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Evaluation of Groundwater Chemistry and Multivariate Statistical Studies in Parts of Tirupur District, India

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ABSTRACT

Groundwater quality at any location depends on the mutual possessions of several progressions beside the subsurface flow path. The natural history and degree of infectivity in a particular region can be ascertained by hydro-chemical statistics. In order to assess the groundwater chemistry and its appropriateness for consumption purposes, sixty-three subsurface water samples were analyzed. Based on the perceptive of the hydro-geological and groundwater environment, the chemical characteristics of the groundwater were evaluated. The favored parameters for the quality assessment were major anions and cations along with pH, turbidity, total dissolved solids, total hardness, fluoride and iron as trace metals. Total dissolved solids distribution, hydro-chemical facies, Piper diagram, factor analysis, correlation studies and cluster analysis were done to monitor the study zone. The total dissolved solids (TDS) were clustered independently. It was concluded from the assessment that the groundwater of the Tirupur region was critically deteriorated by different anthropogenic activities.

Keywords: Cluster analysis; Correlation studies; Factor analysis; Groundwater chemistry.

1. INTRODUCTION

The quality of water plays a significant role in promoting both the set of human physical conditions and cultivation. If aggravation starts in water quality, it will influence the crop-soil-water system and human being health. Groundwater quality is controlled by many factors, together with the typical weather of the area, soil distinctiveness, movement method of groundwater throughout the rocks, the landscape of the vicinity, intrusion of saline water in coast zone, human being activities on the surface of the ground, etc. (Sharif *et al.* 2008). To facilitate the data set and to acquire consistent analysis, the relevance of data is important. The study of multivariate arithmetic data analysis has a high advantage in hydro-geochemical dealings. To classify groundwater sources, Steinhorst and Williams (1985) employed multivariate numerical data analysis of groundwater chemistry statistics in field investigations. The elements of ion concentration of the groundwater move starting from the recharge part to the discharge region with quality changes by different geochemical processes. Colloidal and dissolved substances in groundwater provide information regarding the environment and geology of the recharge vicinity (Afsin, 1997). The circulation of trace elements in soils can influence the plant cluster growing in the region; consequently, the varieties have been used effectively as tracers during environmental deprivation in several areas (Kfayatullah *et al*. 2001). Hydro-chemical studies for facies determination replicate the general characteristics of aquifer coordination. Subsurface water quality mainly depends upon rock-water interface processes in arid and semi-arid environments (Ettazarini, 2005). Hydro-chemical facies show the possessions of the interface between groundwater and aquifer mineral deposits in lithological structures. Residence time, flow conduit and interaction of rock-water process within the aquifers are the most important factors for determining the hydro-chemical facies (Singh *et al*. 2017). Fluoride is a common component of subsurface water. The substratum containing fluoride is usually liable for lofty absorption of the ion in the subsurface. Various forms of fluoride revelation influence the body's fluoride content raising the threat of fluoride-prone problems. The probable natural sources are associated with different rocks; farming fertilizers and manufacturing performance contribute to the lofty fluoride attention in groundwater. All are ultimately associated with human physical conditions (Ramesh and Elango, 2018). The technique of multivariate analysis is used to determine hydro-geological factors such as groundwater flow path, hydro-chemical parameters and boundaries of aquifer boundaries (Belkhiri *et al*. 2010**)**. Hierarchical techniques show the genealogical affiliation between fundamental elements whereas non-hierarchical technical procedures estimate a resemblance matrix in an iterative progression (Mahlknecht *et al*. 2004). Although statistical analysis does not directly identify causes and consequences, it does compile sequences into a more manageable style, which helps to produce hypotheses for the explanation of various hydro-chemical processes (Guler *et al.* 2002). A multivariate study of parameters operates on the observation that every aquifer precinct has its individual distinctive subsurface water quality mark, based on the parameter uniqueness of the soil to facilitate its surroundings (Singh and Mukherjee, 2015**)**. Cluster study assumption techniques comprise identical variance (homoscedasticity) and standard distribution of the parameter variables (Alther, 1979). The main goal is to describe how various factor scores are used to identify the hydro-geochemically dynamic processes that the primary factors reflect.

