is bound by Bodinayakkanur and Theni taluk on the western side, south by Andipatti taluk and in the north and eastern side by Dindigul and Madural districts. Vaigai dam is located in this taluk and flowing during monsoon season and it normally is dry during summer season. The average temperature of the taluk is about 13ºC to 40ºC and average annual rainfall is about 868 mm. Agriculture is principle occupation of the people and is backbone of the rural economy. The crops cultivated are paddy, millets, cereals, sugarcane, groundnut etc. Geologically this area is characterized by granitie gnesiss, charnockite and pegmatite of hard crystalline rocks. Deep red soil, laterite soil and red sandy soil overlay the rock formation. Farmers are using huge amount of chemical fertilizers and pesticides. The villages are well connected by roads to the nearest towns are Periyakkulam. The map of the study is shown in fig 1.

Material and Methods

Groundwater samples were collected after well inventory survey from 30 representative wells during August 2011 and February 2012. The parameters like EC, pH were measured on the spot at the time of sample collection using potable kit. The collected groundwater samples were transferred into plastic container for analysis of chemical characters. Chemical analyses were carried out for the major ions, and trace ions concentrations using the standard procedures recommended by American Public Health Association[1]. Generally groundwater is used as for drinking and irrigation purpose in this taluk.

Results and Discussion

The physical observations of the samples are colourless and odorless in natures which are given in the table 1. From these data, the following observations were made for different parameters:

pH and Electrical conductivity (EC): pH is a measure of the intensity of acidity or alkalinity conditions of a solution. Most of the water samples are slightly alkaline due to presence of carbonates and bicarbonates [11]. The pH values of water samples varied between 6.9 to 7.9 in pre and 6.8 to 7.9 in post monsoon and were found within the limit (6.5 - 8.5) prescribed by BIS. EC is the most important parameter to demarcate salinity hazard and suitability of water for irrigation purpose. It signifies the amount of total dissolved solid. EC values were in the range of 100 to 2620 µS/cm and 80 to 5300 µS/cm during pre and postmonsoon, respectively. The high conductivity in some of the samples is likely due to prolonged and intensive agricultural practices and geological conditions acquiring high concentrations of the dissolved minerals.

Calcium (Ca^{2+}) and Magnesium (Mg^{2+}): Calcium content is very common in groundwater, because they are available in most of the rocks, abundantly and directly related to hardness. Calcium concentration varies between 10 to 140 mg/l and 40 to 150 mg/l during both the seasons and found exceed permissible limit (<75 mg/l) in many locations as per BIS. Magnesium (Mg^{2+}) usually occurs in lesser concentration than calcium due to the fact that the dissolution of magnesium rich minerals is slow process. Magnesium concentration varies between 6 to 84 mg/l and 14 to 100 mg/l during both the seasons which were found most of samples exceed the prescribed limit (<30 mg/l) as per BIS. If the concentration of calcium and magnesium in drinking water is more than the permissible limit, it causes unpleasant taste to the water.

Sodium (Na^{+}) and Potassium (K): Sodium concentration more than 50 mg/l makes the water salt taste and cause health problems. Sodium concentrations were found in between 45 to 114 mg/l and 49 to 141 mg/l during both the seasons. In general sodium salts are not actually toxic substances to humans because of the efficiency with which mature kidneys excrete sodium. Sodium concentrations values were found within the permissible limit (<250 mg/l) as per BIS. Potassium is slightly less common than sodium in igneous rocks, but more abundant in all the sedimentary rocks. The main source of potassium in groundwater is weathering of potash silicate minerals, potash fertilizers and also due to surface water for irrigation. Potassium varies from 0.5 to 19.20 mg/l and 0.18 and 26.3 mg/l during both the seasons.

