Assessment of the chemical facies of groundwater using factor analysis in the Chunnakam aquifer, Jaffna Peninsula

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Abstract

The Jaffna Peninsula has four main types of aquifer systems, namely,Chunnakam (in the Valikamam area), Thenmaradchi, Vadamaradchi, and Kayts. The water resources of the Valikamam region depend totally on rainfall recharge to the Miocene limestone aquifer. Valikamam is an intensified agricultural and high population density area in the Jaffna Peninsula. Groundwater is an extremely valuable resource and the pollution of groundwater resources is a matter of serious concern in the Jaffna Peninsula. Therefore, this study examines the hydro-chemical facies of groundwater in the Chunnakam aquifer using factor analysis. Forty four wells were selected to represent the entire Chunnakam aquifer during the months of January, March, April, July and October 2011 to denote various rainfall regimes within a year. Samples were analyzed for Electrical Conductivity (EC), pH, chloride, nitrate as nitrogen, calcium, magnesium, carbonate, bicarbonate, sulfate, sodium and potassium concentration based on Sri Lankan Standard (SLS) procedure. Groundwater was classified based on the Chadha diagram and factor analysis was performed using software XLSTAT 2012. Interpretation of the hydro-chemical analysis reveals that the groundwater of Chunnakam aquifer is alkaline in nature. All water quality parameters except EC, NO_3^- as N, and SO_4^{2-} are within the Sri Lankan Standard for drinking purposes. Two major hydro-chemical facies Ca^{2+}-Mg^{2+}-Cl^- and Na^+-Cl^--SO_4^{2-} were identified using the Chadha diagram and permanent hardness and salinity problems were deemed probable. Salinization, water–soil/rock interaction, and anthropogenic activities are identified in the factor analysis. Salinity development and high nitrate as nitrogen content in drinking water are problems identified in the Chunnakam aquifer.

Keywords:*Chunnakam aquifer, factor analysis, groundwater, salinity, Jaffna Peninsula.*

1. INTRODUCTION

The suitability of groundwater for drinking, irrigation, and other domestic purposes depends on its quality. Naturally, changes in groundwater quality are due to variations in climatic conditions, the duration of the presence of aquifer material in the water, and soil inputs during percolation

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(Krishnakumar*et al.*, 2008). Anthropological activities have become a major reason for groundwater pollution in recent times. In particular, the haphazard disposal of urban and industrial waste, overuse of agrochemicals, and the unplanned disposal of human waste are the main sources of groundwater pollution in many countries. The Jaffna Peninsula lies in the northern most part of Sri Lanka and its population depends entirely on groundwater resources to meet all of their water requirements (drinking, irrigation, etc.). The Peninsula has four main aquifer systems, namely, Chunnakam (Valikamam area), Thenmaradchi, Vadamaradchi, and Kayts (Punthakey and Gamage, 2006). All four aquifers depend on rainfall recharge, which is their only source of fresh water. Groundwater is an extremely valuable resource and the pollution of groundwater resources is a matter of serious concern. Among the major threats to groundwater from which drinking water supplies are obtained are leachates from human and animal waste matter along with other chemical pollutants. Agricultural leachates often contribute significantly to groundwater pollution.

Understanding groundwater characteristics is important for groundwater management in the Jaffna Peninsula. Early studies on the characterization of groundwater facies and chemical evolutionary history utilized the graphical representation of major ionic compositions of groundwater (Piper, 1944; Stiff, 1951). These schemes were useful in visually describing differences in major ion chemistry in groundwater and in classifying water compositions into identifiable groups (Freeze and Cherry, 1979), which are usually of similar genetic history. Recently, factor analysis has been used with remarkable success as a tool in the study of groundwater chemistry. Therefore, this study aimed to characterize the hydro-chemical quality of groundwater in the Chunnakam aquifer using factor analysis and relating them to specific geochemical processes to ensure the better water resource management.

2. EXPERIMENTAL

Description of the studied area

The major rainy season in the Peninsula occurs during the North-East monsoon from October to December.The South-West monsoon provides rainfall in April and May but the amount of rainfall is less compared to that of the North-East monsoon. The period between the South-West monsoon and the North-East monsoon is the dry season and extends from June to September. The major soils are the calcic red-yellow latosols which are shallow (less than 2m deep), fine textured and well-drained and have a very rapid infiltration rate (De Alwis and Panabokke, 1972).Agriculture is the main source of livelihood for 65% of the population and about 34.2% of the land is cultivated intensively for commercial purposes with high value cash crops (Thadchagini and Thirudchelvam, 2005).The land in the Jaffna Peninsula can be characterized as flat with less than a 5% slope. The Chunnakam aquifer feeds most parts of the Valikamam area, which is highly populated and practises intensive agriculture.