2. MATERIAL AND METHODS

The study zone of Tirupur is a city in the Kongunadu region of Tamil Nadu, India, and located between latitudes 11^{0}00’05” N to 11^{0}13’10” N and longitudes 77^{0}12`10” E to 77^{0}29’25” E (Fig. 1). It has an average elevation of 296 m and geographically covers the area of 460 km^2. The Noyyal-Nallar river runs diagonally within the study vicinity, practically dividing it into two halves.

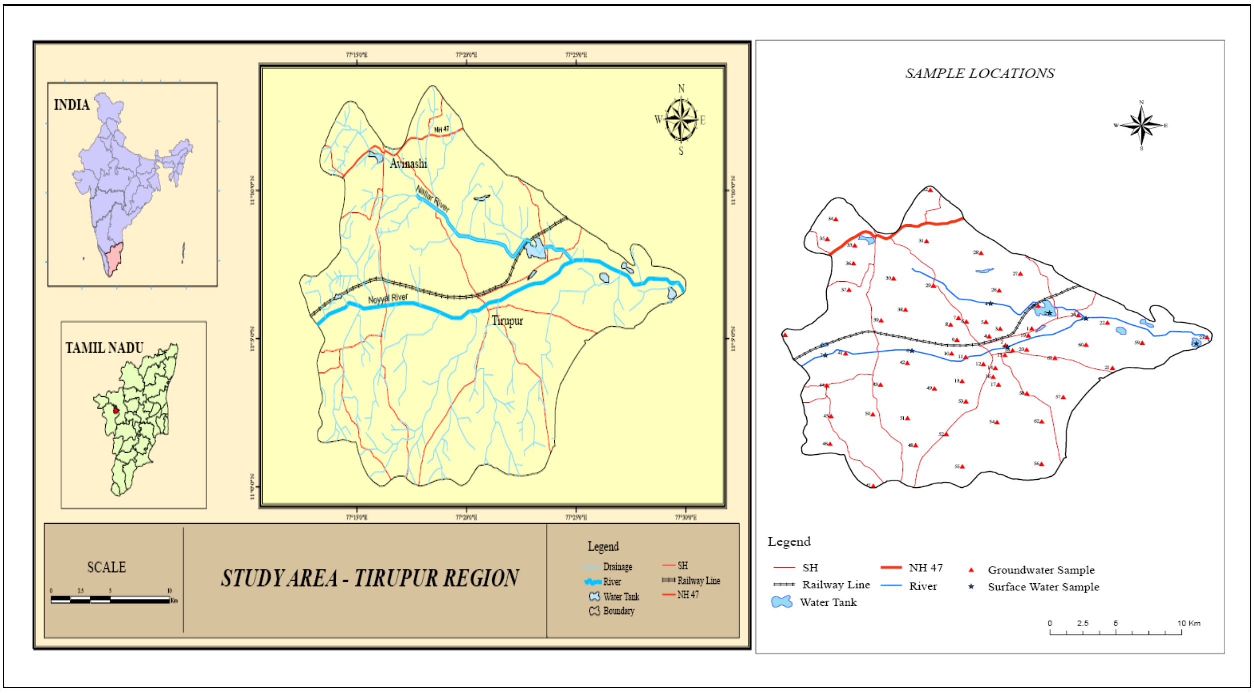

Fig. 1: The study area along with sample stations

The rivers have been negatively impacted by untreated wastewater discharge, which has been upsetting many lives near the river. Groundwater quality in Tirupur-Avinashi province has been worsening swiftly throughout the previous decade. The drainage prototype reflects the attribute of surface and subsurface configuration. Therefore, the lesser the drainage concentration, the higher the likelihood of recharge. The study vicinity is with the dentritic drainage class. The soil types are: red, non-red and calcareous soils. Physically, the region is with a widespread variety of highly weathered gneissose rock varieties.

Petrology deals with the zone as uncertain gneiss rock, charnockite igneous class, multifarious gneiss and pink granite with 54.08% (248.78 km^2), 39.05% (179.63 km^2), 4.63% (21.16 km^2) and 2.24% (10.31 km^2), respectively. The drainage system, soil and the rock types are illustrated in Fig. 2.

