Original Article

Exploring Multivariate Statistical Methods For Evaluating Ground water Quality In Edappaditaluk, Salem District, Tamil Nadu, India

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Abstract: *Groundwater samples from open wells, bore wells, and hand pumps were gathered from 18 diverse sites across EdappadiTaluk in Salem District. These samples were collected during two distinct periods: the Pre-Monsoon (PM1) phase and the Post-Monsoon (PM2) phase. Subsequently, the samples underwent analysis to assess their physico-chemical properties. Each parameter measured was juxtaposed against the standard permissible limits established by the World Health Organization (WHO). Additionally, multivariate statistical techniques such as Correlation Coefficient Analysis (CCA), Factor Analysis (FA), and Cluster Analysis (CA) were employed to decipher the water quality data and its spatial distribution.*

Keywords*: Cluster Analysis, Correlation Coefficient Analysis, Factor Analysis, Edappadi, physico-chemical parameters, and water quality.*

INTRODUCTION

Water serves as a vital necessity for sustaining life. Groundwater contamination primarily stems from the release of domestic wastewater, livestock waste, industrial effluents, climate variations, precipitation patterns, and soil composition. In India, multiple researchers have conducted studies to evaluate water quality, particularly focusing on fluoride levels [1],[2],[3],[4],[5].

Employing multivariate statistical techniques like Canonical Correlation Analysis (CCA), Factor Analysis (FA), and Cluster Analysis (CA) aid in comprehending the findings to glean enhanced insights into water quality parameters. The evaluation of groundwater quality through multivariate analysis has garnered extensive attention both in India and across various regions worldwide[7], [8],[9],[10],[11],[12],[13],[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, limestone, soapstone, dunite, roughstone, granites. Itreceives rainfall in the South-west monsoon and North- east monsoon. Major industries in this District are steel and cottage industries. Paddy, Cholam, Cumbu, RagiRedgram, Greengram, Blackgram, Horsegram, Turmeric, Sugarcane, Mango, Bannana, Tapiaco and Groundnut are the major food crops of this District [16].

Edappadi is a taluk of Salem district in the Indian state of Tamil Nadu.Edappadi is located at 11°34´48´´N,77°51´E[17]. (https://en.wikipedia.org/wiki/Idappadi_taluk) .Ground water is the main source of

potable water in the villages of EdappadiTaluk. So, an attempt is made to study the water quality.
The main objectives of the study are

1. collection of ground water samples from open wells, bore wells and hand pumps - GangavalliTaluk, Salem District, Tamil Nadu
2. analysis of a few physico-chemical water quality parameters
3. assessment of the relationship between the water quality parameters
4. interpretation of water quality data and its spatial variations

METHODS OF INVESTIGATION

Sampling and ground water analysis

Among the 36 samples, 18 samples during PM1 season(June-July) and 18 samples during PM2 season (December-January) have been collected. All the samples were analyzed by following the standard guidelines (APHA)[18].The corresponding locations of the water samples collected for analysis have been furnished in Table1

Table 1.Location of sampling stations

Sample No.	Sampling station	Source
SE1	Aodaiyur	HP
SE2	Katchupalli 1	BW
SE3	Katchupalli 2	OW
SE4	Keelanayakkanpatti	BW
SE5	Konnaganapuram 1	OW
SE6	Konnaganapuram 2	HP
SE7	Madathur	HP
SE8	Nedukulam 1	HP
SE9	Nedukulam 2	BW
SE10	Pakkanadu	HP
SE11	Ponparappipatti	HP
SE12	Pulampatti	HP
SE13	Samudram	BW
SE14	Thangayur 1	HP
SE15	Thangayur 2	BW
SE16	Thathapuram 1	HP
SE17	Thathapuram 2	BW
SE18	Vellalapuram	BW

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 Dissolved Solids (TDS) were estimated using systronics water analyzer. Total Hardness (TH) and Calcium Hardness (CH) as CaCO3 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 inmillisiemens(mS)

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Multivariate 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 [19]. 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 [20].

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 [21]. 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 [22] is used. A low distance that shows the two objects are similar or "close together", whereas a large distance indicates dissimilarity.

RESULTS AND DISCUSSION

Table 2. Potable status of ground water samples in the EdappadiTaluk of Salem District in PM1 and PM2 seasons

Parameter	WHO (2006)	BPL		WPL		APL	
	Permissible Level	PM1	PM2	PM1	PM2	PM1	PM2
pH	6.5-8.5	-	-	18	18	-	-
EC (mS)	1.4	14	16	3	1	1	1
Salinity (mg/l)	200-600	-	-	13	14	5	4
TS (mg/l)	500-1000	4	6	14	12	-	-
TDS (mg/l)	500-1000	10	11	8	7	-	-
TSS (mg/l)	0-5	-	-	-	-	18	18
TH (mg/l)	300-500	4	5	14	13	-	-
CH (mg/l)	75-200	-	-	4	5	14	13
MH (mg/l)	30-150	-	-	17	18	1	-
TA (mg/l)	200	5	-	13	18	-	-
F (mg/l)	0.5-1.5	-	-	7	12	11	6

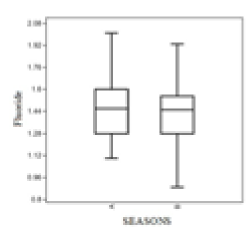
Potable status of ground water samples in PM1 and PM2 seasons