Bicarbonate (HCO_3^-) and Carbonate (CO_3^-): The primary source of CO_3^- and HCO_3^- ions in groundwater is the dissolved CO_2 in rainwater that on entering in the soil dissolves more CO_2. Bicarbonate concentration varied from 136 to 480 mg/l in pre monsoon and 125 to 460 mg/l in post monsoon. HCO_3^- concentration few groundwater samples exceed the permissible (>250 mg/l) limit as per BIS. Carbonate concentration varied from 0 to 20 mg/l in pre monsoon and 0 to 35 mg/l in post monsoon. Both CO_3^- and HCO_3^- contribute to the alkalinity of the water and are associated with the hardness of water which gives an unpleasant taste to water. Normally in natural water as the pH value ranges from 7.0-8.0 would contain much more bicarbonates than carbonates (Chow 1964).Alkalinity of the circulating water is mainly responsible for the increase concentration of fluoride.

Chloride and Sulphate (SO_4^{2-}): The chloride concentration due to domestic sewage, fertilizers applications and/or leaching from upper soil layers in semi arid climates. Small amounts of chlorides are required for normal cell functions in plant and animal life. Chloride concentration varies between 7.5 to 542 mg/l and 9 to 1490 mg/l during both the seasons and found few samples exceed the prescribed limit (<250 mg/l) as per BIS. Sulphate occurs naturally in water due to leaching from gypsum, other common minerals and discharge of domestic sewage tends to increase its concentration. Sulphate concentration varied between 8 to 200 mg/l and 10 and 180 mg/l during both the seasons and found within the prescribed limit (<400 mg/l) as per BIS. Sulphate are related to the types of minerals in the soil and bedrock. Sulfur in the form of sulphate is an essential plant nutrient and is considered toxic to plants or animals at lower concentration, but at higher concentrations, it imparts a bitter taste and may cause laxative effects.

Nitrate and Fluoride: Groundwater contain nitrate due to leaching of nitrate with the percolating water. Nitrate concentration in the sample ranges from 1 to 12 mg/l and 4 to 21 mg/l during both the seasons and found within the permissible limit (<45 mg/l) as per BIS. The permissible limit of fluoride in drinking water is 1.0 mg/l, which can extend to 1.5 mg/l in case of non availability of other sources. Higher fluoride level in drinking water gives rise to dental decay and physical deformation. The fluoride content in the study area varied in the range 0.2 to 2.8 mg/l and 0.2 to 2.6 mg/l during both the season as shown in fig 2. It has been observed that groundwater in A.Vadipatti Gullapuram

Bomminayanpatti Marugalpatti locations contained higher fluoride concentration than prescribed limit and the habitant in this area affected by dental fluorosis diseases, The concentration of fluoride in groundwater is not uniform in the area. This may be due to the difference in the presence and accessibility of fluorine-bearing minerals to the circulating water and also due to the weathering and leaching activities.

Total Hardness: Total hardness is an important parameter of water for its use in domestic purpose. Calcium and magnesium are important parameter for total hardness in groundwater. The acceptable limits for domestic use 75 mg/l. Total hardness of groundwater ranged from 50 to 700 mg/l and 53 to 800 mg/l during both the seasons. Excess hardness is undesirable mostly for economic or aesthetic reasons [13]. Most of the samples are hard to very hard water.

Hydrochemical Facies: Major cations and anions such as Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^-, HCO_3^-, SO_4^{2-} and Cl^- in mg/l were plotted in Piper diagram [12] to evaluate the hydrogeochemistry of groundwater of Periyakulam taluk with th help of Aquachem Software (Fig 3). The plot shows that most of groundwater samples fall in the field of mixed $CaHCO_3$ type and mixed CaMgCl type facies type of water in both the seasons.

Classification of groundwater samples: Groundwater samples were classified based on Cl^-, SO_4^{2-}, and HCO_3^- concentrations [1, 18]. Based on the Soltan's classification, majority of the groundwater samples are of normal sulfate type followed by normal chloride and normal bicarbonate type.