For groundwater quality monitoring and evaluating purposes, sixty-three subsurface samples were analyzed. The instruments were calibrated for physico-chemical parameter concentration studies owing to the possible grade calibration values before the measurements, using the standard procedures specified (APHA, 1995). The preferred physico-chemical parameters for assessing the water quality distinctiveness are: pH, turbidity, total dissolved solids, total hardness, calcium (Ca++), sodium (Na+), magnesium (Mg++), potassium (K+), bicarbonate (HCO3-), chloride (Cl-), nitrate (NO3-), sulphate (SO4-), fluoride (F-) and iron-trace metals. Using SPSS software, the principal component analysis was employed to assess the quality of the data set that was assembled from the study zone. Furthermore, reagents used, chemical parameter limits and investigative techniques may all contribute to inaccuracies in groundwater chemical parameter analysis (Prasanna *et al.* 2010). By adjusting ionic-balance errors in areas where variances are typically around 10%, the accuracy of the chemical parameter studies was determined (Arumugam *et al.* 2020). Fig. 3 illustrates the accuracy of the groundwater cation-anion ion analysis results.

3. RESULTS AND DISCUSSION

3.1 Groundwater Chemistry

Subsurface water quality acquiesces information concerning the environments by which the water attribute is distributed (Raju 2006). Results of the chemical ion analysis diagnostic data set and arithmetic statistics, including mean, median, maximum and minimum, are presented in Table 1. pH is from 7.12 to 8.91, with a mean and median of 7.10 and 7.83 respectively. pH reveals that the subsurface water samples are alkaline categories. Variation of total dissolved solids of the study locality is depicted in Fig. 4.

Table 1. Summary statistics of parameters of the groundwater

Parameters	WHO International Standard (WHO, 1993)		Parameter chemical analysis			
	Highest desirable	Max. permissible	Min.	Max.	Mean	Median
pH	7-8.5	6.5-9.5	7.12	8.91	7.10	7.83
TDS	500	1,500	215	5,134	1,177	921
TH	100	500	118	2,573	722	565
Ca^{++}	75	200	19	1,030	158	118
Mg^{++}	50	150	8.0	338	77	72
Na^{+}	-	200	12	229	96	92
K^{+}	-	12	10	97	31	17
Cl^{-}	200	600	24	2,265	375	240
HCO_3^-	-	-	56	659	199	188
SO_4^{2-}	200	400	24	432	84	54
NO_3^-	45	-	7.0	132	38	32.8
F^-	-	1.5	0.2	1.02	0.45	0.49
Fe	0.3	1.0	0.0	1.21	0.16	0.11

Most of the groundwater in the region leads to brackish (1000-10,000) type (Arumugam *et al.* 2016). The Noyyal-Nallar river basins are extremely unnatural because of lofty total dissolved solids. Piper diagram (Piper, 1944) is broadly used to perceive the problem relating to the geochemical progression of water. It resembles in load of the chart proposed by Hill (1940). In the chart, the proportion equivalents per mole of the most important ions were plotted on triangles of cation and anion, and the values were projected to a particular point on a quadrilateral in place of both cation and anion values. The central field was used to explain the general chemical nature of the subsurface water (Deutsch and Siegel, 1997). Distributions and the type of water obtained are: sodium (Na) - calcium (Ca) - chloride (Cl) - bicarbonate (HCO_3^-) type, sodium (Na) - bicarbonate (HCO_3^-), chloride (Cl) type, bicarbonate (HCO_3^-) - calcium (Ca) type, calcium (Ca) - sodium (K) - chloride (Cl) type, sodium (Na) - chloride (Cl) type, calcium (Ca) - sodium (Na) - bicarbonate (HCO_3^-) type, calcium (Ca) - bicarbonate (HCO_3^-) - chloride (Cl) type, bicarbonate (HCO_3^-) - sodium (Na) type and calcium (Ca) - chloride (Cl) type. Hence nine water types are formed (Fig. 5).

