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Ground water quality assessment of Gangavalli Taluk, Salem District, Tamil Nadu, India using multivariate statistical techniques

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ABSTRACT

Ground water samples of open wells, bore wells and hand pumps collected from 15 different locations in Gangavalli Taluk in Salem District during the Pre-Monsoon (PM1) period (June -July 2010) and Post-Monsoon (PM2) period (December 2010 - January 2011) were analyzed for their physico-chemical characteristics. Each parameter was compared with the standard permissible limit of the parameter as prescribed by World Health Organization (WHO). The multivariate statistical tools such as Correlation Coefficient Analysis (CCA), Factor Analysis (FA) and Cluster Analysis (CA) were also used for the interpretation of water quality data and its spatial variations.

Keywords- Cluster Analysis; Correlation Coefficient Analysis; Factor Analysis; Gangavalli; physico-chemical parameters; water quality

I. INTRODUCTION

Water is an indispensable source of our life. The ground water is contaminated mainly by the discharge of domestic water, livestock waste, effluents from industry, change in climate, precipitation and soil type. In India, research on the assessment of water quality, especially with reference to fluoride has been carried out by various workers [1-6].

The application of multivariate statistical tools such as CCA, FA and CA helps in the interpretation of the results to get better information about the water quality parameters. The ground water quality assessment using multivariate analysis has been widely studied in India and in the different parts of the World [7-14]. The major problem with the ground water is that once contaminated, it is difficult to restore its quality. Hence there is a need and concern for the protection and management of ground water quality [15].

Study Area

Salem District in Tamil Nadu is geographically situated between 11°14´ and12°53´ N and 77 °44´ and 78° 50´ E covering an area about 5245 Km^2. On the Northern side, it is bounded by Dharmapuri District; on the Western side, Erode District; on the Eastern side, Viluppuram District and on the Southern side, Namakkal and Tiruchirappalli Districts. Salem District consists of nine Taluks viz., Attur, Edappadi, Gangavalli, Mettur, Omalur, Salem, Sangagiri and Yercaud. Salem District experiences arid and semi-arid climate with an average annual minimum and maximum temperatures 19.7° C and 39.1°C respectively. The geographical formation of Salem District comprises hard rock types of granites, gneiss, charnockite, dunite, pyroxinite and quartzite. The minerals found in the District are magnesite, bauxite, quartz, felspar,

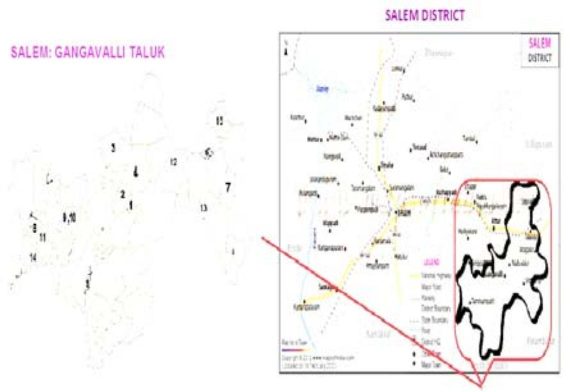

Fig.1 Geographical distribution of sampling stations

limestone, soapstone, dunite, roughstone, granites. It receives rainfall in the South-west monsoon and North- east monsoon. Major industries in this District are steel and cottage industries. Paddy, Cholam, Cumbu, Ragi Redgram, Greengram, Blackgram, Horsegram, Turmeric, Sugarcane, Mango, Bannana, Tapiaco and Groundnut are the major food crops of this District [16]. The present study area is Gangavalli Taluk (Fig.1) which is one of the nine Taluks in Salem District [17]. Gangavalli is located at 11º 28'60 N and 78º39'0 E. It has an average elevation of 291 metres (958 feet) [18]. Ground water is the main source of potable water in the villages of Gangavalli Taluk. So, an attempt is made to study the water quality.

The main objectives of the study are

i) collection of ground water samples from open wells, bore wells and hand pumps - Gangavalli Taluk, Salem District, Tamil Nadu.
ii) analysis of a few physico-chemical water quality parameters
iii) assessment of the relationship between the water quality parameters
iv) interpretation of water quality data and its spatial variations.