Base-exchange indices (r1): The base-exchange indices were estimated using equation[18] to further classify groundwater.

$$r_1 = (Na^+ - Cl^-) / SO_4^{2-}$$

Where r_1 is the Base Exchange index and Na^+, Cl^- and SO_4^{2-} concentrations are expressed in meq/l. If $r_1 < 1$, the groundwater sources are of $Na^+ - SO_4^{2-}$ type, while $r_1 > 1$ indicates the sources are of $Na^+ - HCO_3^-$ type. Based on the Base Exchange indices (r_1) about 80% groundwater samples are classified as $Na^+ - SO_4^{2-}$ type ($r_1 < 1$) and rest are $Na^+ - HCO_3^-$ type ($r_1 < 1$). Base-exchange indices classified 83% of the groundwater sources as the Na^+-SO_4^{2-} and 73% belong to Na^+-HCO_3^- type pre and postmonsoon which are given in the table 2.

Meteoric genesis indices (r2): The groundwater sources can also be classified based on meteoric genesis index and can be computed using equation [18].

$$r_2 = ((Na^+ + K^+) – Cl^-) / SO_4^{2-}$$

Where r_2 is the Meteoric genesis index and the concentrations of K^+, Na^+, Cl^- and SO_4^{2-} are expressed in meq/l. If $r_2 < 1$the groundwater source is of deep meteoric water percolation type while $r_2 > 1$ indicates that is of shallow meteoric genesis indices (r_2). Based on r_2 values groundwater sources are of deep meteoric water percolation type and the rest are shallow meteoric water percolation type. Furthermore all $Na^+ - SO_4^{2-}$ (except sample) type groundwater samples are of deep meteoric water and percolation type in nature. Similar findings were reported earlier[16]. The meteoric genesis indices demonstrated that 73% of groundwater sources belong to a deep meteoric water percolation type before monsoon and 76% belong to a shallow meteroric water type in after monsoon season which are given in the table 2.

Mechanisms of controlling groundwater chemistry (Gibbs ratio): Gibbs diagram represents the ratio of Na+K+/Na+K+Ca and Cl/(Cl+HCO3) as a function of TDS which is widely used to assess the functional sources of dissolved chemical constituents such as, precipitation dominance, rock dominance and evaporation dominance[7]. The chemical data of the groundwater samples from periyakulam taluk are plotted in Gibb's diagram (Fig 4) which shows that most of the samples of the study area fall in the category of rock dominance and the evaporation, indicating that this process is also responsible for the groundwater chemistry. So the chemical weathering of the rock minerals could be the main processes which also contribute ions to the groundwater of the study area.

Suitability for irrigational purposes: Groundwater in the study area is extensively used for irrigation. Good quality irrigation water is essential for achieving maximum crop productivity. Groundwater suitability for irrigation purpose in this study was assessed using salinity, chlorinity and sodicity indices (Mills 2003). Groundwater in most of the study area was found to be suitable for irrigation.

Salinity index: Salinity index of the water samples was computed using the measured EC values. Salinity is related to TDS and EC. The total salt content of water gives the salinity. High concentrations of TDS and EC in irrigation water may increase the soil salinity, which affects the plant salt intake. Furthermore, salts types responsible for make up this salinity determine the water suitability for its intended use according to the following classification[10, 16]. The salinity index was estimated using the measured EC values. Majority of groundwater samples (97%) in the study area are categorized as class I–III, and thus, may be considered safe for irrigation. However, 3% water samples exhibit high to very high salinity (classes IV– V) and may not be suitable for irrigation (Fig. 5).

Chlorinity index: The chloride ion can be toxic to plants having high salt tolerance when taken up by their roots and absorbed through their leaves. The chlorinity index of the groundwater sources was computed using measured chloride ion concentrations. Water samples in the study area were classified [10, 16] based on the following chlorinity index diagram. Based on the chlorinity index diagram, all the groundwater samples can be considered suitable (classes I and II) for irrigation (Fig. 6).

Sodium Adsorption Ratio: Sodium Adsorption Ratio (SAR) is most commonly used to assess suitability of irrigation water. The SAR measures sodicity in terms of the relative concentration of sodium ions to the sum of calcium and magnesium ions in a water sample. Sodium concentration in water effects deterioration of the soil properties reducing permeability [15]. SAR is calculated using the following formula:

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+}/2)}$$

Where the ionic concentrations are expressed in meq/l. The SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali [10]. Based on the sodicity diagram the groundwater samples are classified and shown in fig 7. It is clear from fig 7 that all samples can be considered suitable for irrigation purposes.