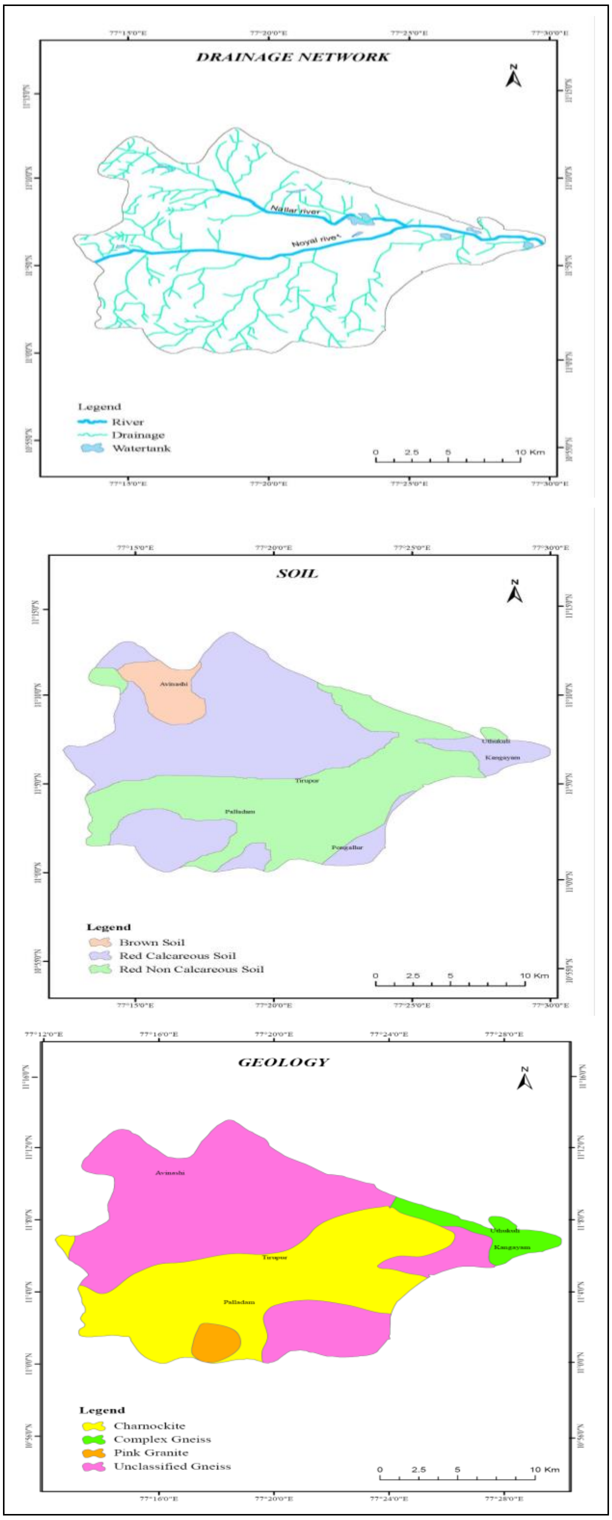

Fig. 2: Drainage arrangement, soil and geology of the zone

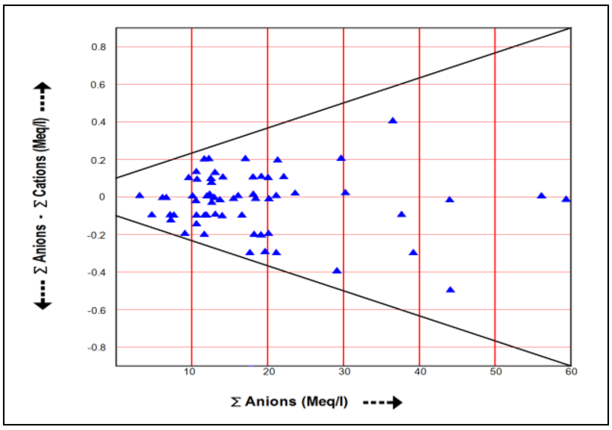

Fig. 3: Control chart for ion balances

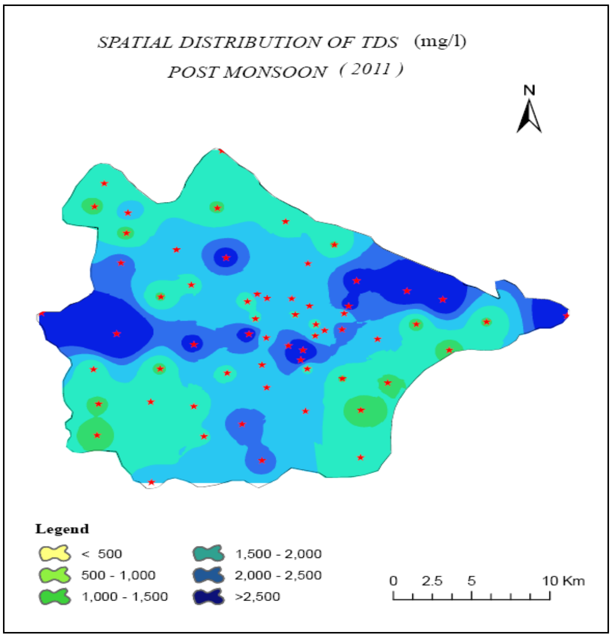

Fig. 4: TDS distribution

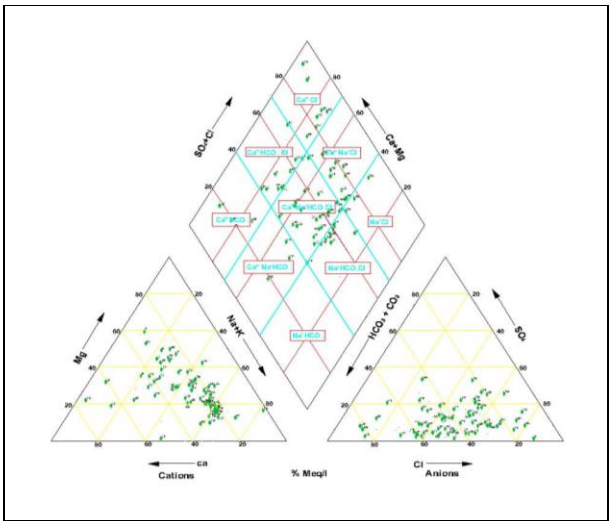

Fig. 5: Piper diagram

The chart shows that the alkalis extensively surpass the alkaline substances and strong acids go beyond the pathetic acids that lead to NaCl form of groundwater. The spatial variations of the species of hydro-chemistry are illustrated (Fig. 6). Fluoride has favorable special effects on teeth at a low down level of 1 mg/l through prevention and tumbling the threat of tooth decay problem. More fluoride in consumption water is the root cause of spotted enamel.

