Quality of Groundwater in the Shallow Aquifers of a Paddy Dominated Agricultural River Basin, Kerala, India

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***Abstract*—**Groundwater is an essential and vital component of our life support system. The groundwater resources are being utilized for drinking, irrigation and industrial purposes. There is growing concern on deterioration of groundwater quality due to geogenic and anthropogenic activities. Groundwater, being a fragile must be carefully managed to maintain its purity within standard limits. So, quality assessment and management are to be carried out hand-in-hand to have a pollution free environment and for a sustainable use. In order to assess the quality for consumption by human beings and for use in agriculture, the groundwater from the shallow aquifers (dug well) in the Palakkad and Chittur taluks of Bharathapuzha river basin - a paddy dominated agricultural basin (order=8[th]; L= 209 Km; Area = 6186 Km^2), Kerala, India, has been selected. The water samples (n= 120) collected for various seasons, viz., monsoon-MON (August, 2005), postmonsoon-POM (December, 2005) and premonsoon-PRM (April, 2006), were analyzed for important physico-chemical attributes. Spatial and temporal variation of attributes do exist in the study area, and based on major cations and anions, different hydrochemical facies have been identified. Using Gibbs'diagram, rock dominance has been identified as the mechanism controlling groundwater chemistry. Further, the suitability of water for irrigation was determined by analyzing salinity hazard indicated by sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and sodium percent (%Na). Finally, stress zones in the study area were delineated using Arc GIS spatial analysis and various management options were recommended to restore the ecosystem.

***Keywords*—**Groundwater quality, agricultural basin, Kerala, India.

I. Introduction

GROUNDWATER has long been regarded as the pure form of water compared to surface water, because of purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange. This is one of the reasons for the excessive consumption of groundwater in rural and semi-urban areas all over the world. Most of the human activities including agriculture need ample quantities of water. Increasing demands of food grain by ever increasing population has resulted in the utilization of water resources to the limit. Groundwater, an underground reservoir, being the sustainable source of municipal and irrigation supplies suffered the most. It is estimated that approximately one third of the world's population uses groundwater for drinking purposes [38]. This is a well-recognized fact that the groundwater, through the ages, continues to be an essential commodity for a large number of users.

The chemical composition of groundwater is determined by a number of processes, which can chiefly be grouped into three - atmospheric inputs, interaction of water with soil and rock and anthropogenic activities. Precipitation, climate change and natural hazards add to the atmospheric inputs, while weathering and erosion of crustal materials result from the interaction of water with soil and rock. The anthropogenic disturbances through industrial and agricultural pollution, increasing consumption and urbanization degrade the groundwaters and impair their use for drinking, agricultural, industrial and domestic uses [34], [7], [18], and [19].

Groundwater, being a fragile and important source of drinking water, must therefore be carefully managed to maintain its purity within standard limits. Groundwater degradation occurs when its quality parameters are changed beyond their natural variations by the introduction or removal of certain substances [29], [37]. In regions of intense agricultural activities, the degradation results from the addition of salts by dissolution during the irrigation process, from salts added as fertilizers or soil amendments and from the concentration of salts by evapo-transpiration. Because irrigation is the primary use of water in arid and semi-arid regions, irrigation return flow can be the major cause of groundwater pollution in such regions [14].

So, quality assessment and management are to be carried out hand-in-hand to have a pollution free environment for the future. Hence, in order to assess the quality of groundwater for its consumption by human beings and for its use in agriculture, it becomes necessary to understand the chemical quality of water by estimating various relevant constituents [12].

The Palakkad district of Kerala State, India, which falls in the Bharathapuzha river basin (Order=8[th]; L= 209 Km; Area = 6186 km^2), is the land of paddy fields and palmyrahs. It is considered as one of the 'rice bowls' of the State. Its economy is sustained primarily by agriculture and to satisfy the needs of growing population, it becomes necessary to apply huge quantity of fertilizers and pesticides in agriculture. Tremendous quantity of fertilizers applied may 'leak' from the agricultural system in to surface water and groundwater through run off and

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seepage and ultimately contaminate them. Moreover, one of the major industrial areas in Kerala (i.e., Kanjikkod industrial area) is located on the banks of the upstream portion of Bharathapuzha River in the study area, and is reported to abstract thousands of liters of water everyday. These factors may also affect the quality of groundwater. In this paper an attempt has been made to study the groundwater quality aspects from an agricultural river basin in Palakkad, Kerala, India.

II. Study Area

The Palakkad (Area= 723.4 km^2) and Chittur (= 1152.0 km^2) taluks of Palakkad district, which fall in the Bharathapuzha River Basin (BRB) in northern Kerala, India have been selected for the present investigation (Fig. 1). It is confined between N. Lat. 10^0 15' 59'' to 10^0 55' 44'' and E. Long. 76^0 26' 49'' to 76^0 54' 29''. Most of the BRB, in the midland and parts of lowland, is under intense cultivation for wet crops like rice paddy and sugar cane and dry crops like, cotton, red pepper, legumes etc. Palakkad district alone contributes about 34% of the total rice paddy production in the State.

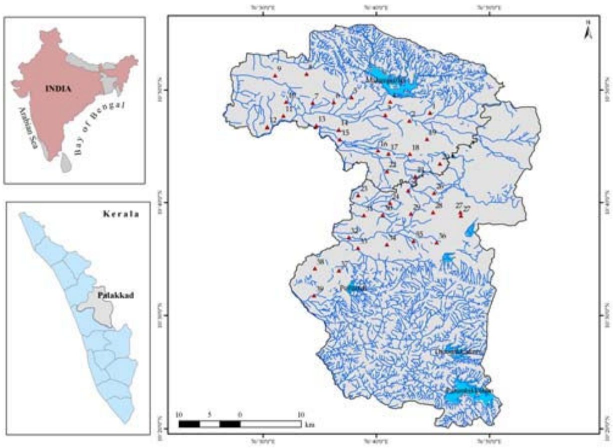


Fig. 1 Study Area

The 'Palakkad Gap' (L= 32 Km), a prominent structural discontinuity in the 960 Km. long Western Ghats of India, lies in the study area and is perhaps the most influential factor for the unique characteristics of the Palakkad district such as climate, commercial as well as cultural exchanges between the State and the rest of the country. Palakkad and Chittur taluks lie within the gap in juxtaposition with the Palakkad towards north and Chittur towards the south of the gap (Fig. 1).

Because of the unique geography, climate, agricultural and industrial activities in the study area, groundwater is of major concern and warrants attention. Hence, the abundance, pathways and sourcing of various physico-chemical constituents and nutrients in the shallow groundwater (dug well) should be systematically looked into for their suitability for drinking and irrigational purposes.

III. Materials and Methods

In order to assess the physico-chemical parameters, a total of 40 shallow groundwater (dug wells) locations covering the Palakkad and Chittur taluks have been selected (Fig. 1). The water samples (n= 120) were collected for monsoon-MON (August, 2005), postmonsoon-POM (December, 2005) and premonsoon-PRM (April, 2006) seasons. The portrait of the sampling locations and depth to water table for different seasons are given in Table I.

The various physico-chemicals attributes of water samples such as pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), Total Alkalinity (TA), Carbonates (CO_3), Bicarbonates (HCO_3), Sodium (Na), Potassium (K), Chloride (Cl), Nitrate (NO_3), Phosphate (PO_4) and Silicate (SiO_2) were analyzed following the standard procedure of APHA [2].

IV. Geology of the Area

Palakkad district is underlain by Archaean metamorphic complex. They include the granulite group, the gneisses and the schist. Intrusives of pegmatites and quartz veins are also common in the NE part of the district [35]. The general geologic succession encountered in the study area is given below.

TABLE II
General Geologic Successions in Palakkad District (Source: CGWB [8]

Recent	Top soil, valley fill and riverine alluvium
Sub-recent	Laterite
Archean	Pegmatites, quartz vein, dolerite, gabbro, granites, quartz-mica schist, hornblende biotite gneiss, ultramafics, charnockite, khondalits and calc-granulites.

The Archaean crystallines are the major rock types encountered in the study area. This includes Charnockites, khondalites, calc-granulites, hornblende gneiss, migmatites and gneisses.

V. Climate

The study area, in general, enjoys a humid tropical climate. Three distinct spells of season dominate the area, viz., premonsoon, monsoon and postmonsoon. The rainfall decreases from west towards east of the study area, varying from 2850.0 mm at Mannarkkad in the west to 1757.0 mm at Chittur near the southeastern part. The annual average rainfall of Palakkad district is 2106.6 mm (Source= IMD, India).

VI. Results and Discussion

The results of the water quality attributes of sallow groundwater for different seasons are given in Tables III-V. The season wise averages for the depth to water table are 7.28 ft. in MON, 7.33 ft in POM and 11.93 ft. in PRM respectively (Table I). The water level was lowered by 4.63 ft. during PRM compared to other seasons. Changes in water level generally affect the concentration of physico-chemical attributes of water. The present study reveals that the concentrations of almost all the ions in PRM were relatively low and exhibit increasing trend towards POM and MON seasons. What follows is a brief description of the important physico-chemical attributes of groundwater.

pH

The seasonal average of pH shows a slightly acidic value of 6.64. The season wise average exhibits relatively higher value in MON (ave.= 6.91) owing to leaching of dissolved salts into the groundwater [15]. Lower values of pH are noticed towards NW part of the study area. Among the samples, 15% each in MON and POM and 8% in PRM in Palakkad taluk record values lower than the minimum (6.5) prescribed for drinking water, whereas, the samples collected from Chittur taluk exhibit values within the permissible limits. Low pH in the groundwater of the study area can be attributed to the acidic lateritic soil [28], and to some extent the influence of fertilizers like ammonium sulphate and super phosphate in agriculture [3].