Selection of wells

Forty-four wells were selected for long- term water quality monitoring in a systematic manner, to represent the entire Chunnakam aquifer. An identification number was painted on each well. These wells were selected to represent different uses such as wells used solely for domestic purposes, those with domestic and home gardening uses, public wells for drinking, and farm wells. Figure 1shows the locations of the wells selected for the monitoring.

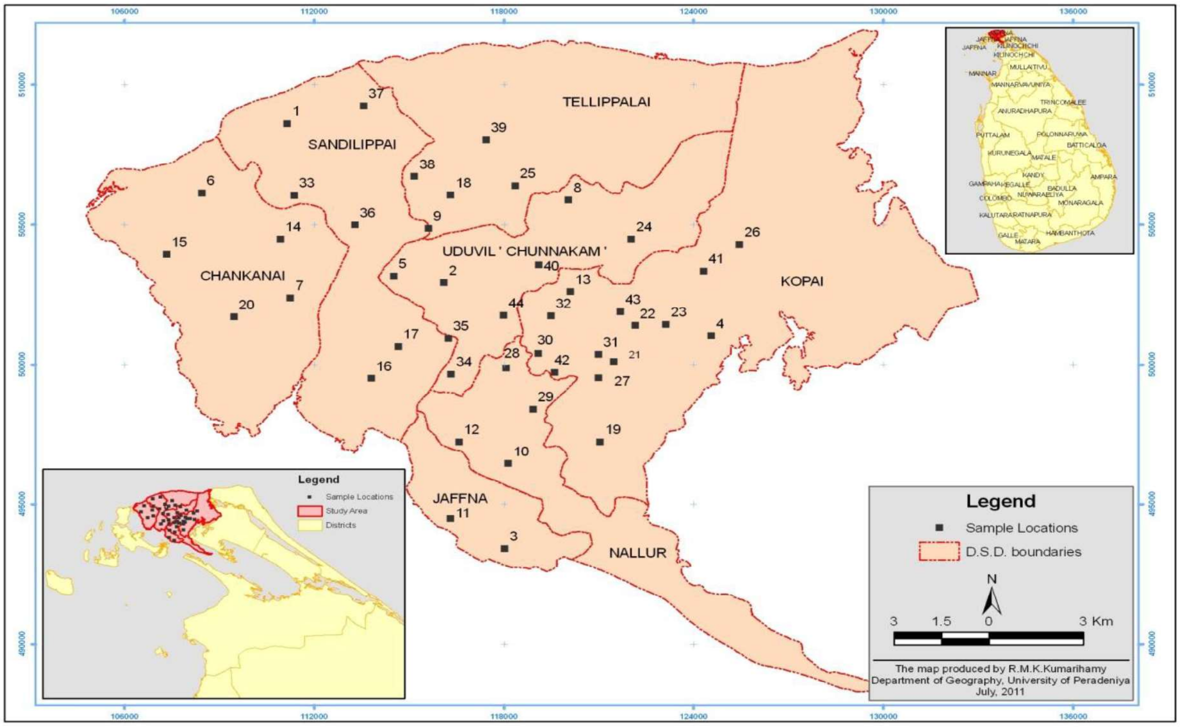

Figure 1: Location of selected wells with different uses in the Chunnakam aquifer

Collection of water samples

Water samples were collected for chemical analysis five times during the year, to cover various rainfall regimes: mid-January, early March, mid-April, mid-July, and mid October, 2011. Each sample was poured into 1 liter plastic bottles, which had been rinsed several times with the same well water. These bottles were tightly closed, labeled, and transported to the laboratory of the National Water Supply and Drainage Board (NWS&DB), Jaffna, for analysis within 48 hours of collection.

Analytical techniques

Samples were analyzed for electrical conductivity (EC), pH, chloride, nitrate as nitrogen, calcium, magnesium, carbonate, bicarbonate, sulfate, sodium and potassium concentrations. Conductivity meters and pH meters were used to measure the EC and pH respectively. Chloride concentration was measured by silver nitrate titration. Nitrate-N concentration was estimated using a colorimetric spectrophotometer. The calcium and magnesium content was determined by EDTA titration using the Eriochrome black T as the indicator. The carbonate and bicarbonate content was measured by acid-base titration. The sulfate content was estimated by the turbidimetric method using a turbidity meter. Sodium and potassium contents were determined by using a flame photometer at the National Institute of Fundamental Studies (NIFS), Hantana, Kandy. The procedures of the analysis were based on Sri Lankan Standard 614 (SLS, 1983).