II METHODS OF INVESTIGATION

A Sampling and ground water analysis

Among the 30 samples, 15 samples during PM1 season (June-July2010) and 15 samples during PM2 season (December2010-January 2011) have been collected. All the samples were analysed by following the standard guidelines [19]. The corresponding locations of the water samples collected for analysis have been furnished in Table 1.

The temperature of water samples was recorded on the spot with the use of the thermometer. pH meter (Systronics digital model 335) was used to determine the hydrogen ion concentration. The samples were analyzed for EC using conductivity meter. Total Alkalinity (TA) was estimated by neutralizing with Standard HCl acid. Salinity and Total

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TABLE 1 Location of sampling stations

Sample No.	Location	Water Source
SG1	A.Vinayakapuram	OW
SG2	Anaiyampatti	BW
SG3	Kadambur	BW
SG4	Gangavalli	HP
SG5	Kodamalai (or) Gudamalai	HP
SG6	Nattar Agraharam	OW
SG7	Pagadapadi	OW
SG8	Sengadu	BW
SG9	Sendarapatti	BW
SG10	Sendarapatti	HP
SG11	Thammampatti	OW
SG12	Thedavoor	HP
SG13	Thittacheri	HP
SG14	Velakkombai	OW
SG15	Veppampoondi	BW

Dissolved Solids (TDS) were estimated using Systronics water analyzer. Total Hardness (TH) and Calcium Hardness (CH) as $CaCO_3$ were determined titrimetrically, using standard EDTA. The calculation of Magnesium Hardness (MH) was done by subtracting the CH from TH value. The fluoride was estimated by SPANDS [2 - (p-sulphophenylazo) 1, 8-dihydroxynaphthalene- 3, 6 - disulphonic acid tri sodium salt), $C_{16}H_9N_2O_{11}S_3Na_3$] colorimetric method. All the parameters are expressed in milligram per litre (mg/l) except pH (units) and EC. The electrical conductivity is measured in millisiemens (mS).

B M ultivariate statistical analysis

The linear relationship between concentrations of the studied parameters can be evaluated through the bivariate correlation analysis [with the Pearson correlation coefficient (r) at two tailed significance level (p)] and FA were applied using SPSS software (Version 13.0). Correlation coefficient is statistically significant if it is higher than the critical value [20]. The methods of varimax rotation and Kaiser Normalization were applied for FA. Only factors having >1 of Eigen value of the data sets were used as factors [21].

CA comprises a series of multivariate methods which are used to find true groups of data. In clustering, the objects are grouped such that similar objects fall into the same class [22]. Hierarchical clustering joins the most similar observations, and then successively the next most similar observations. The levels of similarity at which observations are merged are used to construct a dendrogram. In this study, a standardized space Euclidian distance [23] is used. A low distance that shows the two objects are similar or "close together", whereas a large distance indicates dissimilarity.

III RESULTS AND DISCUSSION

Table 2 gives the potable status of ground water samples in the Gangavalli Taluk of Salem District in PM1 and PM2 seasons.

A Potable status of ground water samples in PM1 and PM2 seasons

pH values in samples varied from 7.16 to 7.70 in the PM1 season and 7.18 to 7.61 in the PM2 season. Though the ground water pH in the study area is slightly alkaline, all the samples during both the seasons were found to be within the permissible limit prescribed by WHO (6.5 to 8.5)[24]. Slight alkalinity in water samples is due to the influx of HCO^{3-} ions in the ground water aquifer, which is due to percolation of rain water through soil as stated by various authors [25, 26]. The EC is an indicator of salinity and it also signifies the amount of TDS. In each season, four samples (SG3, SG4, SG9, SG15 and SG2, SG8, SG9, SG15 respectively) were found to have high EC values as compared with the WHO recommended limit (EC = 1.4 mS). Three samples (SG5, SG8, SG12) in the PM1 season and only one sample (SG4) in the PM2 season were found to have EC value equal to 1.4 mS as per the WHO recommended limit in the PM2 season. Other water samples (8 in PM1 and 10 in PM2 season) were observed to be below the WHO permissible limit for EC. EC values of most of the samples were found to be reduced after monsoon.