Electrical Conductivity (EC)

EC values range from 30 to 4900 µs/cm during MON, 130 to 3000 µs/cm during POM and 130 to 2140 µs/cm during PRM with the corresponding averages of 830, 644 and 634 µs/cm. The EC shows higher values towards the eastern part for all seasons. Samples from location Nos. 20, 27, 27a and 36 in all the seasons, No. 17 in POM and PRM, No.21 in MON, No.18 in POM and Nos. 1, 25 and 28 in PRM show values beyond 1000 µs/cm. Nutrient enrichment due to fertilizers may enhance TDS and it, in turn, increases the EC since these two parameters are directly related to each other [24]. The higher values of EC in the eastern parts may be due to semi-arid type climatic condition, high evaporation rate and incidence of inland salinity.

Total Dissolved Solids (TDS)

TDS content is usually the main factor, which limits or determines the use of groundwater for any purpose [26]. Nearly 25% of the samples in each season exhibit TDS values outside the permissible limit (500 mg/L). The values range between 54 and 3240 mg/L during MON, 75 and 1853 mg/L during POM and 66 to 1417 mg/L during PRM respectively. Season wise averages show that the concentrations are high during MON (ave.= 498 mg/L), followed by PRM (= 419) and POM (= 397 mg/L). Since EC is directly related to TDS, the locations showing high contents of EC support higher TDS. The spatial distribution of TDS shows higher values towards the eastern part of the study area. Peak values during MON may be due to the leaching of ions from the soils and rocks, and also from the agricultural fields [15].

Total Hardness (TH)

Hardness exhibits a minimum content of 20 to a maximum of 1480 mg/L during MON, 28 to 1120 mg/L during POM and 32 to 960 mg/L during PRM with the averages of 257, 210 and 228 mg/L respectively. The spatial distribution of hardness shows higher concentrations towards the eastern part. The dissolution of salts and minerals present in soil and nearby agricultural fields due to the rise in water table particularly during MON enhances its concentration in groundwater [21].

According to the classification put forwarded by [37], 47% samples in MON, 35% in POM and 38% in PRM fall in the hard category (i.e., 150-300 ppm). The very hard category (>300 ppm) comprises 15% in MON, 23% in POM and 22% in PRM. Nearly 60% of total samples for all seasons spread between hard and very hard types. Most of them belong to Chittur taluk.

The climate and geology of the area plays a very important role in contributing to the total hardness. The eastern part of the study area (i.e., Chittur taluk) enjoys a semi-arid type climate with an annual average rainfall of 1570 mm. Further, geologically, khondalites are one of the important rock types in the area and are associated with crystalline limestone. The leaching of Ca and Mg from these rocks adds to the hardness. Further, the agricultural activities directly or indirectly affect the concentrations of a large number of inorganic chemicals in groundwater such as NO3–, Cl–, SO42–, H+, PO4, C, K+, Mg2+, Ca2+ etc [6].

Total Alkalinity (TA)

Most of the alkalinity of natural waters is caused by bicarbonates, carbonates and hydroxides. The alkalinity content spans between 20 and 488 mg/L in MON, 16 to 488 mg/L in POM and 16 to 416 mg/L in PRM with the corresponding seasonal averages of 176, 154 and 174 mg/L. Majority of the samples in each season (i.e., 70%- MON, 55%- POM and 65%- PRM) exhibit alkalinity values above the permissible limit of 120 mg/L [41]. The spatial distribution of alkalinity shows higher values towards the central and eastern parts of the study area. This may be due to the dissolution of crystalline limestone in the Palakkad Gap region [35]. It may also be noted that in polluted waters, other negative ions like PO4, NO3 may contribute to alkalinity [25].

Carbonates and Bicarbonates

Carbonates in the dug well samples are present in fairly low concentrations. Moreover, only 40% samples in MON and 50% each in POM and PRM seasons showed its presence. Among the anions, bicarbonate is the dominant one and shows wide variation in concentration during all the seasons. It varies between 24.4 and 527.04 mg/L in MON, 19.52 and 458.72

mg/L in POM and 19.52 to 419.68 mg/L in PRM respectively. The averages for different seasons are 204 mg/L in MON, 169 in POM and 190 in PRM respectively.

The primary source of carbonate and bicarbonate ions in groundwater is the dissolution of carbonate minerals in the study area. The decay of organic matter present in the soil releases CO2. Water charged with CO2 dissolves carbonate minerals, as it passes through soils and rocks to give bicarbonates. Bicarbonates also show high positive correlation with alkalinity [13], [27]. The present study too reveals such positive relationship.

Calcium and Magnesium

Among the cations, Ca content shows seasonal variation and majority of the samples in all the seasons fall within the permissible limit (75 mg/L). Among the total samples, 15% in MON and 10% each in POM and PRM seasons register values beyond the permissible limit. The content of Ca spreads between 3 and 403 mg/L, 7 and 303 mg/L and 5 to 185 mg/L averaging 58.73, 44.48 and 41.55 mg/L during MON, POM and PRM respectively. The content up to 1800 mg/L does not impair any physiological reaction in man [22].

High concentration of Ca is not desirable in washing, laundering and bathing. Sample Nos. 20, 27 and 36 in all the seasons, Nos.18, 21 and 27a in MON, No. 2 in POM and No. 25 in PRM exhibited values far beyond the permissible limit. Although the sources of Ca in groundwater resources are mainly the crystalline limestone associated with khondalitic rocks, the prolonged agricultural activities prevailing in the study area may also directly or indirectly augment the mineral dissolution in groundwater [6].

The content of Mg is comparatively less than that of Ca. The Mg exhibits gradual increase in concentration from MON to non-monsoon seasons. Of the total samples, 23% in MON, 33% in POM and 44% in PRM show concentrations outside the permissible limit. The geochemistry of the rock types may have an influence in the concentration of Mg in groundwater.

Sodium and Potassium

Na is one of the important naturally occurring cations and its concentration in fresh waters is generally lower than that of Ca and Mg. But in the present investigation, the average concentration of Na is comparatively higher than that of Ca and Mg. Previous studies [8] in the same area also corroborate these results. For aesthetic reason, the guideline value given by WHO is 200 mg/L. Comparatively higher values were recorded from the north-eastern part of the study area and the values range between 10 and 527 mg/L in MON, 9 and 186 mg/L in POM and 5 and 172 mg/L in PRM with the averages of 66, 57 and 49 mg/L respectively. Sample No. 27a in MON registered value above the permissible limit. Since the eastern parts are covered mainly by hornblende-biotite gneiss and are migmatised, the geological influence on the concentration of the cations is well understood [35].

The concentration of K shows very low values in all the seasons with the averages of 9.5 in MON and 6.45 mg/L both in POM and PRM. Though, most of the source rocks contain approximately equal amounts of Na and K, and both are released during weathering, a part of the K go into clay structure and thereby its concentration gets reduced in water. However, sample Nos. 9 and 20 throughout the study period, 17 in MON and POM, 27 and 39 in MON and 27a in POM registered values above the drinking water standard of 12 mg/L [16], [40]. K contamination in groundwater can result from the application of inorganic fertilizer at greater than agronomic rates. Loss of nutrients, including K, from agricultural land have been identified as one of the main causative factors in reducing water quality in many parts of arid and semi-arid regions [40], [17], [20].

Chloride

Chloride occurs naturally in all types of waters. The chloride content of MON samples varies between 28 and 2043 mg/L (ave.= 208.05 mg/L), while in the POM samples it ranges from 33 to 1306 mg/L (ave.=165.38 mg/L). In the PRM samples it spread between 28.4 and 852 mg/L (ave.= 167.06 mg/L). Of the total samples, 15% in MON, 18% in POM and 23% in PRM exceed the permissible limit. Among them, sample Nos. 17, 25, 27, 27a and 36 in all the seasons, No.18 in MON and POM, No.24 in POM and PRM and Nos.20, 28 and 29 in PRM alone are included.

In natural waters, the probable sources of chloride comprise the leaching of chloride-containing minerals (like apatite) and rocks with which the water comes in contact, inland salinity and the discharge of agricultural, industrial and domestic waste waters [1], [8]. Agricultural application of K as a plant nutrient commonly results in chloride contamination of recharging shallow groundwater [6].

Nitrate

Nitrate in the study area is found to be comparatively very low in concentration. However, the season wise averages show slightly higher values during MON (0.97 mg/L), followed by PRM (0.8 mg/L) and POM (0.58 mg/L) respectively. The peak values registered during MON, POM and PRM are 8.97 (S.No.9), 3.38 (S.No.36) and 5.21 (S.No.36) mg/L respectively and none of the samples exceeds the permissible limit. Being loosely bound to soils, nitrate is expected to be more in run off and hence its concentration increases during rainy seasons [30].

Phosphate

Phosphate in natural water mostly ranges between 0.005 and 0.020 mg/L [9]. For this range, phosphate values of all the samples in the study area are comparatively high during all the seasons. Its content in the present investigation ranges from below detectable levels to 3.74 with an average of 0.26 mg/L during MON, below detectable levels to 1.52 with an average of 0.11 mg/L during POM and 0.02 to 3.79 mg/L with an average of 0.24 mg/L during PRM respectively. Sample No. 20 exhibits abnormally high values (3.74, 1.52, and 3.79 mg/L during MON, POM and PRM respectively) throughout the investigation. Use of phosphate as fertilizer perhaps contributed in this context as the basin is predominantly agricultural and in Kerala, application of fertilizers is a common practice [10]. The enrichment in MON period reveals that leaching through soil has a strong bearing on the nutrient levels in groundwater [4].

Silicate

Silicate shows dominance over other nutrients such as nitrate and phosphate. Its content spans from 7.51 to 40.49 mg/L in MON, 4.11 to 13.66 mg/L in POM and 3.66 to 44.06 mg/L in PRM with the averages at 17.65, 9.78 and 25.02 mg/L respectively. The higher concentration might be due to the mineral weathering process in the study area [5].

The results of the physico-chemical parameters show that among major cations, Na and Ca are generally dominant throughout the study period. Na represents 41.53% in MON, 44.15% in POM and 38.03% PRM. The next dominant cation is Ca and it represents 36.87% in MON, 33.95% in POM and 34.22% in PRM. Mg ions are of secondary importance only. The K ion is present in very low amounts (seasonal ave.= 4.83%). Thus, the order of abundance of the cations in the groundwater can be shown as Na>Ca>Mg>K. Among major anions, HCO3 (seasonal ave.= 57.56%) is the dominant one, followed by Cl (= 40.18%) and carbonate (= 2.26%). The order of anionic abundance is HCO3>Cl>CO3.