Groundwater was classified based on the Chadhadiagram (Chadha, 1999). This technique examines the relationships between variables (such as chemical parameters in groundwater), shown in a number of cases (such as sampling points).Factor analysis was performed using software XLSTAT 2012. The principal factor method was applied iteratively to generate several factors enhanced by the selection of varimax rotation to facilitate interpretation of the results. The variance of a factor is described by the factor's Eigen value. Eigen values of 1.0 or greater are considered significant (Kim and Mueller, 1987). The output of factor analysis is a list of significant factors, with each factor grouping several chemical parameters. Once the factors have been determined, factor scores can be calculated for each case. In considering groundwater quality, factor scores calculated for each case (sampling point) can be plotted on contour diagrams to get the distribution of factors within an aquifer (David *et al*., 2004). The interpretation was based on rotated factors, rotated loadings and rotated Eigen values. Spatial distribution maps for different factors were developed using ArcGIS 10. Here, the Inverse Distance Weighted interpolation technique was used to develop the maps.

3. RESULTS AND DISCUSSION

Hydro-chemical characteristics

The chemical compositions of the groundwater samples were statistically analyzed and the obtained results are summarized in Table 1. The EC of the water samples is an indicator of their salinity. The values of EC ranged from 556 to 4701 µS/cm, with a mean of 1534µS/cm. This behavioral response was used to determine the nature of salinity in the studied area. The chloride concentrations of water samples were between 153.9 mg/L and 1146 mg/L and the mean value was 327.4 mg/L. All values of measured wells were below the permissible level of the Sri Lankan Standard (SLS) for drinking. All wells were suitable for drinking. The results revealed that pH ranged from 7.20 to 8.26 and all groundwater samples were found to be below the desirable SLS level for the pH value of drinking water with a mean of 7.53 and slight alkalinity.

Table 1: Statistical summary of the hydro chemical parameters of groundwater

					SLS for drinking water	
Variable	Minimum	Maximum	Mean	Std. deviation	Max Des	Max Per
EC	556.0	4701.0	1534.3	1045.7	750	3500
Cl^-	153.9	1146	327.4	246.2	200	1200
pH	7.20	8.26	7.53	0.17	7-8.5	6.5-9.0
NO_3^- -N	0.28	13.9	4.9	4.0	-	10
Ca^{2+}	58.9	203.1	95.5	35.7	100	240
Mg^{2+}	4.27	20.9	10.2	3.5	30	150
CO_3^{2-}	11.7	61.4	28.2	9.5	-	-
HCO_3^-	158.5	545.8	258.7	91.0	-	-
Na^+	17.7	763	149	172	-	-
K^+	0.39	92.0	9.14	15.0	-	-
SO_4^{2-}	35.2	499.5	151.0	106.7	200	400

Except pH and EC (µS/cm), the others parameters are expressed in mg/L**.**

SLS: Sri Lankan Standard

The nitrate- N concentration ranged from 0.28 to 13.9 mg/L. The values of all domestic, domestic with home garden and public wells were recommended for drinking because the average value of nitrate-N was below the limit of the Sri Lankan drinking water standard. Some of the farm wells exceeded the limit of the Sri Lankan drinking water recommended level of 10 mg/L and was not suited for drinking.

The farmers practiced applying excessive amounts of inorganic fertilizer, which leaches out to the shallow groundwater. But all farm wells were below the irrigation requirement of 30 mg/L. The concentration of calcium values of selected wells varied from 58.9 mg/L to 203.1 mg/L and magnesium values of selected wells varied from 4.27 mg/L to 20.9 mg/L. All wells measured were below the desirable SLS level for drinking water. The concentration (mg/L) of other ions varied as CO_3^{2-} from 11.7 to 61.4; HCO_3^-158.5 to 545.8; Na^+ 17.7 to 763; K^+ 0.39 to 92.0; and SO_4^{2-} 35.2 to 499.5.