Out of 30 water samples, the salinity values of 11 in the PM1 season and 13 in PM2 season were found to be within the WHO permissible limit (Salinity= 200-600 mg/l). Remaining samples were found to exceed the WHO permissible limit.

15 samples in the PM1 and 11 samples in the PM2 season were observed with the TS values within the permissible limit of WHO (500-1000 mg/l) and 4 samples below the limit in the PM2 season.

8 samples in the PM1 season and 7 samples in the PM2 season were found to have TDS content within the permissible limit of WHO (500-1000mg/l) and the remaining samples (7 and 8 in the pre-and post monsoon seasons respectively) were observed with TDS values below the desirable limit of WHO (500 mg/l). As per TDS classification given by Fetter (1990)[27], the total ground water samples were registered with 100% belonging to fresh type (TDS< 1000 mg/l) in both the pre- and PM2 seasons.

Only one sample was observed with TH value between the range of 100-300 mg/l, 10 samples were found to be within the permissible limit and the remaining 4 samples were found to exceed the permissible limit in the PM1 season whereas 11 samples were found to be within the permissible limit in the PM2 season. According to TH classification [28] (Sawyer and Mc Carty 1967), the ground water range from hard (150-300 mg/l) to very hard (> 300).

All the samples were observed with high CH values (WHO; CH = 75-200 mg/l) in the PM1 and PM2 seasons. As stated by Ramachandramoorthy *et al*., 2010[2], the excessive calcium content of water samples may be due to the abundant concentration of calcium-rich minerals, calcite and gypsum in the study area. In the PM1 season, as per the guidelines of WHO (30-150 mg/l), MH in only one sample (Sendarapatti, BW) was found to be above the permissible limit and in 14 samples, it was within the permissible limit. In the PM2 season, all the 15 samples were recorded to be within the permissible limit. In the PM1 season, the total alkalinity of all the 15 samples was found to be above the permissible limit (200 mg/l; WHO) and in post- monsoon season, TA exceeded in 14 samples. A total of 9 samples during PM1 and 11 samples during PM2 season, depicted F contents ranging between 0.5 mg/l and 1.5 mg/l. A few samples (6 in PM1 and 4 in PM2) were found with higher F content (>1.5 mg/l).

Table 2 Potable status of ground water samples in the Gangavalli Taluk of Salem District in pre-monsoon and post-monsoon seasons

Parameter	**WHO (2006)**	**Pre-monsoon**				**Post-monsoon**			
	Permissible Level	***Sample range***	***BPL***	***WPL***	***APL***	***Sample range***	***BPL***	***WPL***	***APL***
pH	6.5-8.5	7.16-7.7	-	15	-	7.18-7.61	-	15	-
EC (mS)	1.4	1.1-1.6	8	3	4	1-1.6	10	1	4
Salinity (mg/l)	200-600	335.5-709.7	-	11	4	302.5-726.4	-	13	2
TS (mg/l)	500-1000	505.1- 873.6	-	15	-	447.6-831.8	4	11	-
TDS (mg/l)	500-1000	401.8 -783.7	7	8	-	327.0-751.6	8	7	-
TSS (mg/l)	0-5	56.7 - 162.1	-	-	15	50.4-169	-	-	15
TH (mg/l)	300-500	282.3- 678.9	1	10	4	252.9-651.2	2	11	2
CH (mg/l)	75-200	226.3- 612.1	-	-	15	204.1-580.9	-	-	15
MH (mg/l)	30-150	46.7 - 208.6	-	14	1	44.5-108.2	-	15	-
TA (mg/l)	200	200.2- 408.9	-	-	15	179.9-401.6	1	-	14
F (mg/l)	0.5-1.5	1.1 - 2.01	-	9	6	0.89-1.93	-	11	4

Fluoride has much detrimental effects such as dental fluorosis and skeletal fluorosis when its presence exceeds the threshold limit. The comparison of fluoride concentration for Salem Taluk in PM1 & PM2 seasons reveals that, in general, F concentration decreases in PM2 as compared with PM1 due to increase in water table.