The spatial distribution of attributes such as EC, TDS, TH and TA shows higher contents towards the central and eastern part of the study area, which falls in the Chittur taluk. The major cations such Ca, Mg, Na and K and anions such as CO3, HCO3 and Cl also follow the same trend. The samples showing higher concentrations for most of the parameters throughout the study period include Nos. 20, 21, 25, 27, 27a and 36. The elevated concentration of parameters in these locations is contributed by over-exploitation of groundwater for both industrial and agricultural activities, intensive agricultural activities using chemical fertilizers, semi-arid type climatic set up and high evaporation rate in the eastern part. Further, seasonal fluctuations show rise in concentrations of all the parameters during MON, followed by PRM and POM. Since the depth to water table is relatively very low and major parts of the study area are agricultural in nature, nutrients from the adjacent soils and agricultural fields in the form of fertilizers may leach into the nearby wells during MON period resulting in their increased concentrations.

VII. Correlation Analysis

In this study, correlation analyses between various attributes of shallow groundwater for different seasons have been done and are presented in Tables VI-VIII. The EC is strongly correlated with TDS, Ca, Mg and Na. Among the anions, Cl shows high correlation with EC. The results show that the dissolved ions in the groundwater are responsible for EC. The hardness is strongly correlated with Ca, Mg and Cl. Only during PRM, it shows moderate correlation with bicarbonates, indicating hardness is mainly due to chloride ions. Alkalinity exhibits high positive correlation with bicarbonates. Chloride is highly correlated with Ca, Mg and Na. Likewise, HCO3 ions show moderate to high correlation with Mg and Na during the study period. A very significant correlation has been noticed between K and PO4. Similarly, in all seasons, the major exchangeable ions Na and Ca; Na and Mg correlate positively. It can therefore be postulated that the concurrent increase/decrease in the composition of ions in these waters is predominantly due to the result of dissolution/precipitation reaction and concentration effects.

VIII. Hydrochemical Facies

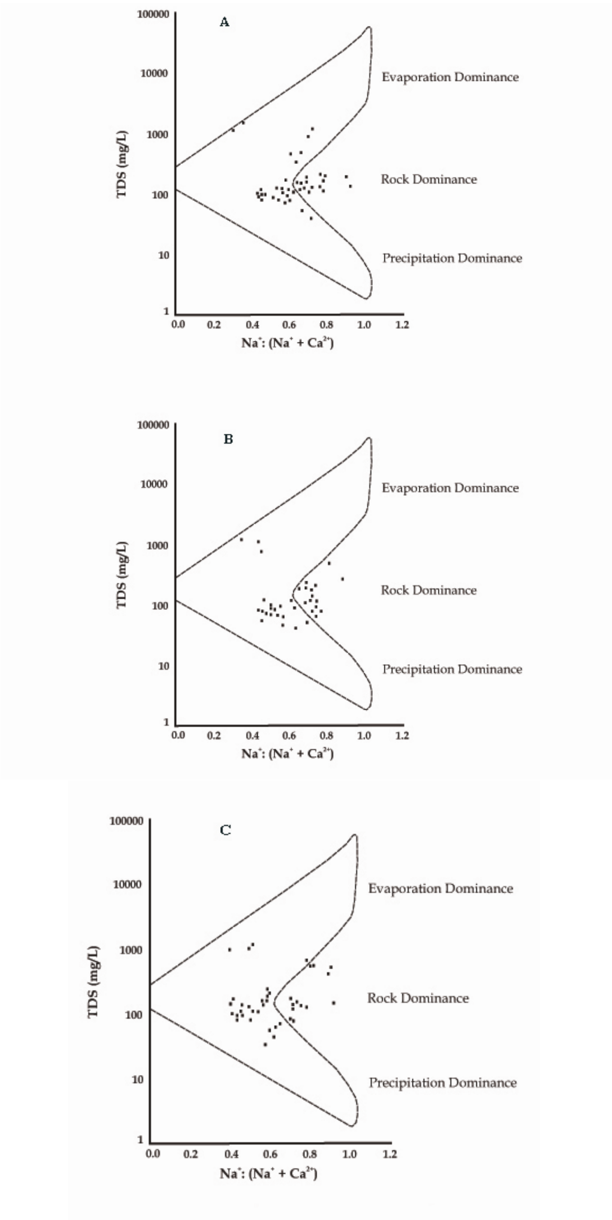
Hydrochemical facies are water masses that have different geochemical attributes and are helpful for comparing the origins and distribution of groundwater masses [23]. In case of a clear domination of a particular cation or anion (>50% of total cations or anions), the facies can be identified based on dominant constituents. In case of no clear-cut domination, 1/3 or 33% is taken as cut-off value. For example, a sample having cation constituents as Na- 40%, Ca- 36%, Mg- 20%, K- 4%, and anion as Cl- 42%, HCO3- 40%, SO4- 14% and NO3- 4%, is marked as Na-Ca-Cl-HCO3 facies [31].

Based on the relative dominance of major cations and anions, different hydrochemical facies have been identified in the study area. Various water masses identified and their average chemical composition for MON, POM and PRM are given in Tables IX-XI. Of the total facies identified, four are found to be represented by most of the samples. Among them, three are Na dominated and one is Ca dominated. These include Na-Ca-HCO3 (MON- 38%; POM- 23%; PRM- 13%) type, Na-HCO3 (MON- 18%; POM- 30%; PRM- 23%) type, Na-Cl (MON- 10%; POM- 15%; PRM- 13%) type and Ca-HCO3 (MON- 15%; POM- 18%; PRM- 23%) type.

IX. Gibb's Diagram

The Gibbs ratio for the ions (Na/ Na + Ca and Cl/ (Cl + HCO3) of groundwater samples were plotted against the respective values of TDS. The plot (Fig. 2) indicates that more than 90% of the groundwater samples in all the seasons fall in the rock dominant category and the rest fall in the evaporation field. Rock dominance of most of the samples is caused by the interaction between the aquifer rocks and groundwater.

Fig. 2 Gibbs diagram showing the controlling mechanism of groundwater a) monsoon, b) postmonsoon and c) premonsoon



X. Irrigation Water Quality

The suitability of water for irrigation was determined by analyzing salinity hazard indicated by sodium adsorption ratio (SAR), residual sodium carbonate (RSC) and sodium percent (%Na). The calculated ionic concentrations are expressed in milliequivalents/litre and the results are given in Table XII.

Salinity Hazard

Majority of the samples i.e., 68% each in MON and POM and 73% during PRM fall in low to medium salinity hazard categories, while 28% show high salinity hazard throughout the seasons. Two samples (S.Nos.27 & 27a) in MON and one sample (S.No.27) in POM come under very high category. The samples having high and very high salinity hazard belong to the central and eastern parts. Medium salinity water can be used if leaching occurs. High salinity water cannot be used on soils with restricted drainage. Very high salinity water is not suitable for irrigation.

Sodium Adsorption Ratio (SAR)

The SAR values of all the samples during all the seasons fall within the low category (1-10). Therefore, in terms of SAR, all the samples are suitable for irrigation.

Residual Sodium Carbonate (RSC)

Almost all the samples show RSC values well within the permissible limit in all the seasons. Sample No.16 in all the seasons and S. No.1 in PRM are found to be not suitable for irrigation as they have high RSC values. Continued usage of high RSC water affects the yield of crops [36]. In addition to SAR and %Na, the RSC also influences the unsuitability of groundwater for irrigation.

Percent Sodium (%Na)

Majority of the samples i.e., 63% each in MON and POM and 70% in PRM fall in good category. Of the remaining samples 18% in MON, 30% in POM and 10% in PRM fall in permissible class. The samples under the excellent category comprise 18% in MON, 13% in PRM and none in POM. As per Indian standards, a maximum of 60% Na is permissible for irrigation water. When the concentration of Na is high in irrigation water, Na ions tend to be absorbed by clay particles, displacing Mg and Ca ions. The exchange process of Na water for Ca and Mg in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [11], [32].

The result of various irrigation quality parameters shows that more than 90% of the shallow groundwater maintain good quality in all the seasons and is very suitable for agricultural purpose. Only a few samples are found to be not suitable for irrigation. Among them, two samples (Nos.27 & 27a) in MON and one (No.27) in POM are having high salinity hazard. Likewise, sample No.16 in all the seasons and S.No.1 in PRM are found to be not suitable as they have high RSC values. This is due to the increased concentration of major cations such as Ca, Mg, Na and K, and anions CO3 and HCO3.

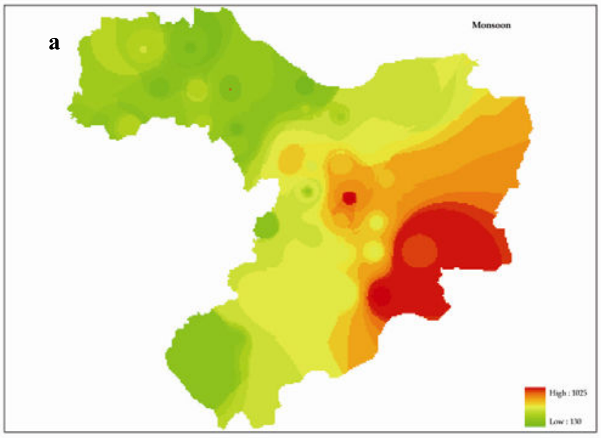
XI. GIS Modeling

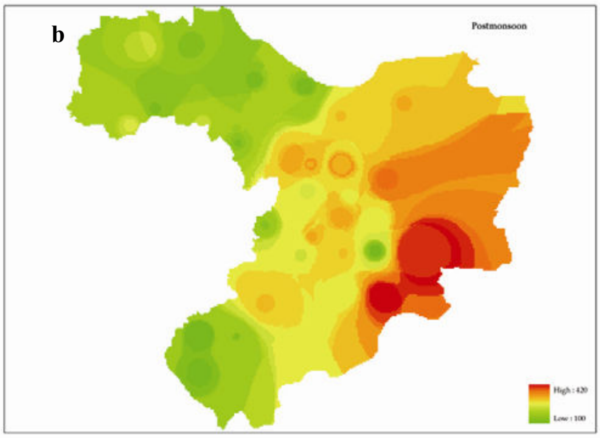
The stress zones based on the selected parameters of hydrochemical data of groundwater for MON, POM and PRM were delineated with Arc GIS 9.1 (Fig. 4). The Arc GIS Spatial Analyst adds a comprehensive and wide range of cell-based GIS functions and among the three main types of GIS data (raster, vector and TIN), the raster data structure provides the most comprehensive modeling environment and operated for spatial analysis.