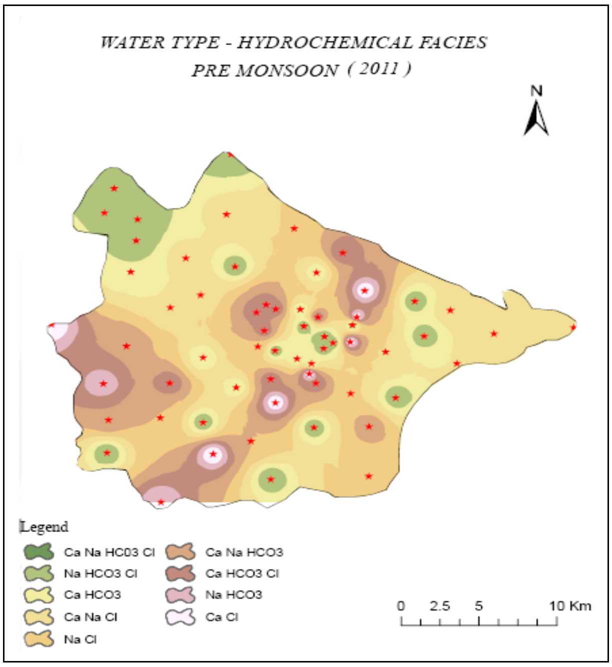

Fig. 6: Spatial distribution of hydro-chemical facies

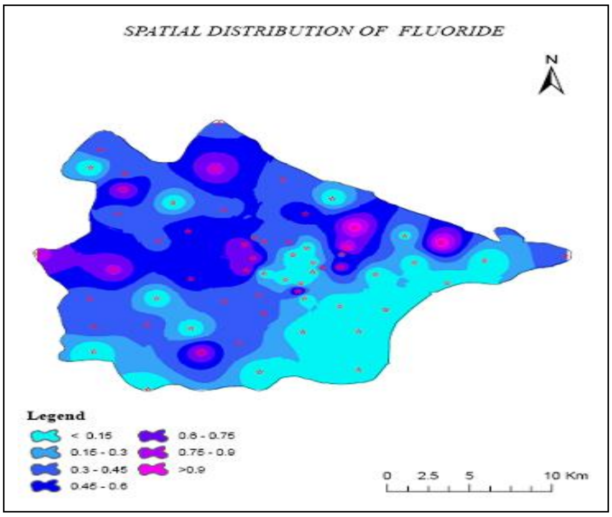

Fig. 7: Fluoride distribution

Mottling does not come out if the fluoride level is in an overindulgence of 1.0 mg/l; the scale and cruelty of mottling increases while the fluoride concentration rises. Nevertheless, concentrations lower than 0.6 mg/l of fluoride increase the threat of tooth decay. Fluoride can be quite harmful at elevated concentrations beyond 1.2- 2 mg/l of water (Schulze 1986). Fluoride within the pleasing limits and exceeding limits are 32.27% and 67.73% respectively. None of the samples exceeds the maximum limit of 1.2 mg/l. The spatial variations are illustrated in Fig. 7. The iron (Fe) in the water samples ranges from 0-1.21 mg/l with average and median values of 0.16 mg/l and 0.11 mg/l, respectively. Five samples (7.94%) of the subsurface water go beyond the suitable limit of 0.3 mg/l.

3.2 FACTOR ANALYSIS

Factor Analysis (FA) is constructive for interpreting subsurface water class from data sets and providing the statistics in explicit anthropogenic activities. Correlation analysis is practically useful to explain the scale of the relation between hydro-chemical parameter ions. The outcome of the correlation analysis is measured in the following interpretation. FA attempts to elucidate the relationships involving the remarks in expressing the fundamental factors that are indirectly apparent (Yu et al. 2003). Subsurface water quality monitoring was performed. The selected quality parameters for evaluating the water standard are: turbidity, pH, TH, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, nitrate, fluoride, iron, etc. The rotated factors, eigen standards, communalities and percentage of the differences are determined by FA structure (Table 2). According to the important factors, the examination shows that the factors are 74.46% of the variance in the data factor sets:

Factor 1 (F1): TDS, TH, Cl^-, Ca^{++}, Mg^{++}, SO_4^{2-}, F^-, NO_3^-, HCO_3^- and Fe
Factor 2 (F2): pH and K^+