The box plots of measured value of water quality physico-chemical parameters in PM1 and post- monsoon seasons are presented in Fig.2. As for as the temporal behavior of pH and EC is concerned, there is no much difference in the values, indicating, monsoon has no effect on pH and EC. The physical parameters, viz., salinity, TS, TDS and the chemical parameters such as TH, CH, TA and fluoride except MH showed decreasing values in PM2 season as compared with PM1 season, indicating the rise in water level after the monsoon.

B Correlation coefficient analysis

Table 3 shows the matrix of correlation between the water quality parameters. The pH-F for the water samples in the PM1 and the PM2 seasons show the positive correlation value of 0.528 and 0.515 respectively. The higher positive values specify good correlation between the parameters EC-Salinity, EC-TDS, EC-TS, Salinity-TDS, Salinity-TS, CH-TH, CH-TDS, CH-TS and TDS -TS. The poor correlation is observed for TA with other parameters. The lower negative values indicate poor correlation between the parameters TS-TSS and TS-F. The correlation co-efficient between TA and F in the PM1 season and PM2 season is 0.570 (significant correlation at 0.05 level) and 0.382 respectively.

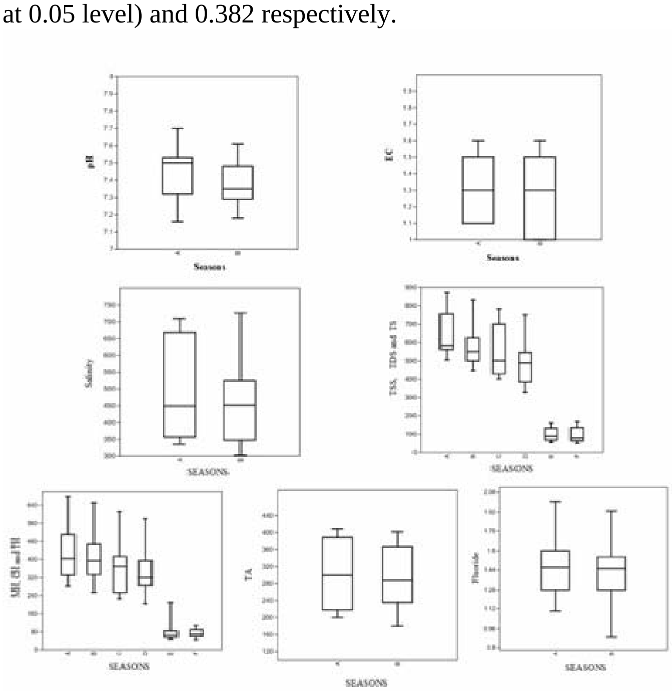

Fig. 2 Boxplots of measured value of water quality physico-chemical parameters in PM1 and post- monsoon seasons; the inner solid line indicates the median; A, C and E indicate the boxes for PM1 season; B, D and F indicate the boxes for PM2 season

The above ‘r’ values prove the influence of the water quality parameter viz., EC, TDS, salinity, CH and F among one another.

C Factor Analysis-Physical parameters

Table 4 illustrates rotated factor loadings and the eigen values of FA application for physical parameters of water quality. The number of eigen values can be calculated from a scree plot for physical parameters of water samples demonstrated in Fig.3.

The first two varifactors accounting for 83.63% and 87.35% of the total variance in the PM1 and PM2 seasons respectively are retained on the basis of the “Eigen value greater than one” rule. For the factor interpretation, factor loadings with values greater than 0.6 were used. The first varifactor, VF-1 was dominant and accounted for 63.92% and 71.42% of the total variance in the pre- and PM2 seasons respectively. The second varifactor, VF-2 was secondary and accounted for only 19.71% and 15.93% of the variance in the pre- and PM2 seasons respectively. In the PM1 season, the first varifactor, VF-1 was documented by Temperature, TDS, TSS and TS with the loadings of 0.918, 0.907, -0.609 and 0.901 respectively. The second varifactor, VF-2 was explained with the loading of EC (0.828), Salinity (0.799) and pH (-0.861). The first (VF-1) and second (VF-2) varifactors were calculated with 4.475 and 1.38 as Eigen values respectively. Similarly, in the PM2 season, the first varifactor VF-1 was dominant and described by Temperature, EC, Salinity, TDS and TS with the positive loadings while TSS with negative loading and second varifactor, VF-2 was positively loaded with pH. The first and second varifactors are calculated with 5 and 1.115 as Eigen values respectively. PCA scatter plots for physical parameters in the PM1 and PM2 seasons are presented in Fig.4.