The sampling locations were mapped with the help of Survey of India toposheet of the scale 1:50000 and Global Positioning System (GPS). The hydrochemical data considered for the modeling were pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH) and Total Alkalinity (TA). The seasonal water chemistry data are related with its spatial dimension and further specially interpolated using Inverse Distance Weighted Method (IDW). This interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

An 'overlay analysis' using GIS platform was done after giving proper weightage for the various 'thematic layers' developed with the above parameter. The attribute EC was given more weightage (weightage factor=30), followed by TH (= 20), TA (= 20), TDS (= 15) and pH (= 15).

The weightages of individual themes (pH, EC, TDS, TH & TA) and feature score were fixed and added to the layers, depending upon their capability to influence the water quality prevailing in the region. This process is most commonly known as Multi-Criteria Evaluation. Of several methods available for determining interclass/inter-map dependency, a probability weighted approach has been adopted that allows a linear combination of probability weights of each thematic maps (Wt) and different categories of derived thematic maps have been assigned scores (Wi) and the total weights of the final integrated maps were derived as sum or product of the weights assigned to the different layers according to their suitability. Based on the analysis, it is evident that for all the three seasons, the study area shows a 'hotspot' towards the eastern part which fall mainly in the Chittur taluk (Fig. 3).





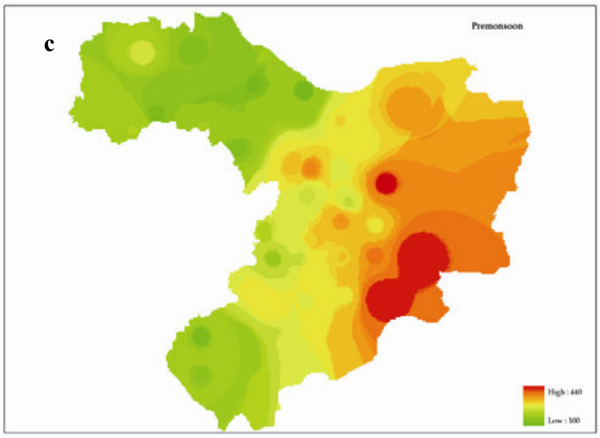


Fig. 3 Spatial variation of stress zones based on water quality parameters during a) premonsoon, b) monsoon and c) postmonsoon

XII. Summary

In order to assess the quality (in terms of physical and chemical content) of the shallow groundwaters (dug well) of Palakkad and Chittur taluks, water samples have been collected and analyzed for different seasons. The study has revealed the following points.

The pH of shallow groundwaters, in general, exhibits slightly acidic nature (ave.= 6.64). The TDS values of nearly 25% of the samples in each season fall outside the desirable limit. The locations showing high contents of EC support higher TDS. Peak values for these two parameters were observed during MON.

The total hardness of nearly 60% of samples for all seasons spreads between hard and very hard types. Most of them belong to the eastern part (Chittur taluk). The total alkalinity of nearly 50% of samples in each season exhibits values above the permissible limit. The spatial distribution of alkalinity shows higher values towards the central and eastern part. Bicarbonates and carbonates also exhibit similar trend.

The majority of the cations show values within permissible limits. Na represents a seasonal average of 41%, Ca- 35%, Mg- 19% and K- 4.83%. The order of abundance of cations is Na>Ca>Mg>K. Among major anions, HCO3 and Cl are generally dominate representing on an average of 57.56% and 40.18% respectively. Carbonate is secondary in importance (ave.= 2.26%). The order of anionic abundance is HCO3>Cl>CO3.

The content of all the nutrients (N, P, K and Si) are higher in MON, followed by PRM and POM, indicating the leaching of nutrients from the agricultural fields during monsoon season.

It has been found that 23% of the samples in MON, 33% in POM and 35% in PRM are not suitable for drinking. The irrigation water quality studies show that more than 90% of samples maintain good quality and is very suitable for agricultural purpose.

Based on the relative dominance of major cations and anions, different hydrochemical facies have been identified and majority of the samples are represented by Na-Ca-HCO3 and Na-HCO3 types of water.

Gibb's diagram shows rock weathering as the dominant process controlling water quality. The spatial variation of groundwater parameters shows an increasing trend in their concentration towards the central and eastern part for all the three seasons, which falls in the Chittur taluks.

Based on GIS modeling using 'overlay analysis' of various 'thematic layers' developed with some selected parameters (pH, EC, TDS, TH & TA), a stress zone or "hotspot" in the study area has been found out towards the eastern part which falls mainly in the Chittur taluk.

XIII. Management Options

Delineate the non-potable groundwater zones and water scarcity zones in the central and eastern part of the study area, and then study the hydraulic characteristics of the aquifer there.

Over-exploitation of groundwater should be avoided in the above sensitive zones.

Rain water harvesting should be encouraged particularly in the eastern part of the study area. Excess rain water stored should be directed to recharging wells.

In order to reduce the contamination on land and groundwater, the effluent from the factories and other point sources should be properly treated or diluted before discharging into the adjacent land or water body.

To avoid over-fertilization in the agricultural area, the rate of nitrogen fertilizer to be applied needs to be calculated on the basis of the "crop nitrogen balance". This takes into account plant needs and amount of nitrogen in the soil.

Encourage the farmers to use biofertilizers and biopesticides to avoid the soil, surface water and groundwater contamination.

The acidic groundwaters in some regions of the study area should be neutralized by adding lime or bleaching powder periodically.

Awareness and training programes should be conducted for the NGO's and the local people for the sustainable use and management of groundwater of the region and for the need for rainwater harvesting.

A short term and long term management action plan should be formulated for the efficient use of the groundwater resources and other natural resources after taking into account the population distribution, industrial activities, agricultural activities etc.

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Table 1. Portrait and season wise depth to water table of ground water sampling sites of Palakkad and Chittur taluks

Loc. No.	Location Name	Taluk Name	Lat.	Long.	DWT (in ft.)		
					MON	POM	PRM
1	Kanjikkod	Palakkad	10:47:57	76:44:46	4	7.33	17.17
2	Pudusseri	Palakkad	10:47:14	76:42:57	2	1.67	6.73
3	Kottekkad	Palakkad	10:47:44	76:40:49	6	2.33	7.33
4	Kunappulli	Palakkad	10:48:56	76:41:14	9.3	8.83	9.67
5	Ummini	Palakkad	10:49:20	76:37:50	g.l	2.53	5.53
6	Muttikulangara	Palakkad	10:48:54	76:36:16	5	4.23	7.90
7	Manakkampadam	Palakkad	10:48:50	76:34:24	12.2	26.93	24.63
8	Mailampully	Palakkad	10:51:22	76:33:52	14	13.33	16.27
9	Kongad	Palakkad	10:51:16	76:31:06	10.5	10.00	9.70
10	Pullode	Palakkad	10:48:55	76:32:03	8	13.33	14.00
11	Tenur	Palakkad	10:47:41	76:31:49	6	5.73	12.33
12	Mankara	Palakkad	10:46:41	76:30:24	g.l	5.00	12.53
13	Edattara	Palakkad	10:46:48	76:34:43	7.5	12.33	12.53
14	Kallekkad	Palakkad	10:46:28	76:36:42	g.l	3.33	6.93
15	Mozhioulam	Palakkad	10:45:37	76:36:48	4	4.20	13.40
16	Yakkara	Palakkad	10:44:37	76:40:11	10	14.33	16.43
17	Tiruvalatur	Palakkad	10:44:20	76:41:06	8.05	7.67	8.50
18	polpulli	Palakkad	10:44:18	76:43:00	7	6.67	7.97
19	Elappulli	Palakkad	10:45:39	76:44:30	6.1	5.83	11.07
20	Kolluparambu	Palakkad	10:43:26	76:45:39	11.3	10.83	15.93
21	Palathulli	Palakkad	10:42:18	76:43:28	10	12.50	15.97
22	Peruvemba	Palakkad	10:42:45	76:40:58	3	3.33	6.87
23	Ethanur	Chittur	10:40:40	76:38:25	2	5.50	22.53
24	Pudunagaram	Chittur	10:39:58	76:41:14	10	10.33	14.67
25	Tathamangalam	Chittur	10:41:13	76:43:02	7		13.40
26	Vilayodi	Chittur	10:40:52	76:45:08	7	6.67	7.87
27	Plachimada	Chittur	10:39:08	76:47:27	g.l	7.50	13.00
27a	Plachimada	Chittur	10:39:08	76:47:27	g.l	6.67	13.67
28	Vandithavalam	Chittur	10:39:08	76:45:03	11		15.17
29	Karuppali	Chittur	10:39:00	76:43:05	15	11.67	16.23
30	Tamarapadam	Chittur	10:38:55	76:40:36	6	9.17	13.50
31	Tachankod	Chittur	10:38:52	76:38:56	g.l	4.33	10.57
32	Kudallur	Chittur	10:36:57	76:37:36	g.l	3.33	8.93
33	Elavancheri	Chittur	10:36:01	76:38:24	2	3.33	7.93
34	Payyalur	Chittur	10:36:20	76:40:58	4	3.67	6.07
35	Manchira	Chittur	10:36:38	76:43:20	7	6.67	9.57
36	Kambrattuchalla	Chittur	10:36:30	76:45:21	g.l	4.00	5.57
37	Chammanthod	Chittur	10:33:59	76:36:43	g.l	6.67	20.13
38	Kaipancheri	Chittur	10:34:10	76:34:35	g.l	3.33	6.53
39	Payyangod	Chittur	10:31:48	76:34:32	3.5	3.33	12.33