Classification of groundwater based on chemical facies

The Chadha diagram is a somewhat modified version of the Piper diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948).This diagram is used to classify the groundwater and identify hydro-chemical processes (Chadha, 1999). In Chadha's diagram (Figure 2), the difference in the milliequivalent percentage between alkaline earths (Ca^{2+} + Mg^{2+}) and alkali metals (Na^+ + K^+) expressed as percentage reacting values is plotted on the X axis, and the difference in the milliequivalent percentage between weak acidic anions (CO_3^{2-} + HCO_3^-) and strong acidic anions (Cl^- + SO_4^{2-}) is plotted on the Y axis.

From this diagram, 68 % of groundwater samples fall within the field of 6 which belong to Ca^{2+}-Mg^{2+}-Cl^- type hydro-chemical facies. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. Another 32% of groundwater samples fall within the field of 7, which belong to Na^+-Cl^--SO_4^{2-} hydro-chemical facies and represent Na^+-dominant Cl^- -type or Cl^--dominant Na^+ -type waters. Such water generally creates salinity problems both in irrigation and drinking use.

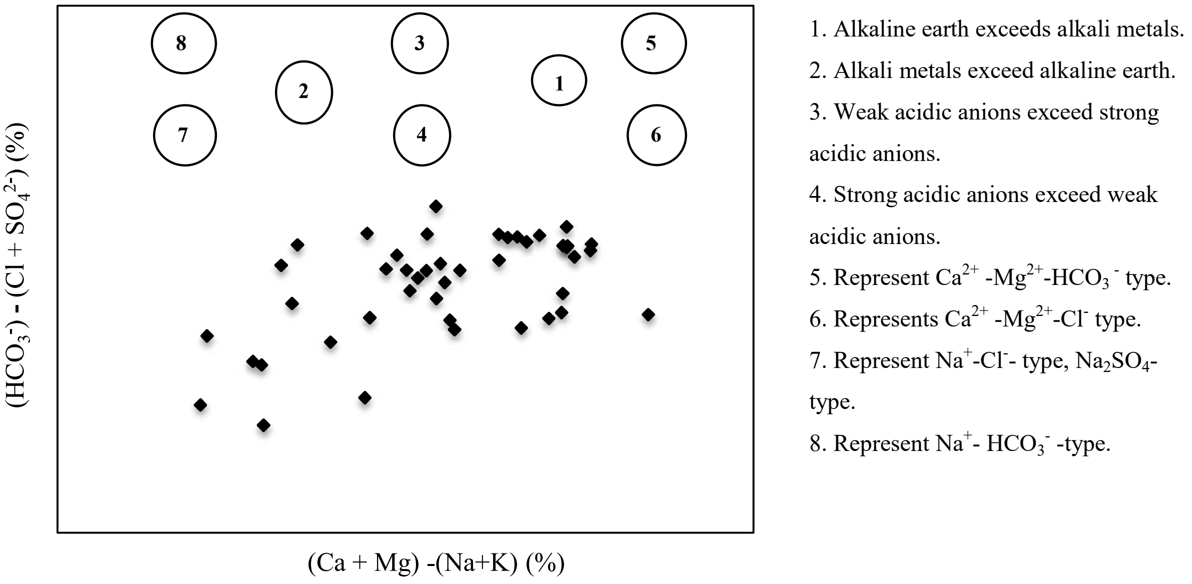

Figure 2: Groundwater quality plotted on Chadha diagram

Factor analysis

Factor analysis is a useful tool for interpreting commonly collected groundwater quality data and relating them to specific geochemical processes. Its aim is to reduce the complex patterns of correlation among many parameters to simpler sets of 'factors', which are then interpretable.

Correlation matrixes of chemical data for the groundwater of the Chunnakam aquifer are given in Table 2. High correlation (> 0.80) is observed between EC and Cl^- (0.95), EC and Na^+ (0.94), EC and Ca^{2+} (0.88), EC and SO_4^{2-} (0.87) as well as EC and HCO_3^- (0.84), due to sea water intrusion. The EC of groundwater is the most efficient water quality parameter used in detecting salinity. It was found that significant correlation exists between salinity and major components of seawater (Na^+, Cl^- and SO_4^{2-}).This is an indication of seawater influence on groundwater salinity. High correlation is also observed between Cl^- and Na^+ (0.92) as well as Cl^- and Ca^{2+} (0.87), which also contributed to the salinity and hardness of groundwater. Certain areas of the Jaffna Peninsula also experience salinity in groundwater as a result of over extraction (Navaratnarajah, 1994).In general, there were two main factors that played an important role in the quality of the water in the aquifer: (i) anthropogenic factors: over abstraction of freshwater from the aquifer, and (ii) natural factors: mixing of seawater and freshwater at the sharp interface (Aris, *et al*., 2007).