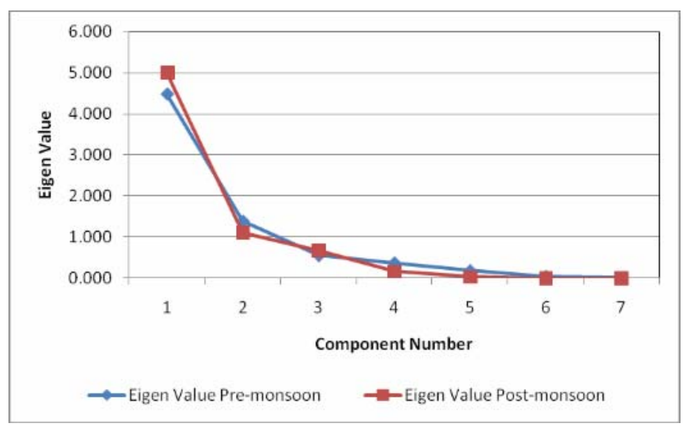

Fig.3 Scree plot for physical parameters of water samples

Table 3 Correlation matrix of the water quality parameters of the study area

Seasons	Parameters	pH	EC	TA	SAL	CH	MH	TH	TDS	TSS	TS	F
PM1	pH	1										
PM2												
PM1	EC	-.518*	1									
PM2		-.096										
PM1	TA	.533*	-.346	1								
PM2		.465	.185									
PM1	Salinity	-.511	.948**	-.257	1							
PM2		.012	.925**	.250								
PM1	CH	-.121	.398	.066	.376	1						
PM2		-.034	.821**	.119	.877**							
PM1	MH	-.275	.383	.156	.426	-.026	1					
PM2		.313	.200	.159	.339	.154						
PM1	TH	-.400	.491	.146	.531*	.568*	.410	1				
PM2		.026	.821**	.143	.900**	.983**	.334					
PM1	TDS	-.213	.639*	.033	.706**	.789**	.344	.518*	1			
PM2		.017	.920**	.273	.998**	.881**	.361	.908**				
PM1	TSS	.338	-.748**	-.077	-.704**	-.667**	-.262	-.552*	-.673**	1		
PM2		.191	-.782**	-.116	-.666**	-.610*	-.330	-.644**	-.665**			
PM1	TS	-.145	.472	.093	.575*	.763**	.381	.569*	.957**	-.493	1	
PM2		.097	.812**	.286	.952**	.832**	.310	.852**	.955**	-.414		
PM1	F	.528*	-.018	.570*	-.084	.220	.193	.006	.233	-.304	.186	1
PM2		.515*	.534*	.382	.502	.458	.329	.499	.499	-.509	.406	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4 Rotated factor loadings and the eigen values of FA application for water quality parameters (Physical)

Parameters	PM1 season		PM2 season	
	VF-1	***VF-2***	***VF-1***	***VF-2***
Temperature° C	0.918		0.872	
EC (mS)		0.828	0.97	
Salinity (mg/l)		0.799	0.979	
TDS (mg/l)	0.907		0.978	
TSS (mg/l)	-0.609		-0.764	
TS (mg/l)	0.901		0.889	
pH (unit)		-0.861		0.928
Eigen value	4.475	1.38	5	1.115
Percentage variance	63.92	19.71	71.42	15.931
Cumulative percentage variance	63.92	83.63	71.42	87.353

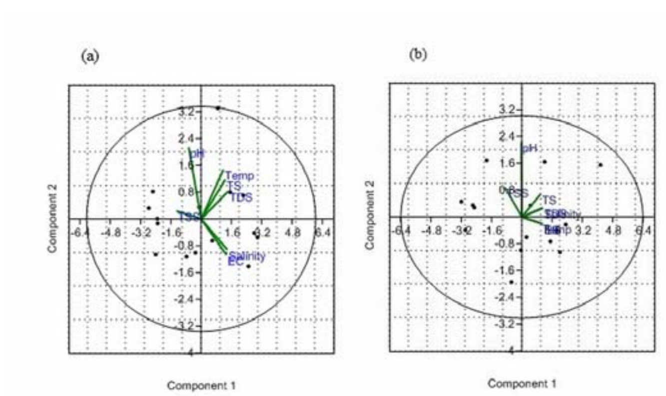

Fig. 4 PCA scatter plots of water quality physical parameters in (a) PM1 season (b) PM2 season