DWT: depth to water table; g.l: ground level

Table 3. Physico-chemical parameters of shallow groundwater samples of Palakkad and Chittur taluks, Monsoon (August) 2005

Loc. No.	Temp	PH	EC	TDS	TH	Ca	Mg	Na	K	Cl	TA	CO3	HCO3-	NO3	PO4	SiO2
1	26.00	7.00	600.00	299.00	156.00	56.00	3.90	60.00	2.00	65.00	176.00	9.60	195.20	0.45	0.10	11.71
2	27.00	7.60	420.00	225.00	156.00	39.00	14.27	19.00	2.00	57.00	148.00	4.80	170.80	0.11	0.15	7.83
3	25.00	6.60	460.00	256.00	152.00	34.00	16.35	37.00	3.00	40.00	172.00	9.60	190.32	0.43	0.25	12.49
4	25.00	6.50	220.00	63.00	44.00	8.00	5.86	13.00	2.00	34.00	40.00	0.00	48.80	0.43	0.06	8.66
5	26.00	6.40	310.00	153.60	100.00	29.00	6.71	15.00	2.00	43.00	96.00	0.00	117.12	0.23	0.08	11.20
6	26.00	6.50	30.00	143.70	80.00	25.00	4.27	18.00	4.00	43.00	96.00	0.00	117.12	1.50	0.09	12.49
7	27.00	5.80	620.00	364.00	128.00	30.00	12.93	60.00	12.00	244.00	64.00	0.00	78.08	1.78	0.10	15.13
8	27.00	5.80	180.00	54.00	20.00	3.00	3.05	10.00	1.00	34.00	20.00	0.00	24.40	0.15	0.07	7.51
9	26.00	5.90	820.00	510.00	152.00	37.00	14.52	83.00	34.00	227.00	68.00	0.00	82.96	8.97	0.16	9.97
10	27.00	6.00	320.00	162.00	60.00	10.00	8.54	29.00	2.00	65.00	56.00	0.00	68.32	1.03	0.12	17.29
11	26.00	6.40	370.00	193.00	84.00	24.00	5.86	30.00	6.00	62.00	84.00	0.00	102.48	0.00	0.21	10.63
12	27.00	7.00	480.00	268.00	180.00	44.00	17.08	25.00	2.00	57.00	172.00	19.20	170.80	0.45	0.15	13.83
13	26.00	6.50	490.00	271.00	140.00	34.00	13.42	47.00	3.00	45.00	176.00	0.00	214.72	0.07	0.20	11.20
14	27.00	6.60	280.00	125.00	64.00	19.00	4.03	16.00	2.00	37.00	64.00	0.00	78.08	0.26	0.12	18.00
15	27.00	6.40	420.00	230.00	80.00	19.00	7.93	50.00	2.00	54.00	120.00	0.00	146.40	0.53	0.16	23.80
16	26.00	7.50	980.00	614.00	176.00	27.00	26.47	150.00	1.00	85.00	488.00	33.60	527.04	0.33	0.93	24.14
17	27.00	7.40	990.00	626.00	292.00	57.00	36.48	86.00	15.00	283.00	176.00	14.40	185.44	3.27	0.53	19.14
18	29.00	7.00	1150.00	722.00	416.00	98.00	41.72	73.00	3.00	397.00	168.00	9.60	185.44	0.06	0.06	20.54
19	29.00	7.30	700.00	414.00	224.00	37.00	32.09	63.00	2.00	145.00	236.00	19.20	248.88	0.07	0.20	23.17
20	27.00	7.00	1180.00	743.00	280.00	77.00	21.35	81.00	147.00	170.00	240.00	14.40	263.52	2.74	3.74	26.23
21	27.00	7.00	1730.00	1171.00	540.00	109.00	65.27	152.00	4.00	525.00	320.00	0.00	390.40	0.03	0.04	19.94
22	25.00	7.80	440.00	239.00	144.00	42.00	9.52	27.00	2.00	145.00	120.00	0.00	146.40	0.00	0.03	15.74
23	26.00	6.60	310.00	137.00	76.00	22.00	5.12	16.00	5.00	37.00	88.00	0.00	107.36	0.00	0.39	17.14
24	25.00	6.50	720.00	425.00	240.00	47.00	29.89	64.00	1.00	145.00	160.00	0.00	195.20	0.58	0.10	20.37
25	26.00	7.00	970.00	592.00	420.00	69.00	60.39	67.00	1.00	241.00	352.00	14.40	400.16	0.00	0.03	22.29
26	25.00	7.50	780.00	451.00	260.00	62.00	25.62	70.00	2.00	108.00	260.00	9.60	297.68	0.20	0.09	20.60
27	25.00	7.20	3460.00	2240.00	1480.00	403.00	115.29	132.00	3.00	1418.00	160.00	0.00	195.20	1.83	0.02	40.49
27a	26.00	7.20	4900.00	3240.00	1220.00	252.00	143.96	527.00	68.00	2043.00	236.00	0.00	287.92	3.36	0.00	30.86
28	27.00	7.30	740.00	444.00	216.00	49.00	22.81	71.00	10.00	93.00	232.00	14.40	253.76	0.09	1.07	22.17
29	27.00	7.50	930.00	473.00	240.00	47.00	29.89	87.00	2.00	213.00	280.00	9.60	322.08	0.59	0.06	33.43
30	27.00	7.40	550.00	309.00	200.00	37.00	26.23	42.00	1.00	43.00	240.00	14.40	263.52	1.14	0.10	21.94
31	26.00	7.50	672.00	335.00	168.00	37.00	18.42	57.00	1.00	74.00	192.00	0.00	234.24	0.00	0.10	24.51
32	27.00	7.50	690.00	386.00	240.00	44.00	31.72	56.00	2.00	170.00	200.00	19.20	204.96	0.59	0.03	15.40
33	27.00	7.00	832.00	429.00	300.00	72.00	29.28	44.00	2.00	82.00	292.00	0.00	356.24	0.00	0.08	14.69
34	26.00	7.40	604.00	398.00	232.00	50.00	26.11	55.00	2.00	28.00	228.00	0.00	278.16	0.49	0.33	15.63
35	25.00	7.50	540.00	263.00	204.40	56.00	15.71	18.50	1.00	31.00	204.00	9.60	229.36	0.69	0.12	12.69
36	25.00	7.00	2080.00	1351.00	780.00	170.00	86.62	125.00	2.00	582.00	320.00	0.00	390.40	5.34	0.09	15.40
37	26.00	7.00	480.00	246.00	124.00	30.00	11.96	34.00	10.00	60.00	124.00	0.00	151.28	0.00	0.10	8.23
38	26.00	6.50	320.00	137.00	96.00	22.00	10.00	12.00	2.00	37.00	80.00	0.00	97.60	0.58	0.07	14.14
39	27.00	6.90	410.00	205.00	88.00	22.00	8.05	30.00	13.00	60.00	100.00	0.00	122.00	0.41	0.11	15.31

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 4. Physico-chemical parameters of shallow groundwater samples of Palakkad and Chittur taluks, Postmonsoon (December) 2005