Percentage Sodium: Sodium is an important parameter for irrigation water and is denoted as Na% which was calculated from the formula given in equation [21] and all concentrations were expressed in meq/l.

$$Na^+ \% = (Na^+ + K^+) \times 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$$

Based on the above Na% groundwater samples are classified as shown in Wilcox diagram (Fig 7). EC and Na% are plotted in Figure 8 which showed that most of the samples good to permissible and few samples fall under doubtful to unsuitable category, indicating the dominance of ion exchange and weathering from litho units of the study area.

Residual sodium carbonate: The concentration of carbonate and bicarbonate higher than the alkaline earth mainly calcium and magnesium concentration, the water quality may be diminished and affects agriculture unfavorably [6,15]. RSC can be computed using the following formula, where ions wee expressed in meq/l.

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

If RSC <1.25 meq/l, the water is considered safe. If RSC lies between 1.25 -2.5 meq/l, the water is of marginal quality. If RSC >2.5meq/l, the water is unsuitable for irrigation. Figure 7 clearly shows that all the samples were <1.25meq/l and fall within the safe category for irrigation purpose (Fig 9).

Conclusion

Groundwater quality of an area must be studied to understand its suitability for domestic and irrigation purposes. Generally, the groundwater quality of the area is hard to very hard, fresh to brackish and slightly alkaline in nature. The dominant groundwater type was Ca-HCO_3 type and mixed Ca-Mg-Cl type. The major ions in most of the locations were found to be within in BIS permissible limit for drinking water. The groundwater is hard to very hard on the basis of TH. The fluoride concentration in the groundwater is also within BIS limit of 1.5mg.l. However some locations in A.Vadipatti, Gullapuram, Bomminayanpatti, Erumalainickenpatti and Marugalpatti the fluoride concentration exceed the limit (>1.5 mg/l) and also observed the dental fluorosis is common among the people. People have to be advised to avoid the groundwater sources and advised to use surface water especially river water supply schemes as far as possible. The suitability of groundwater for irrigation was assessed from salinity indices, chloronity indices, sodicity indices, sodium percentage, and residual sodium carbonate classification. The groundwater in this area was seen to be good and suitable for irrigation purposes.

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Table-1
Groundwater samples of study area exceeding the permissible limits prescribed by BIS for domestic purposes

Parameters	Pre monsoon (August 2011)	Post monsoon (February 2012)	BIS standards (1998)	
			Permissible limit	Maximum limit
pH	6.9 – 7.9	6.8 – 7.9	6.5-8.5	6.5-9.2
EC	100 – 2620	80 – 5300	-	-
TDS	70 – 1834	53 – 3392	500	1000
Ca^{2+}	10 – 140	40 – 150	75	200
Mg^{2+}	6 – 84	14 – 100	30	70
Na^{+}	45 – 114	49 – 141	50	200
K^{+}	0.5 – 19.2	0.18 – 26.3	-	-
HCO_3^{-}	136 – 480	125 – 460	30	
Cl^{-}	7.5 – 542	9 – 1490	250	1000
SO_4^{2-}	8 – 200	10 – 180	200	400
NO_3^{-}	1 – 12	4 – 21	45	No relaxation
F^{-}	0.2 – 2.8	0.2 – 2.6	1.0	1.5
TH	50 – 700	53 – 800	300	600

Units of all parameters are in mg/l except EC(µS/cm) and pH

Table-2
Groundwater classification according to base-exchange index (r_1) and Meteoric genesis index (r_2) criteria for premonsoon and postmonsoon seasons