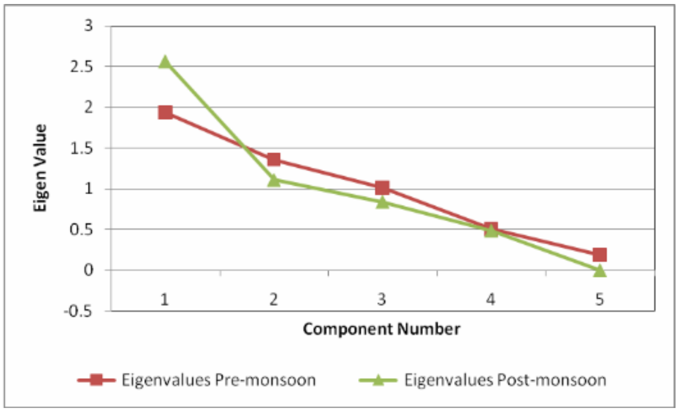

Fig.5 Scree plot for chemical parameters of water samples

Table 5 Rotated factor loadings and the eigen values of FA application for water quality parameters (Chemical)

Parameters	PM1 season			PM2 season	
	VF-1	***VF-2***	***VF-3***	***VF-2***	***VF-1***
CH		0.939		0.877	
MH			0.957	0.48	
TH		0.791		0.927	
F	0.897			0.747	
TA	0.862				0.743
Eigen value	1.935	1.355	1.014	2.564	1.108
Percentage variance	38.7	27.1	20.3	51.29	22.162
Cumulative percentage variance	38.7	65.8	86.1	51.29	73.452

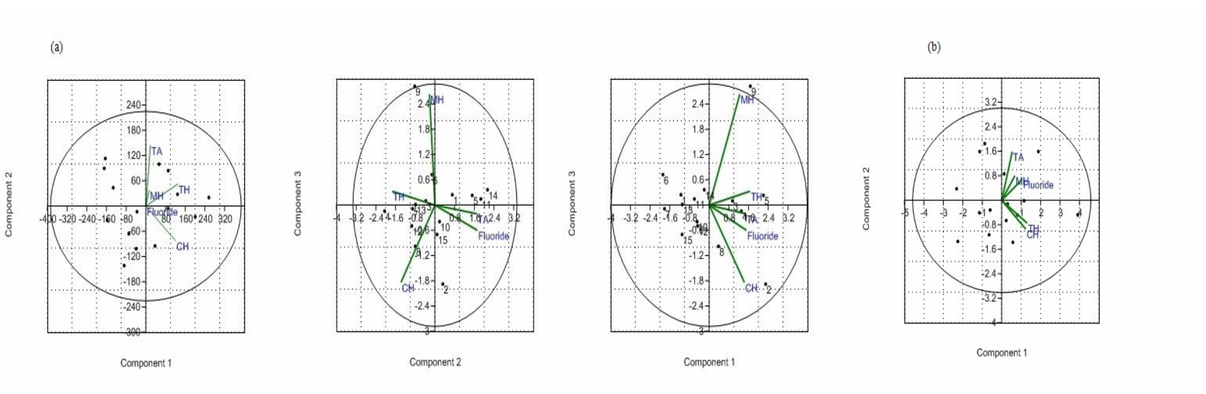

Fig. 6 PCA scatter plots of water quality chemical parameters in (a) PM1 season (b) PM2 season

D Factor Analysis-Chemical parameters

Fig.5 shows the scree plot for chemical parameters of water samples for both the seasons. The sorted rotated FA for chemical parameters of water quality results along with Eigen values and percentage of variance are presented in Table 5. In the PM1 season, the first varifactor (VF-1) accounted for correlation with TH. This varifactor can be termed as factor responsible for hardness. Third varifactor (VF-3) explained 20.3 % of the variance with an Eigen value 1.014 and was positively associated with MH.