Loc. No.	Temp	PH	EC	TDS	TH	Ca	Mg	Na	K	Cl	TA	CO3	HCO3-	NO3	PO4	SiO2
1	26.00	7.00	970.00	512.00	188.00	40.00	21.47	140.00	2.00	142.00	308.00	33.60	307.44	0.23	0.00	8.46
2	25.00	6.50	710.00	418.00	312.00	82.00	26.11	33.00	3.00	111.00	246.00	38.40	222.04	0.28	0.03	6.49
3	23.00	6.50	320.00	196.00	104.00	20.00	13.18	24.00		43.00	108.00	9.60	112.24	0.16	0.18	7.57
4	21.00	6.50	130.00	75.00	28.00	8.00	1.95	11.00	1.00	33.00	40.00	0.00	48.80	0.07	0.00	5.37
5	23.00	6.00	180.00	109.00	72.00	19.00	5.98	9.00	1.00	33.00	60.00	0.00	73.20	0.00	0.03	4.94
6	23.00	6.50	210.00	132.00	56.00	15.00	4.51	21.00	2.00	43.00	72.00	4.80	78.08	0.55	0.13	9.23
7	23.00	6.00	350.00	223.00	76.00	20.00	6.34	39.00	4.00	114.00	52.00	0.00	63.44	0.30	0.01	7.57
8	23.00	5.50	140.00	82.00	28.00	7.00	2.56	14.00	1.00	50.00	16.00	0.00	19.52	1.03	0.04	4.11
9	25.00	6.00	630.00	397.00	112.00	30.00	9.03	70.00	23.00	151.00	66.00	4.80	70.76	1.88	0.10	5.51
10	24.00	6.00	200.00	122.00	44.00	8.00	5.86	21.00	1.00	57.00	52.00	0.00	63.44	0.45	0.08	9.31
11	22.00	6.00	180.00	110.00	48.00	12.00	4.39	16.00	4.00	48.00	44.00	0.00	53.68	0.58	0.01	8.06
12	24.00	6.50	460.00	286.00	176.00	34.00	22.20	24.00	2.00	80.00	160.00	19.20	156.16	0.12	0.13	12.46
13	22.00	6.50	440.00	280.00	144.00	37.00	12.57	44.00	2.00	62.00	172.00	14.40	180.56	0.10	0.10	10.74
14	22.00	6.50	230.00	150.00	80.00	22.00	6.10	14.00	1.00	40.00	72.00	0.00	87.84	0.07	0.12	12.83
15	24.00	6.00	190.00	124.00	40.00	10.00	3.66	21.00	1.00	38.00	64.00	0.00	78.08	0.40	0.09	12.51
16	23.00	7.50	860.00	557.00	168.00	25.00	25.74	157.00	1.00	97.00	488.00	67.20	458.72	0.53	0.09	13.66
17	24.00	6.50	1070.00	699.00	292.00	56.00	37.09	115.00	13.00	355.00	192.00	24.00	185.44	1.33	0.29	12.17
18	26.00	6.50	1160.00	692.00	376.00	67.00	50.87	94.00	2.00	412.00	112.00	9.60	117.12	0.32	0.03	12.97
19	27.00	6.50	670.00	421.00	216.00	32.00	33.18	67.00	1.00	105.00	204.00	24.00	200.08	1.65	0.08	13.20
20	25.00	6.60	1300.00	846.00	332.00	94.00	23.67	79.00	123.00	190.00	268.00	14.40	297.68	0.99	1.52	13.46
21	25.00	7.00	760.00	462.00	224.00	47.00	25.99	93.00	2.00	213.00	192.00	9.60	214.72	0.76	0.01	9.89
22	24.00	6.50	520.00	332.00	192.00	55.00	13.30	37.00	1.00	102.00	120.00	9.60	126.88	0.54	0.03	10.91
23	23.00	6.50	220.00	142.00	72.00	19.00	5.98	14.00	5.00	45.00	64.00	0.00	78.08	0.26	0.18	5.46
24	22.00	6.50	940.00	595.00	316.00	67.00	36.23	85.00	1.00	327.00	204.00	21.60	204.96	0.66	0.11	11.60
25	25.00	7.00	920.00	580.00	352.00	60.00	49.29	70.00	1.00	256.00	284.00	0.00	346.48	0.78	0.05	12.14
26	23.00	6.50	740.00	381.00	220.00	37.00	31.11	64.00	1.00	111.00	172.00	9.60	190.32	1.03	0.03	10.43
27	25.00	7.50	3000.00	1853.00	1120.00	303.00	88.45	150.00	2.00	1306.00	108.00	0.00	131.76	2.33	0.02	12.26
27a	25.00	6.50	1460.00	872.00	348.00	61.00	47.70	186.00	35.00	589.00	276.00	9.60	317.20	0.00	0.03	12.40
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	25.00	6.50	820.00	508.00	292.00	47.00	42.58	82.00	3.00	155.00	280.00	0.00	341.60	0.18	0.00	12.37
30	25.00	6.50	450.00	274.00	172.00	22.00	28.55	42.10	1.00	54.00	192.00	14.40	204.96	0.33	0.00	11.23
31	22.00	7.00	500.00	341.00	208.00	39.00	26.96	55.00	1.00	92.00	196.00	14.40	209.84	0.00	0.16	13.66
32	23.00	7.00	630.00	428.00	260.00	47.00	34.77	48.00	2.00	105.00	216.00	0.00	263.52	0.55	0.09	12.09
33	25.00	6.50	710.00	432.00	340.00	71.00	39.65	43.00	2.00	108.00	284.00	0.00	346.48	0.02	0.07	11.20
34	23.00	6.50	670.00	390.00	236.00	37.00	35.01	60.00	1.00	99.00	200.00	14.40	214.72	0.00	0.06	11.29
35	24.00	7.50	580.00	291.00	216.00	39.00	28.91	34.00	1.00	60.00	164.00	4.80	190.32	1.12	0.07	7.69
36	24.00	6.50	1930.00	1232.00	760.00	151.00	93.33	145.00	1.00	653.00	244.00	0.00	297.68	3.38	0.05	11.69
37	24.00	6.50	210.00	138.00	72.00	19.00	5.98	18.00	3.00	51.00	72.00	0.00	87.84	0.13	0.03	5.51
38	24.00	6.50	130.00	82.00	48.00	12.00	4.39	10.00	1.00	40.00	48.00	0.00	58.56	0.00	0.05	10.34
39	24.00	6.50	170.00	102.00	40.00	8.00	4.88	18.00	4.00	45.00	52.00	0.00	63.44	0.00	0.02	8.46

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 5. Physico-chemical parameters of shallow groundwater samples of Palakkad and Chittur taluks, Premonsoon (April) 2006

Loc. No.	Temp	PH	EC	TDS	TH	Ca	Mg	Na	K	Cl	TA	CO3	HCO3-	NO3	PO4	SiO2
1	28.00	7.50	1150.00	707.00	224.00	13.46	46.46	171.70	2.00	198.80	416.00	43.20	419.68	0.56	0.21	28.77
2	27.00	7.00	720.00	454.00	312.00	47.10	47.43	29.90	3.00	122.12	224.00	19.20	234.24	1.99	0.09	17.03
3	26.00	6.50	310.00	189.00	104.00	18.50	14.10	19.40	2.00	51.12	112.00	0.00	136.64	0.01	0.32	25.11
4	27.00	6.50	130.00	66.00	44.00	6.73	6.64	5.10	2.00	28.40	48.00	0.00	58.56	0.00	0.10	12.97
5	28.00	6.50	180.00	108.00	64.00	16.82	5.37	7.60	1.00	39.76	60.00	0.00	73.20	0.00	0.11	14.26
6	28.00	6.50	210.00	129.00	64.00	16.82	5.37	15.00	2.00	45.44	68.00	9.60	63.44	1.08	0.30	26.11
7	29.00	6.50	270.00	171.00	68.00	16.82	6.34	23.40	4.00	85.20	64.00	0.00	78.08	0.00	0.06	21.43
8	28.00	5.50	140.00	82.00	40.00	6.73	5.66	7.90	2.00	48.28	16.00	0.00	19.52	1.37	0.03	8.83
9	28.00	5.50	590.00	382.00	120.00	30.28	10.83	60.30	26.00	164.72	80.00	0.00	97.60	2.08	0.24	9.29
10	27.00	6.00	210.00	135.00	60.00	10.09	8.49	15.50	1.00	68.16	52.00	0.00	63.44	0.69	0.19	20.60
11	28.00	6.50	170.00	112.00	52.00	10.09	6.54	11.00	4.00	51.12	44.00	0.00	53.68	0.56	0.08	14.69
12	27.00	6.50	330.00	223.00	156.00	30.28	19.62	10.80	4.00	56.80	144.00	19.20	136.64	0.00	0.21	3.66
13	26.00	7.50	380.00	248.00	136.00	30.28	14.74	30.80	2.00	53.96	164.00	19.20	161.04	0.28	0.27	16.03
14	28.00	6.50	240.00	158.00	88.00	25.23	6.10	12.60	2.00	48.28	76.00	9.60	73.20	0.00	0.11	35.57
15	29.00	6.50	250.00	163.00	32.00	5.05	4.73	32.80	1.00	51.12	60.00	0.00	73.20	1.00	0.54	44.06
16	28.00	7.00	800.00	520.00	168.00	21.87	27.67	127.90	1.00	85.20	416.00	48.00	409.92	0.36	0.13	40.49
17	29.00	7.00	1340.00	876.00	432.00	67.28	64.42	128.30	10.00	468.60	200.00	24.00	195.20	0.69	0.26	30.86
18	29.00	6.50	600.00	389.00	208.00	30.28	32.31	53.80	2.00	198.80	184.00	14.40	195.20	0.05	0.04	32.29
19	26.00	6.50	620.00	395.00	216.00	31.96	33.23	48.70	2.00	107.92	208.00	24.00	204.96	1.23	0.11	33.49
20	28.00	7.50	1760.00	1228.00	592.00	153.07	51.19	107.10	124.00	340.80	356.00	19.20	395.28	0.35	3.79	33.74
21	28.00	6.50	410.00	273.00	152.00	33.64	16.59	33.70	1.00	184.60	152.00	14.40	156.16	0.64	0.07	22.60
22	29.00	7.00	520.00	342.00	200.00	55.51	14.98	36.40	2.00	116.44	120.00	0.00	146.40	0.45	0.07	28.06
23	27.00	7.00	480.00	288.00	192.00	38.69	23.28	27.00	5.00	105.08	126.00	0.00	153.72	0.19	0.09	19.43
24	26.00	7.50	920.00	601.00	336.00	74.01	36.89	71.90	1.00	355.00	196.00	9.60	219.60	0.72	0.11	28.77
25	27.00	6.50	1150.00	761.00	472.00	75.69	69.05	71.40	2.00	369.20	296.00	0.00	361.12	0.72	0.08	29.43
26	29.00	6.50	660.00	429.00	248.00	28.60	43.09	50.00	3.00	105.08	204.00	14.40	219.60	0.69	0.06	21.34
27	29.00	7.00	2030.00	1397.00	960.00	185.03	121.51	93.90	2.00	852.00	204.00	0.00	248.88	2.78	0.03	41.57
27a	27.00	6.50	1130.00	756.00	332.00	58.87	45.14	130.60	9.00	340.80	356.00	14.40	405.04	0.60	0.08	37.83
28	27.00	6.50	1150.00	773.00	360.00	72.33	43.77	127.00	10.00	369.20	324.00	38.40	317.20	1.23	1.17	35.43
29	27.00	6.50	770.00	513.00	272.00	48.78	36.65	69.80	3.00	255.60	308.00	14.40	346.48	0.88	0.08	37.83
30	25.00	7.00	450.00	301.00	172.00	25.23	26.60	36.00	2.00	56.80	200.00	24.00	195.20	1.74	0.08	31.83
31	27.00	6.50	300.00	204.00	128.00	26.91	14.84	15.00	1.00	53.96	132.00	0.00	161.04	0.00	0.09	36.23
32	27.00	7.00	620.00	421.00	256.00	45.42	34.79	42.00	2.00	105.08	220.00	0.00	268.40	1.22	0.06	27.94
33	28.00	6.50	580.00	371.00	264.00	47.10	35.72	20.00	2.00	79.52	228.00	14.40	248.88	0.93	0.06	29.09
34	27.00	6.50	510.00	335.00	192.00	33.64	26.35	34.00	1.00	76.68	196.00	19.20	200.08	0.03	0.04	21.94
35	28.00	7.00	620.00	407.00	264.00	33.64	43.92	37.50	1.00	65.32	236.00	9.60	268.40	1.43	0.05	13.20
36	27.00	6.50	2140.00	1417.00	920.00	136.25	141.47	114.70	2.00	712.84	256.00	0.00	312.32	5.21	0.02	21.26
37	29.00	6.50	260.00	170.00	92.00	26.91	6.05	17.50	3.00	51.12	92.00	0.00	112.24	0.07	0.05	15.29
38	26.00	6.00	170.00	111.00	64.00	13.46	7.42	9.10	2.00	51.12	56.00	0.00	68.32	0.01	0.05	16.71
39	26.00	6.50	230.00	152.00	64.00	13.46	7.42	18.50	7.00	62.48	72.00	0.00	87.84	0.05	0.02	15.91