Factor 3 (F3): Na^+ and Turbidity

The variance of Factor: 1, Factor: 2 and Factor: 3 have been illustrated as 51.95%, 65.78% and 74.46%, respectively. Factor: 1 has an elevated positive loading with TDS, Cl^-, TH, Ca^{++}, Fe, Mg^{++}, SO_4^{2-}, F^- and NO_3^-, which are 0.967, 0.966, 0.947, 0.865, 0.842, 0.798, 0.777, 0.701 and 0.568, respectively. Lofty positive loading indicates the powerful linear relationship among the factors and parameters. The interrelated matrix intended for the preferred parameter concentrations is presented in Table 3. The links of factor loadings of subsurface water variables are shown (Fig. 8). The statistical data set shows that a variety of human activities are significantly degrading the groundwater in the area.

Table 2: Rotated factor loadings of the samples

Parameters	Factors			Communalities
	1	2	3	
Turbidity	00.518	00.247	00.550	00.629
TDS	00.967	-00.031	-00.120	00.949
pH	-00.412	00.566	-00.213	00.536
TH	00.947	00.152	-00.127	00.935
Ca^{++}	00.865	-00.037	-00.435	00.937
Mg^{++}	00.798	-00.099	00.119	00.661
Cl^-	00.966	00.104	-00.105	00.955
F^-	00.701	00.018	00.069	00.497
SO_4^{2-}	00.777	00.237	-00.249	00.722
Na^+	00.605	-00.028	00.615	00.745
K^+	00.400	00.528	00.358	00.567
HCO_3^-	00.186	-00.861	00.171	00.804
Fe	00.842	00.162	-00.123	00.749
NO_3^-	00.568	-00.637	-90.354	00.737
Eigen value	07.275	51.946	51.946	111.164
% of Variance	51.947	13.825	08.687	74.457
Cumulative %	51.947	65.776	74.457	-

Table 3. Summary statistics of the groundwater quality parameters

Parameters	Min.	Max.	Mean	Variance	Standard deviation
Turbidity	0.00	38.0	7.58	5.925	35.107
TDS	198.0	5,119	1,164.68	831.18	690859.40
pH	7.07	8.85	7.68	0.34695	0.12038
TH	114.0	2,558	696.0	470.821	221672.45
Ca ++	15.0	1,023	149.27	164.461	27047.35
Mg++	0.00	319	74.56	61.638	3799.299
Cl^-	18.00	2,249	359.89	403.596	162890.07
F^-	0.00	1.0	0.40	0.330	0.1090
SO^{4-}	0.00	427	79.47	85.331	7281.36
Na+	8.00	220.0	88.63	50.552	2555.4
K+	1.00	91.0	22.82	19.732	389.36
HCO_3^-	53.00	650.0	186.0	134.099	17982.61
Fe	0.00	1.20	0.166	0.2055	0.0422
NO_3^-	0.00	125.0	34.05	25.408	645.56