In the PM2 season, only two varifactors were sorted. The first varifactor (VF-1) accounted for 51.29% of the total variance with an Eigen value 2.564. This varifactor has high positive connection with TH, moderate correlation with CH, F and low association with MH. This varifactor (VF-1) can be termed as factor responsible for hardness. The second varifactor (VF-2) was positively correlated with TA. The second varifactor explained 22.162% of the percentage variance and both the varifactors together accounted for 73.45% of the total variance with Eigen values 2.564 and 1.108 for VF-1 and VF-2 38.7 % of the total variance and it was positively correlated with F and TA. This varifactor revealed that water has alkaline nature and cause for fluorosis. The Eigen value for the first varifactor was 1.935. The second varifactor, on the other hand, accounted for 27.1 % of the variance with an Eigen value 1.355 and strong positive correlation with CH and moderate respectively. PCA scatter plots for physical parameters in the PM1 and PM2 seasons are presented in Fig.5.

E Cluster Analysis

The HCA is a data classification technique that is widely applied in Earth sciences [23] and often used in the classification of hydrogeochemical data [29-33]. The main result of the HCA performed on the 15groundwater samples is the dendrogram (Fig. 7 and 8). In this study, the Euclidean distance is selected as the distance measure. The sampling sites with the larger joined with a linkage rule and the steps are repeated until all observations have been classified. With this geochemical dataset, Ward's method was more successful to form clusters that are more or less homogenous and geochemically distinct from other clusters, compared with other methods such as the weighted pair-group average. Ward's method is distinct from other linkage rules because it uses an analysis of variance approach to evaluate the distances between clusters. Other studies used Ward's method as linkage rule in their CA [30, 32]. Guler et al., 2002[31]; Daughney and Reeves, 2005 [34]; Daughney and Reeves, 2006 [35] also found that using the Euclidean distance as a distance measure and Ward's method as a linkage rule produced the most distinctive groups.

CA was used to identify the similarity between the sampling sites. The dendrogram (cluster tree) of water samples for the PM1 season is shown in Fig.7. It can be classified into four groups based on the visual observation of the dendrogram namely, C1, C2, C3 and C4.

C2 and C3 have the lower linkage distance between the defined clusters; therefore, have the greater similarity between all clusters. It can be expected that the geochemistry of C2 samples would have similarity with the ones of C3. To explain the uniqueness of each cluster of samples, Table 6 provides the median values of geochemistry data, including the 12 physico-chemical parameters. C1 and C3 have an elevated linkage distance between the defined clusters. Samples from C1 cluster are characterized by high concentration of TA and by low concentration of TSS whereas samples from C2 cluster are characterized by low concentrations of pH, TS, MH, TA and F. Samples from C3 are characterized by high concentration of pH and TSS and by low concentration of EC, Salinity, TDS and TH while samples from C4 are characterized by high concentration of Temperature, EC, Salinity, TS, TDS, TH, CH, MH and F.

Fig.8 shows the dendrogram of water samples for PM2 season where it can be classified into 3 groups, named C1, C2 and C3. By observing dendrograms, the level of similarity between three clusters was indicated. C1 and C3 have an elevated linkage distance between the defined clusters. To make clear the exclusivity of each cluster of samples, Table 6 represents the median values of geochemistry data, including the 12 physico-chemical parameters. Samples from C1 cluster are characterized by high concentration of pH and by low concentration of salinity, TS, TDS and CH whereas samples from C2 cluster are characterized by high concentration of TSS and by low concentrations of pH, MH, TA and F. Samples from C3 are characterized by high concentrations of Temperature, EC, Salinity, TS, TDS, TH, CH, MH, F and by low concentration of TSS.