Table 2:Pearson Correlation matrix of the groundwater aquifer

Variables	EC	Cl^-	pH	NO_3^-	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Na^+	K^+	SO_4^{2-}
EC	1										
Cl^-	**0.95**	1									
pH	-0.18	-0.13	1								
NO_3^-	-0.34	-0.36	0.00	1							
Ca^{2+}	**0.88**	**0.87**	-0.20	-0.16	1						
Mg^{2+}	0.50	0.48	-0.22	-0.17	0.55	1					
CO_3^{2-}	0.38	0.35	0.05	-0.57	0.20	0.21	1				
HCO_3^-	**0.84**	0.76	-0.24	-0.44	0.74	0.45	0.48	1			
Na^+	**0.94**	**0.92**	-0.06	-0.40	**0.77**	0.43	0.42	**0.79**	1		
K^+	0.61	0.56	-0.25	-0.18	0.69	0.60	0.26	0.50	0.45	1	
SO_4^{2-}	**0.87**	0.76	-0.17	-0.26	**0.78**	0.51	0.43	0.74	**0.79**	0.71	1

The rotated factor loading, Eigen values, percentages of variance, and cumulative percentages of variance associated with each factor for principal factor analysis are summarized in Table 3. Two factors with respective eigen values closer or greater than one were identified which account for above 65 % of the total chemical parameters in the original data set.

The pairs of factors are plotted on the bi-plot diagram (Figure 3), which explains the positive and negative loading of the parameters on each factor. It is clear from the diagram that most of the parameters have positive loading on factor 1 and factor 2.

Table 3: Factor pattern after Varimax rotation in the Chunnakam aquifer

Variables	F1	F2
EC	**0.888**	0.419
Cl^-	**0.828**	0.406
pH	-0.264	0.085
NO_3^-	-0.074	**-0.716**

Ca^{2+}	**0.947**	0.129
Mg^{2+}	0.580	0.114
CO_3^{2-}	0.127	**0.734**
HCO_3^-	0.693	0.519
Na^+	**0.739**	0.524
K^+	0.698	0.122
SO_4^{2-}	**0.811**	0.352
Eigenvalue	6.110	0.969
Variability (%)	45.157	19.201
Cumulative variance %	45.157	64.358

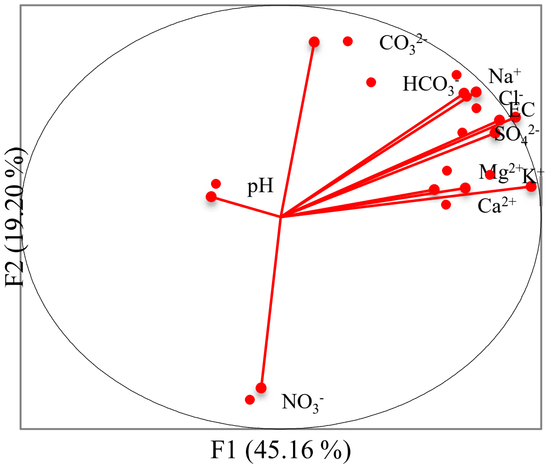

Figure 3: Factor loading (F1 and F2:64.36 %) after varimax rotation

The following factors are indicated:
Factor 1: EC, Cl^-, Na^+, Ca^{2+} and SO_4^{2-}
Factor 2: CO_3^{2-} and NO_3^- as N

Factor 1 has a high loading of EC, Cl^-, Na^+, Ca^{2+} and $SO_4^{2-}$and explains 45 % of the total variance (Table 3). The concentration of Na^+, Cl^-, and SO_4^{2-} in seawater is much greater than in continental water. This factor can be ascribed to the intrusion of seawater into the aquifer system, which increases the concentration of these ions and hence the values of the dissolved solids. Figure 4 shows a similar pattern between the score of factor 1 and EC. Therefore, *Factor 1* is defined as the salinization factor and is an indication of seawater intrusion in the studied aquifer.

The spatial distribution of factor 1 parameters is presented as an iso-scores map, shown in Figure 5. The high values are indicated with dark grey representing high salinization regions, and the low values are shown with light grey denoting low salinization regions. This indicates the intensity of saltwater activity to be more prevalent closer to the coast and decreasing inland in the Jaffna Peninsula.Several wells once used to supply potable water are not in use now due to the increase of salinity in the Jaffna Peninsula

(Nandakumar, 1983). Puvaneswaran (1985) reported that the salinity of groundwater in a location at the Valukaiaru drainage basin of the Valikamam area is inversely related to its distance from the sea.