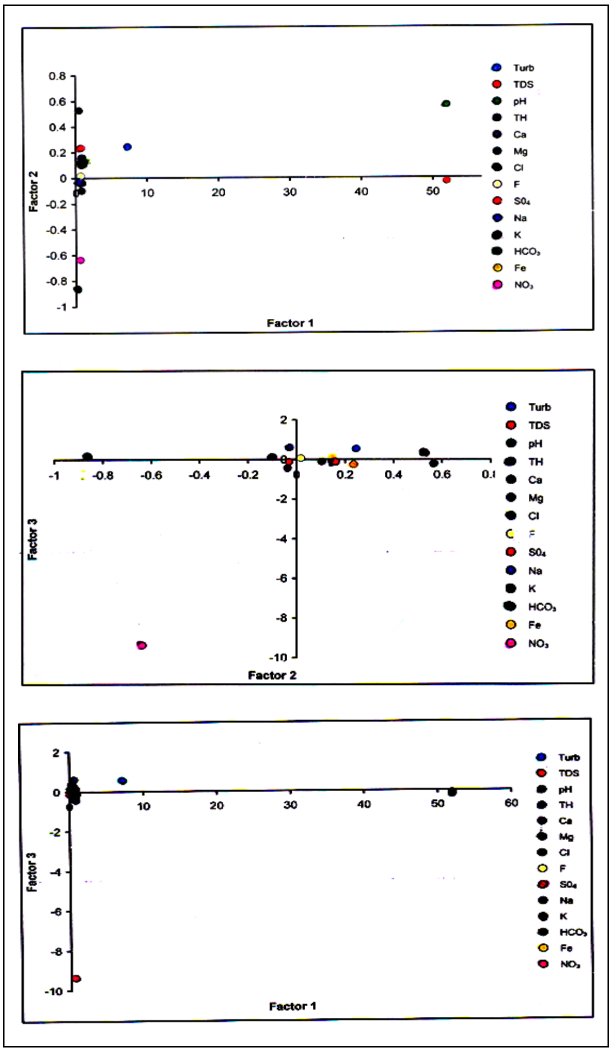

Fig. 8: Associations of factor loadings on the subsurface water variables by factor analysis

3.3 CORRELATION OF PARAMETERS OF THE GROUNDWATER

The correlation coefficient is frequently appraised for establishing the affiliation involving two different variables. They are merely a computation to display how well a single variable predicts the other variables. It is made use of to report on the degree of mutual unevenness that exists between specific groundwater class variable pairs. The subsurface water quality parameter concentrations considered for the correlation study are: turbidity, pH, TH, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, nitrate, fluoride, iron, etc. The revision displayed that TDS showed a superior direct correlation with chloride (Cl^-) and TH. The pairs of TDS & TH, TDS & Na^+, TH & Ca^{++}, TH & Mg^{++}, Mg^{++} & Cl^- and Na & K showed more imperative correlations. Moreover, TDS and Ca^{++}, TDS & Mg^{++}, TDS & SO_4^{2-}, TH and SO_4^{2-}, Ca^{++} & Cl^-, Cl^- & SO_4^{2-}, Cl^- & Na^+ and Na^+ & SO_4^{2-} indicated excellent positive correlations. Additionally, TDS & K^+, TH & Fe and Cl^- & Fe exhibited constructive correlations. The particulars are presented in Table 4.

3.4 CLUSTER ANALYSIS

Entity of groundwater samples are evaluated with particular similarity/dissimilarity and relationship methods are grouped to clusters. The relationship system iteratively ties the nearby points of the samples with the correspondence matrix. The preliminary cluster is created by the relationship of the two samples with the maximum resemblance. Ward's technique is used for calculating the error computation of squares which are the total of the distances as of each individual to the middle of its close relative group (Judd, 1980). The cluster analysis (CA) has been conceded out for substituting the geo-understanding of hydro-geochemical facts. The similarity or dissimilarity dimensions and linkage technique used for clustering significantly affect the consequence of the Hierarchical Cluster Analysis (HCA). Hierarchical cluster analysis was used on constituents' parameter values. Correlation coefficient indices have been used to link relevant groups of chemical parameter pairs; then, the next most similar group pairs, and so on, until an averaging process has clustered the chemical ion concentrations in the dendrogram (Davis and Dewiest, 1996). Two sizable clusters emerged from the cluster analysis results:

Cluster 1: Fluoride, iron, turbidity, pH, magnesium, potassium, calcium, sulphate, nitrate and sodium)

Cluster 2: Chloride, bicarbonate and total hardness

Table 4. Correlation matrix of parameters of groundwater

Parameters	Turbidity	TDS	pH	TH	Ca ++	Mg++	Cl-	F-	SO42-	Na+	K+	HCO3-	Fe	NO3-
Turbidity	01.0000													`
TDS	00.3708	01.0000												
pH	-00.1936	-00.3611	01.0000											
TH	00.4946	00.9078	-00.3348	01.0000										
Ca ++	00.2267	00.9066	-00.2854	00.8601	01.0000									
Mg++	00.3873	00.7985	-00.3380	00.7003	00.5477	01.0000								
Cl-	00.4209	00.9772	-00.3155	00.9331	00.8813	00.8045	01.0000							
F-	00.4296	00.6283	-00.1685	00.6857	00.5260	00.6286	00.6350	01.0000						
SO42-	00.3718	00.7410	-00.1637	00.7560	00.7786	00.5205	00.7676	00.4072	01.0000					
Na+	00.5315	00.7410	-00.2976	00.4535	00.2900	00.4614	00.5360	00.3647	00.4021	01.0000				
K+	00.2825	00.3785	00.0215	00.3759	00.1973	00.2787	00.4142	00.2225	00.2705	00.3939	01.0000			
HCO3-	-00.1226	00.2196	-00.4344	0-0.0066	00.1179	00.3154	00.0723	00.1121	-00.0833	00.2536	-00.1984	01.0000		
Fe	00.3763	00.7810	0-0.2796	00.8587	00.7407	00.583	00.8070	00.4917	00.6718	00.4364	00.41300	00.0093	01.0000	
NO3-	00.1834	00.5479	-00.4698	00.4392	00.5888	00.3573	00.4536	00.3892	00.2958	00.3175	-00.1033	00.0093	00.3976	01.0000

A suspicious concern about the content of the clusters states that the initial cluster included the dominant chemical ion concentration of fluoride (F), iron (Fe), turbidity, potassium (K), nitrate (NO_3^-), magnesium (Mg), sodium (Na), sulphate (SO^{4-}), calcium (Ca) and bicarbonate (HCO_3^-) and a physical parameter (turbidity). The second cluster integrated chloride total hardness (Fig. 9). The physical parameter - total dissolved solids (TDS), was clustered independently.

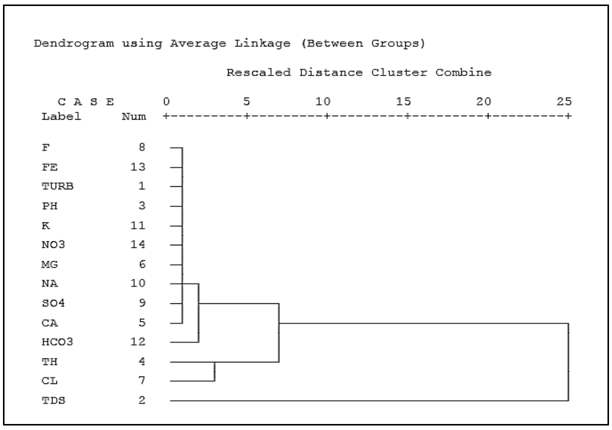

Fig. 9: Dendrogram for cluster studies of groundwater

4. CONCLUSION

The groundwater quality evaluation reveals that the region is alkaline and brackish in its characteristics. The Noyyal-Nallar river basin has elevated total dissolved solids. Nine water types show that the alkalis widely surpass alkaline earth and strapping acids go beyond the weak acids, leading to sodium-chloride type of groundwater. 67.73% of the groundwater exceeds the fluoride limit. 8.06% of the groundwater goes beyond the acceptable limit of iron. The study concluded that TDS showed greater correlating equivalence with chloride (Cl^-) and TH. Cluster analysis proves that total dissolved solids were clustered independently. The statistical data indicates that the subterranean environs are seriously deteriorated by a range of anthropogenic activities.

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