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 6. Correlation matrix of physico-chemical parameters of shallow groundwater in Palakkad and Chittur taluks, Monsoon (August), 2005

	Temp	*PH*	*EC*	*TDS*	*TH*	*Ca*	*Mg*	*Na*	*K*	*Cl*	*TA*	*CO3*	*HCO3-*	*NO3*	*PO4*	*SiO2*
Temp	1.000															
PH	-0.014	1.000														
EC	-0.118	0.250	1.000													
TDS	-0.116	0.236	0.998	1.000												
TH	-0.169	0.286	0.945	0.943	1.000											
Ca	-0.207	0.259	0.893	0.890	0.981	1.000										
Mg	-0.104	0.307	0.958	0.958	0.960	0.889	1.000									
Na	-0.047	0.210	0.903	0.907	0.726	0.625	0.825	1.000								
K	0.088	-0.013	0.357	0.363	0.209	0.199	0.210	0.398	1.000							
Cl	-0.110	0.149	0.976	0.978	0.924	0.881	0.926	0.879	0.305	1.000						
TA	0.009	0.629	0.366	0.362	0.358	0.269	0.464	0.396	0.071	0.194	1.000					
CO3	0.288	0.486	-0.034	-0.039	-0.052	-0.097	0.018	0.048	0.080	-0.136	0.613	1.000				
HCO3-	-0.034	0.609	0.402	0.398	0.396	0.306	0.501	0.423	0.065	0.231	0.993	0.515	1.000			
NO3	-0.146	-0.221	0.370	0.382	0.308	0.289	0.316	0.346	0.404	0.357	-0.036	-0.107	-0.023	1.000		
PO4	0.130	0.090	0.017	0.022	-0.050	-0.028	-0.079	0.028	0.823	-0.087	0.214	0.342	0.181	0.138	1.000	
SiO2	0.107	0.394	0.634	0.622	0.646	0.627	0.631	0.522	0.251	0.585	0.460	0.243	0.463	0.042	0.209	1.000

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 7. Correlation matrix of physico-chemical parameters of shallow groundwater in Palakkad and Chittur taluks, Postmonsoon (December), 2005

	Temp	*PH*	*EC*	*TDS*	*TH*	*Ca*	*Mg*	*Na*	*K*	*Cl*	*TA*	*CO3*	*HCO3-*	*NO3*	*PO4*	*SiO2*
Temp	1.000															
PH	0.897	1.000														
EC	0.308	0.351	1.000													
TDS	0.300	0.345	0.997	1.000												
TH	0.271	0.330	0.960	0.961	1.000											
Ca	0.232	0.295	0.929	0.931	0.970	1.000										
Mg	0.298	0.343	0.902	0.901	0.936	0.821	1.000									
Na	0.314	0.354	0.828	0.820	0.681	0.586	0.743	1.000								
K	0.115	0.040	0.247	0.264	0.108	0.158	0.024	0.208	1.000							
Cl	0.206	0.238	0.935	0.935	0.920	0.919	0.821	0.713	0.099	1.000						
TA	0.331	0.435	0.473	0.471	0.397	0.268	0.539	0.695	0.195	0.198	1.000					
CO3	0.151	0.245	0.172	0.166	0.051	0.011	0.104	0.457	0.059	-0.031	0.686	1.000				
HCO3-	0.345	0.441	0.504	0.503	0.446	0.308	0.597	0.688	0.211	0.237	0.983	0.539	1.000			
NO3	0.211	0.168	0.635	0.647	0.638	0.611	0.608	0.456	0.109	0.599	0.114	-0.022	0.137	1.000		
PO4	0.091	0.077	0.164	0.190	0.072	0.128	-0.016	0.068	0.929	-0.005	0.185	0.107	0.187	0.107	1.000	
SiO2	0.536	0.596	0.481	0.496	0.451	0.354	0.542	0.513	0.177	0.343	0.587	0.295	0.605	0.158	0.240	1

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 8. Correlation matrix of physico-chemical parameters of shallow groundwater in Palakkad and Chittur taluks, Premonsoon (April), 2006

	Temp	*PH*	*EC*	*TDS*	*TH*	*Ca*	*Mg*	*Na*	*K*	*Cl*	*TA*	*CO3*	*HCO3-*	*NO3*	*PO4*	*SiO2*
Temp	1.000															
PH	-0.067	1.000														
EC	0.116	0.401	1.000													
TDS	0.118	0.397	0.999	1.000												
TH	0.086	0.349	0.954	0.958	1.000											
Ca	0.109	0.368	0.899	0.914	0.949	1.000										
Mg	0.061	0.308	0.927	0.922	0.967	0.838	1.000									
Na	0.126	0.404	0.812	0.798	0.616	0.529	0.641	1.000								
K	0.090	0.226	0.379	0.400	0.277	0.462	0.107	0.265	1.000							
Cl	0.141	0.229	0.919	0.921	0.932	0.887	0.899	0.676	0.181	1.000						
TA	-0.065	0.528	0.699	0.689	0.553	0.469	0.580	0.833	0.265	0.457	1.000					
CO3	-0.073	0.423	0.281	0.267	0.097	0.026	0.147	0.614	0.108	0.062	0.720	1.000				
HCO3-	-0.058	0.512	0.741	0.733	0.615	0.534	0.635	0.819	0.281	0.513	0.987	0.600	1.000			
NO3	-0.023	-0.049	0.608	0.602	0.676	0.543	0.732	0.333	-0.039	0.625	0.212	-0.048	0.256	1.000		
PO4	0.063	0.289	0.363	0.384	0.253	0.436	0.087	0.291	0.944	0.166	0.301	0.216	0.297	-0.069	1.000	
SiO2	0.112	0.330	0.426	0.431	0.349	0.362	0.313	0.510	0.098	0.385	0.510	0.334	0.512	0.065	0.207	1.000

EC-Electrical Conductivity; TDS-Total dissolved Solids; TH-Total Hardness; TA-Total Alkalinity

Table 9. The chemical composition (%) and the hydrochemical facies of shallow groundwater during Monsoon (August) 2005

Loc. No.	Ca	Mg	Na	K	CO3	HCO3-	Cl	Facies Type
1	45.94	3.20	49.22	1.64	3.56	72.35	24.09	Ca-Na-HCO3
2	52.51	19.22	25.58	2.69	2.06	73.43	24.51	Ca-HCO3
3	37.63	18.09	40.95	3.32	4.00	79.33	16.67	Ca-Na-HCO3
4	27.72	20.29	45.05	6.93	0.00	58.94	41.06	Na-HCO3
5	55.02	12.73	28.46	3.79	0.00	73.15	26.85	Ca-HCO3
6	48.76	8.33	35.11	7.80	0.00	73.15	26.85	Ca-Na-HCO3
7	26.10	11.25	52.20	10.44	0.00	24.24	75.76	Na-Cl
8	17.60	17.89	58.65	5.87	0.00	41.78	58.22	Na-Cl
9	21.96	8.62	49.25	20.18	0.00	26.76	73.24	Na-Cl
10	20.19	17.24	58.54	4.04	0.00	51.25	48.75	Na-HCO3
11	36.44	8.89	45.55	9.11	0.00	62.31	37.69	Ca-Na-HCO3
12	49.95	19.39	28.38	2.27	7.77	69.15	23.08	Ca-HCO3
13	34.90	13.78	48.24	3.08	0.00	82.67	17.33	Ca-Na-HCO3
14	46.31	9.81	39.00	4.87	0.00	67.85	32.15	Ca-Na-HCO3
15	24.07	10.05	63.35	2.53	0.00	73.05	26.95	Na-HCO3
16	13.20	12.95	73.36	0.49	5.20	81.63	13.17	Na-HCO3
17	29.31	18.76	44.22	7.71	2.98	38.41	58.61	Na-Cl
18	45.43	19.34	33.84	1.39	1.62	31.32	67.06	Ca-Na-Cl
19	27.59	23.93	46.98	1.49	4.65	60.25	35.10	Na-HCO3
20	23.59	6.54	24.82	45.04	3.21	58.83	37.95	K-HCO3
21	33.00	19.76	46.02	1.21	0.00	42.65	57.35	Ca-Na-Cl
22	52.16	11.82	33.53	2.48	0.00	50.24	49.76	Ca-Cl-HCO3
23	45.72	10.65	33.25	10.39	0.00	74.37	25.63	Ca-Na-HCO3
24	33.12	21.07	45.11	0.70	0.00	57.38	42.62	Ca-Na-HCO3
25	34.96	30.59	33.94	0.51	2.20	61.04	36.76	Ca-Na-HCO3
26	38.84	16.05	43.85	1.25	2.31	71.68	26.01	Ca-Na-HCO3
27	61.69	17.65	20.21	0.46	0.00	12.10	87.90	Ca-Cl
27a	25.43	14.53	53.18	6.86	0.00	12.35	87.65	Na-Cl
28	32.07	14.93	46.46	6.54	3.99	70.26	25.75	Na-HCO3
29	28.33	18.02	52.44	1.21	1.76	59.13	39.11	Na-HCO3
30	34.83	24.69	39.54	0.94	4.49	82.11	13.40	Ca-Na-HCO3
31	32.62	16.24	50.25	0.88	0.00	75.99	24.01	Na-HCO3
32	32.90	23.72	41.88	1.50	4.87	52.00	43.13	Ca-Na-HCO3
33	48.89	19.88	29.88	1.36	0.00	81.29	18.71	Ca-HCO3
34	37.56	19.61	41.32	1.50	0.00	90.85	9.15	Ca-Na-HCO3
35	61.39	17.23	20.28	1.10	3.56	84.96	11.48	Ca-HCO3
36	44.31	22.58	32.58	0.52	0.00	40.15	59.85	Ca-Na-Cl
37	34.90	13.91	39.56	11.63	0.00	71.60	28.40	Ca-Na-HCO3
38	47.82	21.75	26.08	4.35	0.00	72.51	27.49	Ca-HCO3
39	30.12	11.02	41.07	17.80	0.00	67.03	32.97	Na-HCO3