	Premonsoon- Water Types		Postmonsoon- Water Types	
Sample no	Base-exchange index (r_1)	Meteoric genesis index (r_2)	Base-exchange index (r_1)	Meteoric genesis index (r_2)
1	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
2	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
3	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
4	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
5	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
6	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
7	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
8	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
9	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
10	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
11	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
12	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
13	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
14	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
15	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
16	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
17	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
18	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
19	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
20	Na^{+} - SO_4^{2-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
21	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
22	Na^{+} - SO_4^{2-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
23	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
24	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
25	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric
26	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
27	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
28	Na^{+} - HCO_3^{-}	Shallow meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
29	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - HCO_3^{-}	Shallow meteoric
30	Na^{+} - SO_4^{2-}	Deep meteoric	Na^{+} - SO_4^{2-}	Deep meteoric

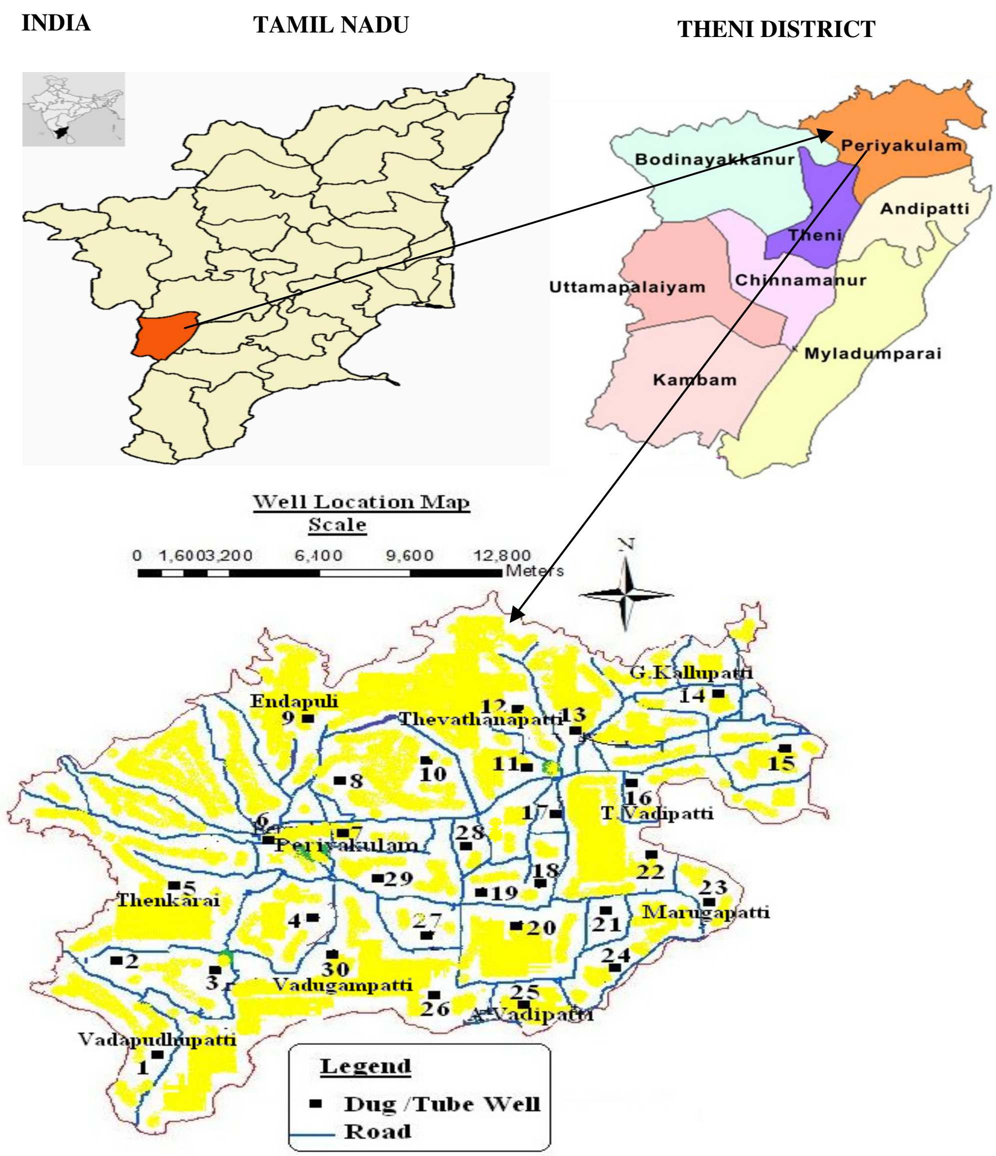

Figure-1
Location of the Study Area with Sampling Wells

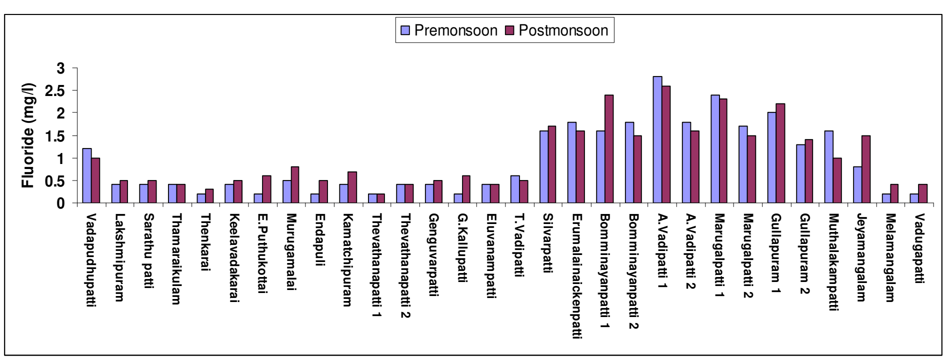