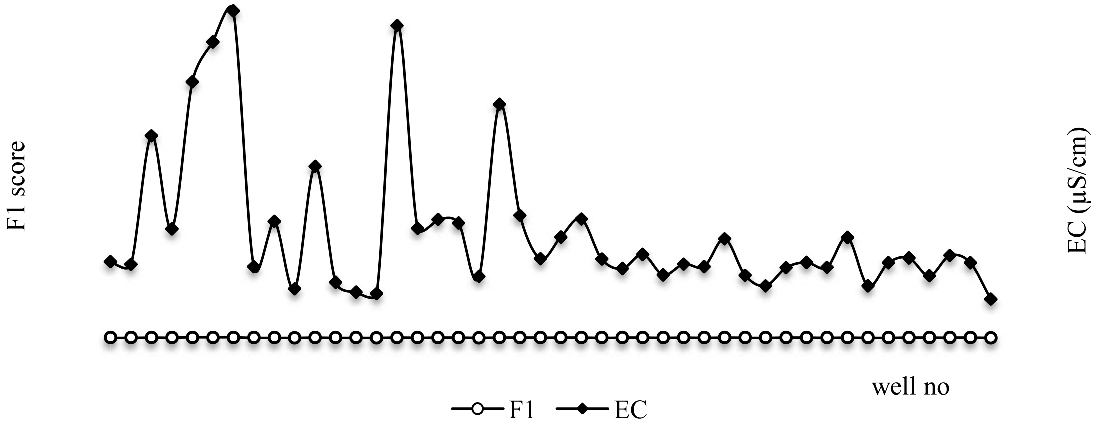

Figure 4: Relationship between the F1 score and EC of groundwater

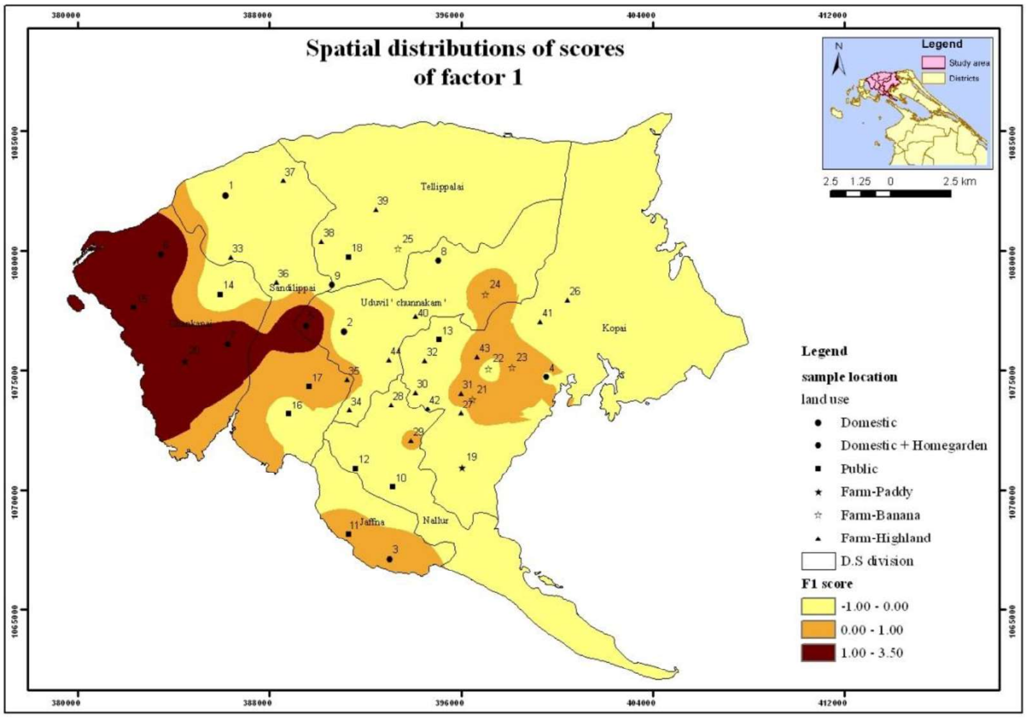

Figure 5: Spatial distribution scores of Factor 1 in Chunnakam aquifer

A significant factor that has contributed to increased salinity in the well water has been the indiscriminate extraction of water from underground aquifers. This has been exacerbated by the increase in population in the region and the rapid rate of extraction using pumps, both electric and petrol- driven, for domestic and agricultural purposes (Navaratnarajah, 1994).