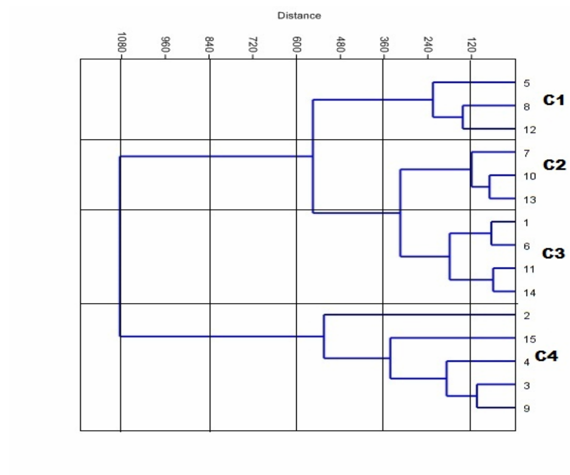

Fig. 7 Dendrogram achieved by CA for water quality parameters during PM1 season

Table 6 Geochemical characteristics of each cluster for dry season (median concentration in mg/L, bold values: highest values)

Parameter	PM1 season				PM2 season		
	C1	***C2***	***C3***	***C4***	***C1***	***C2***	***C3***
Temperature º C	32	30	30	**33**	26	26	**30**
pH (unit)	7.5	*7.32*	**7.52**	7.38	**7.48**	*7.28*	7.32
EC (mS)	1.4	1.3	*1.1*	**1.5**	1	1	**1.4**
Salinity (mg/l)	548.1	438.8	*354.1*	**680**	*327.3*	347.7	**520**
TS (mg/l)	627.5	*557.3*	569.8	**769.8**	496	499.5	**605.2**
TDS (mg/l)	560.3	469.1	*425.5*	**728.8**	*349*	385.3	**540.2**
TSS (mg/l)	*68.8*	90.1	**140.1**	76.1	135.4	**149.3**	*71.3*
TH (mg/l)	484.5	391.1	*321.9*	**512.1**	286.6	375.1	**456.3**
CH (mg/l)	405	346.9	*236.6*	**413.1**	*218.2*	289.6	**379.8**
MH (mg/l)	60.4	*56.6*	72.1	**84.7**	68.4	*60.1*	**79.3**
TA (mg/l)	**371.6**	*218.1*	344.6	299.8	**367**	*240.4*	326.6
F (mg/l)	1.46	*1.28*	1.46	**1.51**	1.45	*0.97*	**1.46**

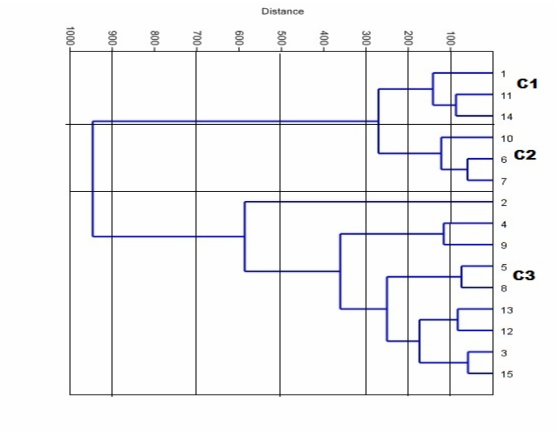

Fig. 8 Dendrogram achieved by CA for water quality parameters during post-monsoon season

IV CONCLUSION

Most of the physico-chemical parameters measured for groundwater samples were within the limits set by the World Health Organization. The study reveals that in few villages, water has high hardness and fluoride content. Hence, ground water must be used for drinking only after proper treatments viz., softening and defluoridation. Correlation analysis indicates that the water quality parameters viz., EC, TDS, salinity, CH and F were significantly correlated with one another. FA showed high loading of physical parameters viz., Temperature, TS, TDS and TS in the PM1 season while high loading of Temperature, EC, Salinity, TS, TDS and TSS in the PM2 season indicates that the contamination of ground water may be due to agricultural runoff, solid waste disposal and surface water pollution from industrial discharges. FA showed high loading of chemical parameters F and TA in the PM1 season indicating the presence of carbonates and bicarbonates added to water when it passes through the soil and rocks. Factors showing high loading of TH, CH and F indicated soil /rock containing Fluorospar (CAF2) in the study area. Thus the factors extracted reduce the overall complexity of the data. Ward's method of CA indicated four clusters in the PM1 season and three clusters in the PM2 season that represent specific patterns of trends in groundwater quality. This study demonstrates the application of multivariate statistical methods in assessing the hydrochemical characteristics of the Gangavalli Taluk and also to provide preliminary assessment of the ground water quality that will serve as a database for future investigations and monitoring of groundwater quality in the study area.

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