Figure -2:
Concentration of Fluoride groundwater samples

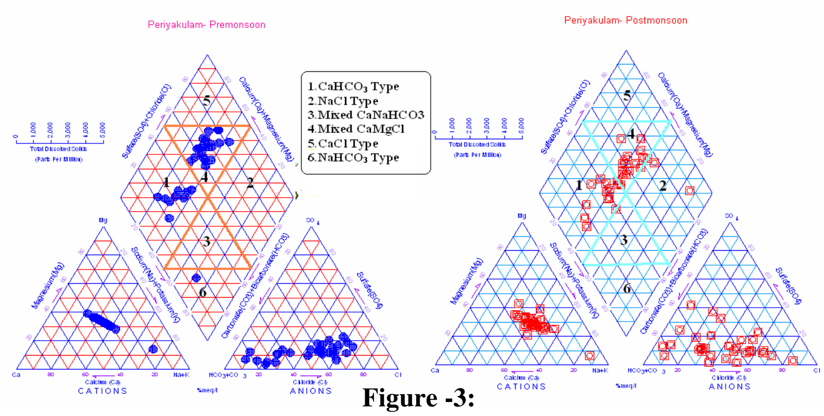

Figure -3:
Piper trilinear diagram for groundwater samples

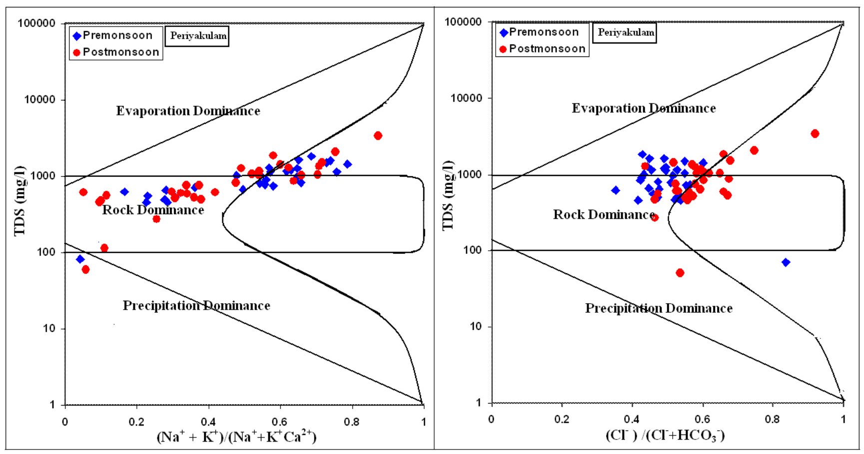

Figure-4
Gibbs diagram for groundwater samples

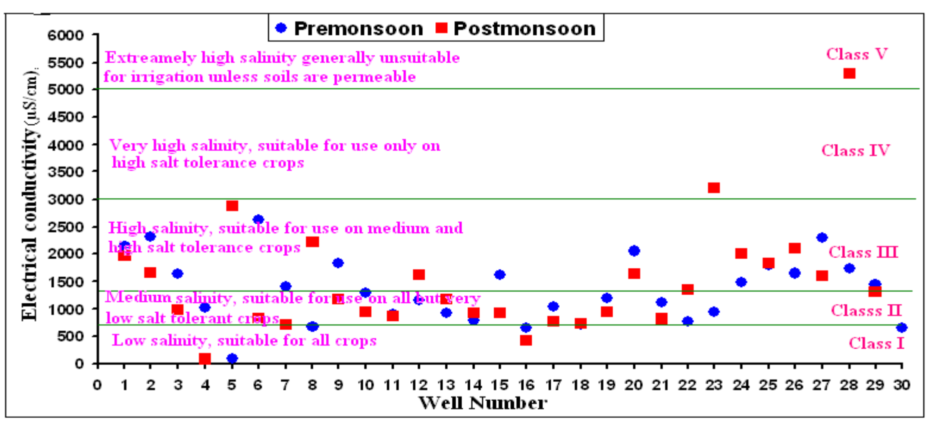

Figure-5
Salinity index for groundwater samples

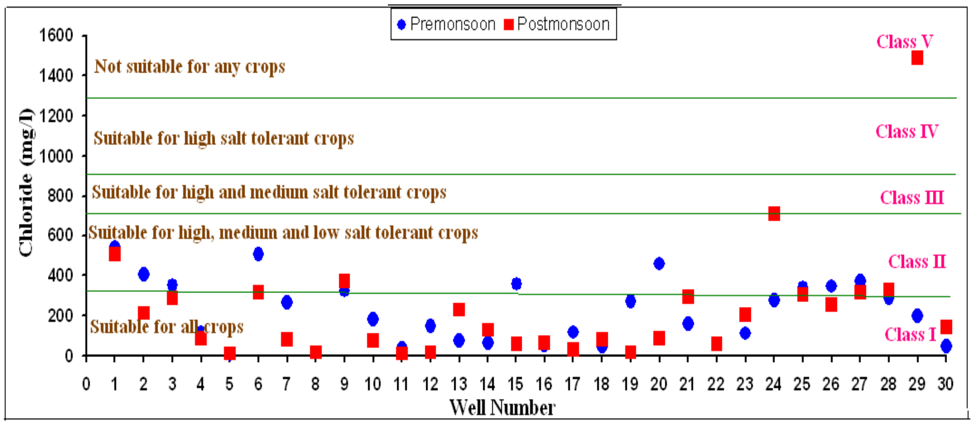

Figure-6
Chlorinity index for groundwater samples

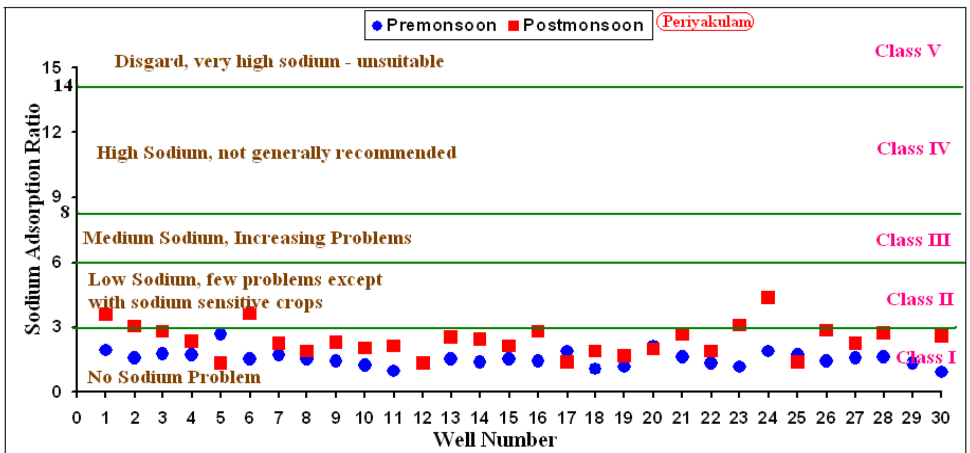

Figure-7
Sodicity index for groundwater samples

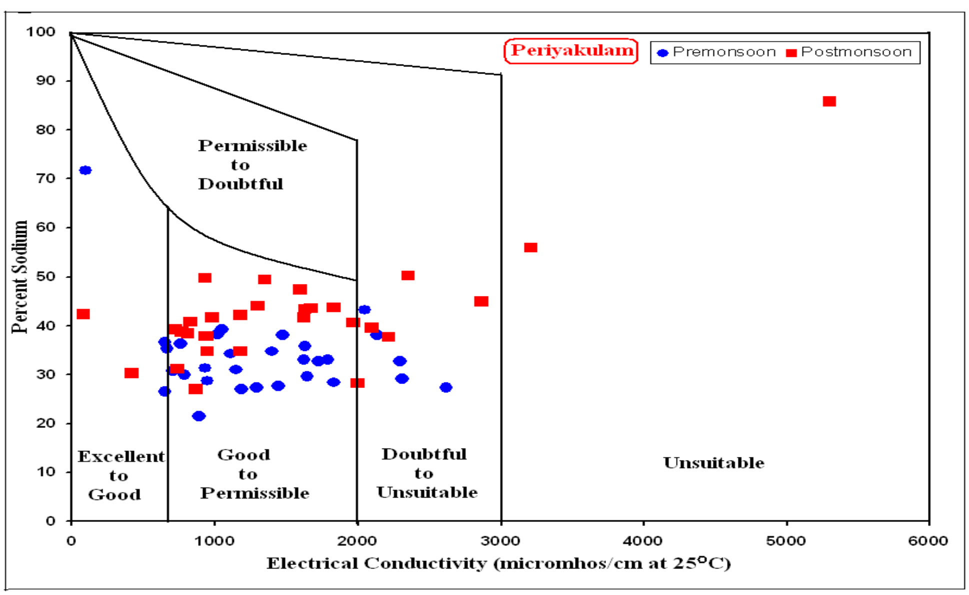

Figure-8
Wilcox diagram for groundwater samples

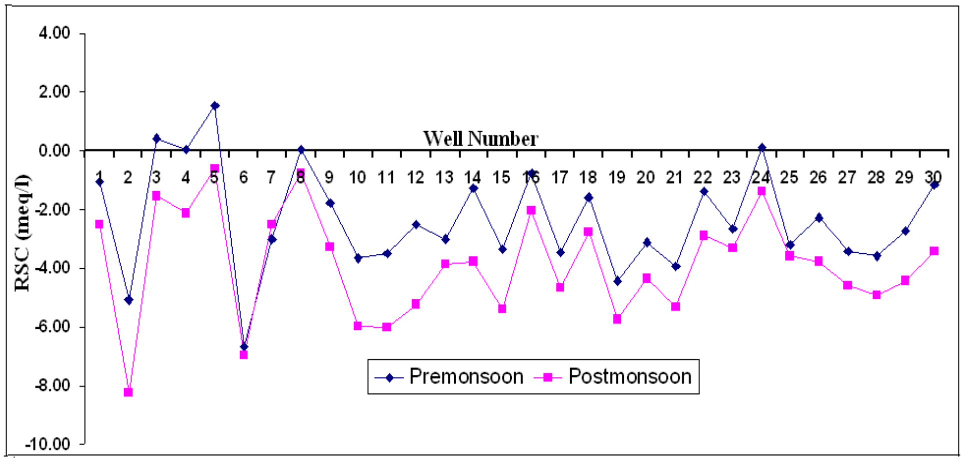

Figure -9
RSC values for groundwater samples