Factor 2, which explains 19 % of the total variance, has a strong positive loading on CO_3^{2-} (Figure 6) and a negative loading on NO_3^- as N (Figure 7). The negative loading of NO_3^- as N on factor 2 confirms that the concentration of NO_3^- as N in the groundwater does not contribute significantly to CO_3^{2-} values.

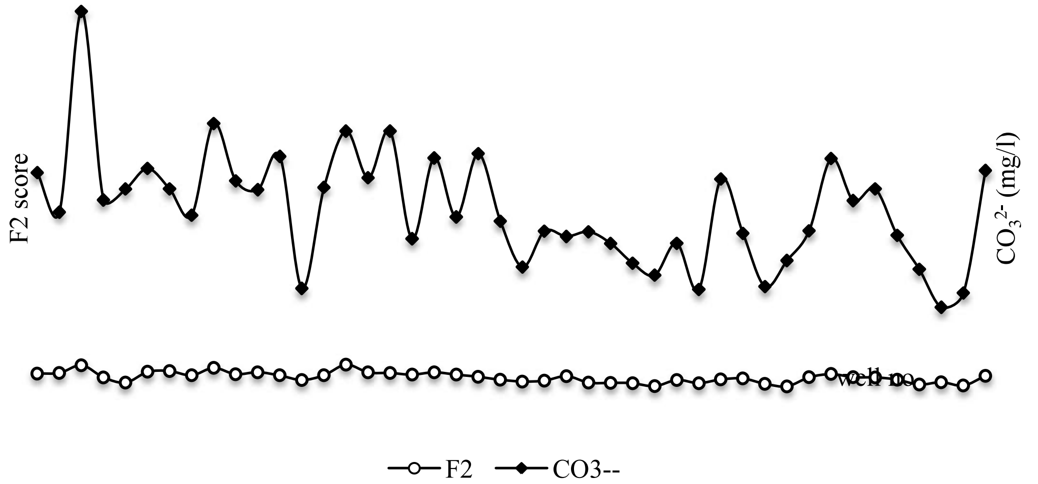

Figure 6: The relationship between F1 score and CO_3^{2} of groundwater

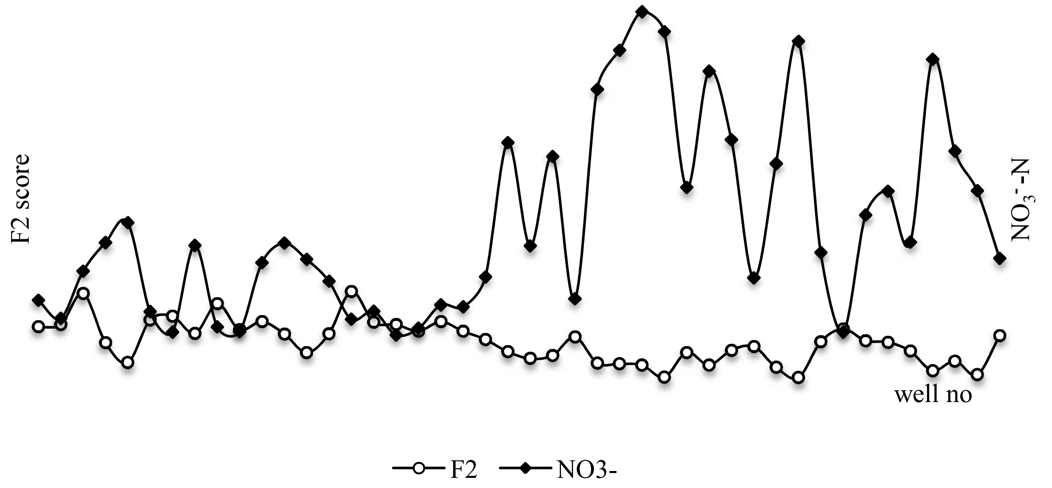

Figure 7: Relationship between F1 score and NO_3^- of groundwater

The limestone aquifer is rich in carbonates. Hence water flowing through limestone brings the carbonate to the groundwater, which increases the alkalinity. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate and hydroxide compounds. Further, the high concentration of NO_3^- as N may be derived from the continuous use of fertilizer chemicals in the agricultural fields. This is due to the fact that nitrate as nitrogen has no significant lithologic source and must be associated with the anthropogenic activities (Belkhiri*et al.*, 2010). Therefore, Factor 2 reflects the signatures of water-soil/ rock interaction and anthropogenic activities.