Table 10. The chemical composition (%) and the hydrochemical facies of shallow groundwater during Postmonsoon (December) 2005

Loc. No.	Ca	Mg	Na	K	Cl	CO3	HCO3-	Facies Type
1	19.66	10.55	68.81	0.98	29.40	6.96	63.65	Na-HCO3
2	56.90	18.12	22.90	2.08	29.88	10.34	59.78	Ca-HCO3
3	34.98	23.04	41.98	0.00	26.09	5.82	68.09	Ca-Na-HCO3
4	36.44	8.89	50.11	4.56	40.34	0.00	59.66	Na-HCO3
5	54.32	17.09	25.73	2.86	31.07	0.00	68.93	Ca-HCO3
6	35.28	10.62	49.40	4.70	34.16	3.81	62.03	Ca-Na-HCO3
7	28.84	9.15	56.24	5.77	64.25	0.00	35.75	Na-Cl
8	28.50	10.43	57.00	4.07	71.92	0.00	28.08	Na-Cl
9	22.72	6.84	53.02	17.42	66.65	2.12	31.23	Na-Cl
10	22.31	16.33	58.57	2.79	47.33	0.00	52.67	Na-HCO3
11	32.97	12.07	43.97	10.99	47.21	0.00	52.79	Na-HCO3
12	41.36	27.01	29.20	2.43	31.33	7.52	61.15	Ca-HCO3
13	38.72	13.15	46.04	2.09	24.13	5.60	70.27	Ca-Na-HCO3
14	51.04	14.15	32.48	2.32	31.29	0.00	68.71	Ca-HCO3
15	28.04	10.26	58.89	2.80	32.74	0.00	67.26	Na-HCO3
16	11.98	12.33	75.21	0.48	15.57	10.79	73.64	Na-HCO3
17	25.33	16.78	52.02	5.88	62.89	4.25	32.85	Na-Cl
18	31.33	23.79	43.95	0.94	76.48	1.78	21.74	Na-Cl
19	24.03	24.92	50.31	0.75	31.91	7.29	60.80	Na-HCO3
20	29.41	7.40	24.71	38.48	37.84	2.87	59.29	K-HCO3
21	27.98	15.47	55.36	1.19	48.71	2.20	49.10	Na-Cl-HCO3
22	51.74	12.51	34.81	0.94	42.77	4.03	53.20	Ca-HCO3
23	43.20	13.59	31.83	11.37	36.56	0.00	63.44	Ca-HCO3
24	35.41	19.15	44.92	0.53	59.07	3.90	37.03	Na-Cl
25	33.28	27.34	38.83	0.55	42.49	0.00	57.51	Ca-Na-HCO3
26	27.80	23.37	48.08	0.75	35.70	3.09	61.21	Na-HCO3
27	55.75	16.28	27.60	0.37	90.84	0.00	9.16	Ca-Cl
27a	18.50	14.47	56.41	10.62	64.32	1.05	34.64	Na-Cl
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	26.92	24.39	46.97	1.72	31.21	0.00	68.79	Na-HCO3
30	23.49	30.48	44.96	1.07	19.75	5.27	74.98	Na-HCO3
31	31.98	22.11	45.10	0.82	29.09	4.55	66.35	Na-HCO3
32	35.67	26.39	36.43	1.52	28.49	0.00	71.51	Ca-Na-HCO3
33	45.62	25.47	27.63	1.28	23.76	0.00	76.24	Ca-HCO3
34	27.82	26.32	45.11	0.75	30.17	4.39	65.44	Na-HCO3
35	37.90	28.10	33.04	0.97	23.52	1.88	74.60	Ca-Na-HCO3
36	38.69	23.91	37.15	0.26	68.69	0.00	31.31	Ca-Na-Cl
37	41.32	13.00	39.15	6.52	36.73	0.00	63.27	Ca-Na-HCO3
38	43.81	16.03	36.51	3.65	40.58	0.00	59.42	Ca-Na-HCO3
39	22.94	13.99	51.61	11.47	41.50	0.00	58.50	Na-HCO3

Table 11. The chemical composition (%) and the hydrochemical facies of shallow groundwater during Premonsoon (April) 2006

Loc. No.	Ca	Mg	Na	K	Cl	CO3	HCO3-	Facies Type
1	5.76	19.89	73.50	0.86	30.04	6.53	63.43	Na-HCO3
2	36.96	37.22	23.46	2.35	32.52	5.11	62.37	Ca-Mg-HCO3
3	34.26	26.11	35.93	3.70	27.23	0.00	72.77	Ca-Na-HCO3
4	32.88	32.44	24.91	9.77	32.66	0.00	67.34	Ca-Mg-HCO3
5	54.63	17.44	24.68	3.25	35.20	0.00	64.80	Ca-HCO3
6	42.92	13.70	38.28	5.10	38.35	8.10	53.54	Ca-Na-HCO3
7	33.27	12.54	46.28	7.91	52.18	0.00	47.82	Ca-Na-Cl
8	30.19	25.39	35.44	8.97	71.21	0.00	28.79	Na-Cl
9	23.77	8.50	47.33	20.41	62.79	0.00	37.21	Na-Cl
10	28.76	24.20	44.18	2.85	51.79	0.00	48.21	Na-Cl
11	31.90	20.68	34.78	12.65	48.78	0.00	51.22	Na-HCO3
12	46.80	30.32	16.69	6.18	26.71	9.03	64.26	Ca-HCO3
13	38.91	18.94	39.58	2.57	23.04	8.20	68.76	Ca-Na-HCO3
14	54.93	13.28	27.43	4.35	36.83	7.32	55.84	Ca-HCO3
15	11.59	10.85	75.26	2.29	41.12	0.00	58.88	Na-HCO3
16	12.26	15.51	71.68	0.56	15.69	8.84	75.48	Na-HCO3
17	24.92	23.86	47.52	3.70	68.13	3.49	28.38	Na-Cl
18	25.58	27.29	45.44	1.69	48.68	3.53	47.80	Na-Cl-HCO3
19	27.58	28.67	42.02	1.73	32.04	7.12	60.84	Na-HCO3
20	35.16	11.76	24.60	28.48	45.12	2.54	52.34	Ca-HCO3
21	39.61	19.53	39.68	1.18	51.98	4.05	43.97	Ca-Na-Cl
22	50.98	13.76	33.43	1.84	44.30	0.00	55.70	Ca-HCO3
23	41.17	24.77	28.73	5.32	40.60	0.00	59.40	Ca-HCO3
24	40.27	20.07	39.12	0.54	60.77	1.64	37.59	Ca-Na-Cl
25	34.70	31.65	32.73	0.92	50.55	0.00	49.45	Ca-Na-Cl
26	22.94	34.56	40.10	2.41	30.99	4.25	64.76	Mg-Na-HCO3
27	45.98	30.19	23.33	0.50	77.39	0.00	22.61	Ca-Cl
27a	24.17	18.53	53.61	3.69	44.83	1.89	53.28	Na-HCO3
28	28.58	17.29	50.18	3.95	50.94	5.30	43.76	Na-Cl
29	30.83	23.16	44.11	1.90	41.46	2.34	56.20	Na-HCO3
30	28.09	29.61	40.08	2.23	20.58	8.70	70.72	Na-HCO3
31	46.60	25.70	25.97	1.73	25.10	0.00	74.90	Ca-HCO3
32	36.57	28.01	33.81	1.61	28.14	0.00	71.86	Ca-Na-HCO3
33	44.93	34.08	19.08	1.91	23.20	4.20	72.60	Ca-Mg-HCO3
34	35.41	27.74	35.79	1.05	25.91	6.49	67.60	Ca-Mg-HCO3
35	28.99	37.84	32.31	0.86	19.03	2.80	78.18	Mg-Na-HCO3
36	34.54	35.87	29.08	0.51	69.53	0.00	30.47	Ca-Mg-Cl
37	50.34	11.32	32.73	5.61	31.29	0.00	68.71	Ca-HCO3
38	42.09	23.20	28.46	6.25	42.80	0.00	57.20	Ca-HCO3
39	29.02	16.00	39.89	15.09	41.56	0.00	58.44	Na-HCO3

Table 12. Irrigation quality characteristics of groundwater

SAR	Hazard	Shallow groundwater		
		No. of samples		
		MON	POM	PRM
1.0-10.0	low	all	all	all
10.0-18.0	medium	none	none	none
18.0-26.0	high	none	none	none
>26.0	very high	none	none	none
RSC	**Hazard**	**No. of samples**		
		MON	POM	PRM
< 1.25	suitable	none	none	38
1.25-2.5	marginal	none	1	none
>2.5	not suitable	1	1	2
Na%	**Hazard**	**No. of samples**		
		MON	POM	PRM
< 20	excellent	7	none	5
20-40	good	25	25	28
40-60	permissible	7	12	4
60-80	some doubtful	1	2	3
EC (μs/cm)	**Hazard**	**No. of samples**		
		MON	POM	PRM
<250	low	3	12	9
250-750	medium	24	15	20
750-2250	high	11	11	11
2250-5000	very high	2	1	none

SAR-Sodium Adsorption Ratio; RSC-Residual Sodium Carbonate; EC-Electrical Conductivity