Figure 8 shows the spatial distribution of the scores of Factor 2. The high scores are shown with dark grey, indicating water-soil/ rock interaction and a high alkalinity aquifer. The negative low scores are indicated with light grey, revealing a high nitrate-N-polluted aquifer. These areas come under intensified agriculture. Dissanayake and Weerasooriya (1985) pointed out in the hydro geochemical atlas of Sri Lanka that the Jaffna Peninsula has the highest nitrate content of groundwater in Sri Lanka. They also mentioned that the major factors responsible for poor water quality in the Jaffna Peninsula are the abundant use of agricultural fertilizers, mainly urea, use of cattle manure and the discharge of human excreta in the form of soakage pits.

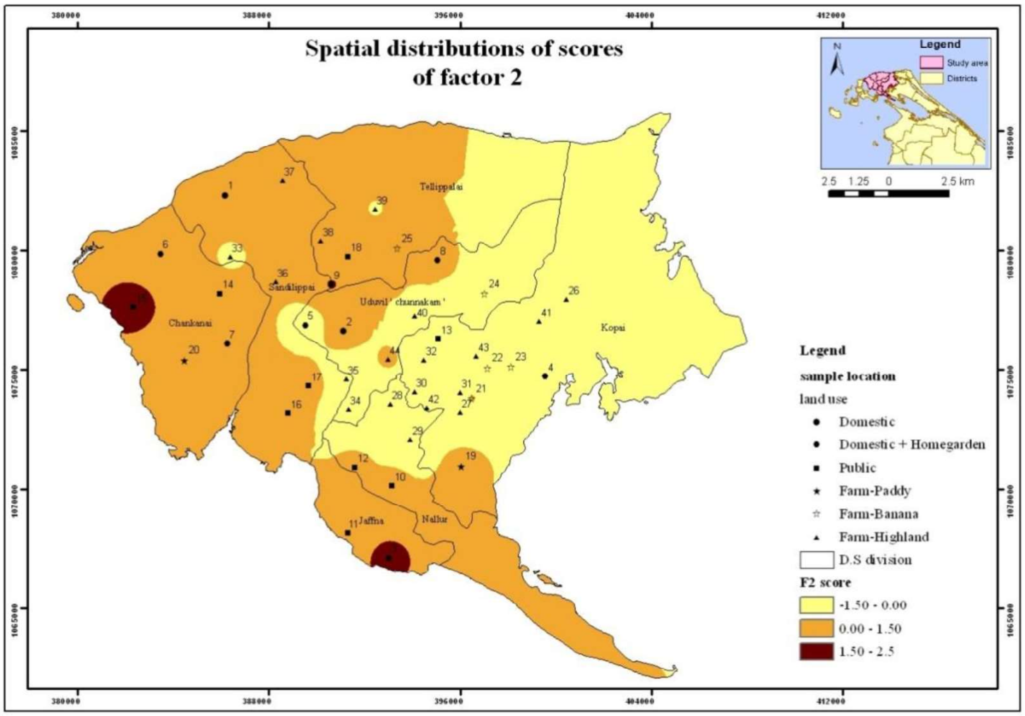

Figure 8: Spatial distribution scores of factor 2 in Chunnakam aquifer

4. CONCLUSION

This study demonstrates the effectiveness of factor analysis in assessing the hydro-chemical processes of groundwater and also provides preliminary assessment of groundwater quality, that will serve as a data base for the future investigations and monitoring of groundwater quality in the study area. Interpretation of hydro-chemical analysis reveals that the groundwater of the study area is alkaline in nature. Except for EC, NO_3^- as N and SO_4^{2-} values, all the others parameters of groundwater quality are within the Sri Lankan Standard (SLS) for drinking purposes. Two major hydro-chemical facies,Ca^{2+}-Mg^{2+}-Cl^- and Na^+-Cl^--SO_4^{2-}, were identified using the Chadha diagram. Accordingly, permanent hardness and salinity problems are probable. In factor analysis, the first salinization factor accounts for 45% of the total variance and includes the variables of EC, Cl^-, Na^+, Ca^{2+}, and SO_4^{2-}. The second signature of water-soil/rock interaction and anthropogenic activities factor specifies 19% and contains the variables of a strong positive loading on CO_3^{2-} and a negative loading on NO_3^- as N. It follows that either naturally occurring processes or human activities may have a significant impact on the water quality of the Chunnakam aquifer.

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