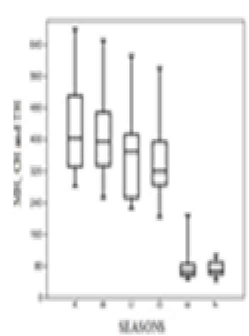
Table 2 gives the potable status of ground water samples in the EdappadiTaluk of Salem District in PM1 and PM2 seasons. pH values in samples varied from 6.76 to 8.01 in the PM1 season and 6.79 to 7.88 in the PM2 season. Though the ground water pH in the study area is slightly alkaline, all the samples during both the seasons were found to be within the permissible limit prescribed by WHO (6.5 to 8.5)[23]. 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[24],[25]. The EC is an indicator of salinity and it also signifies the amount of TDS. In each season, the sample were found to have high EC SE2 (EC = 1.5 mS) value as compared with the WHO recommended limit (EC = 1.4 mS). Three samples (SE1, SE13, SE18) in the PM1 season and only one sample (SE18) in the PM2 season were found to have EC value equal to 1.4 mS as per the WHO recommended limit. Other water samples (14 in PM1 and 16 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 36 water samples, the salinity values of 13in the PM1 season and 14 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.14 samples in the PM1 and 12 samples in the PM2 season were observed with the TS values within the permissible limit of WHO (500-1000 mg/l) and 4 samples in the PM1 season and 6 samples in the PM2 season have values below the limit.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 (10 and 11 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.4 samples in PM1 and 5 samples in PM2 were observed with TH value between the range of 100-300 mg/l, 14 samples were found to be within the permissible limit in the PM1 season whereas 13 samples were found to be within the permissible limit in the PM2 season. According to TH classification [26], the ground water range from hard (150-300 mg/l) to very hard (> 300).4 samples were observed with CH values within the permissible limit (WHO; CH = 75-200 mg/l) in the PM1 and PM2 seasons. Remaining samples were observed with high CH values. As stated by Ramachandramoorthyet al., [28] 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 (Nedukulam1, HP) was found to be above the permissible limit and in 17 samples, it was within the permissible limit. In the PM2 season, all the 18 samples were recorded to be within the permissible limit.

In the PM1 season, the total alkalinity of 5 samples was found to be below the permissible limit (200 mg/l; WHO) and in post- monsoon season, less TA values found 14 samples. A total of 7 samples during PM1 and 12 samples during PM2 season, depicted F contents ranging between 0.5 mg/l and 1.5 mg/l. A few samples (11 in PM1 and 6 in PM2) were found with higher F content (>1.5 mg/l). 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 EdappadiTaluk in PM1&PM2 seasons reveals that, in general, F concentration decreases in PM2 as compared with PM1 due to increase in water table.

The boxplots of measured value of water quality physico-chemical parameters in PM1 and post- monsoon seasons are presented in Fig.1. 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 comparedwithPM1 season, indicating the rise in water level after the monsoon.





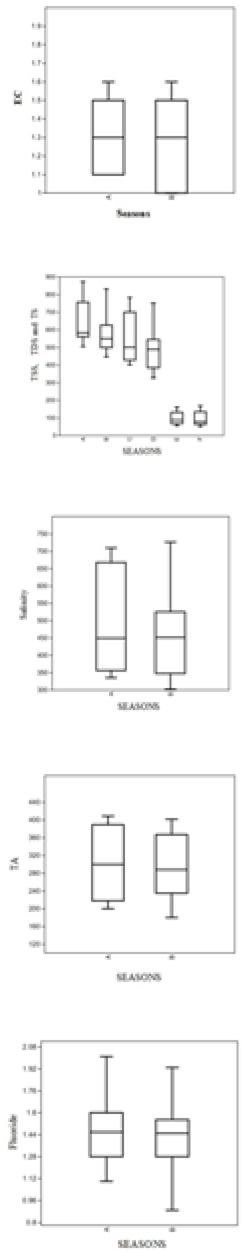


Fig.1 Boxplots of measured value of water quality physico-chemical parameters in PM1 and post- monsoon seasons; the inner solid line indicates the median; A, C and E indicate the boxes for PM1 season; B, D and F indicate the boxes for PM2 season

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 negative correlation value of - 0.196 and - 0.177 respectively. The higher positive values specify good correlation between the parameters pH-TA, pH-CH, pH-MH, pH-TH, pH-TDS, 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 pH with EC. The lower negative values indicate poor correlation between the parameters TSS and other parameters. The correlation co-efficient between EC and F in the PM1 season and PM2 season is 0.723 (significant correlation at 0.05 level) and 0.646 respectively. The above 'r' values prove the influence of the water quality parameter viz., EC, TDS, salinity, CH and F among one another.

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

Seasons	Parameters	pH	EC	TA	Salinity	CH	MH	TH	TDS	TSS	TS	F
PM1	pH	1										
PM2												
PM1	EC	-.083	1									
PM2		-.046										
PM1	TA	.213	.819**	1								
PM2		.452	.188									
PM1	Salinity	-.184	.740**	.679**	1							
PM2		.010	.763**	.345								
PM1	CH	.107	.700**	.568*	.749**	1						
PM2		.324	.687**	.559*	.731**							
PM1	MH	.357	.124	.172	.063	.253	1					
PM2		.291	.231	.314	.184	.271						
PM1	TH	.213	.644**	.546*	.665**	.945**	.556*	1				
PM2		.370	.674**	.584*	.700**	.962**	.522*					
PM1	TDS	.013	.752**	.716**	.918**	.861**	.246	.823**	1			
PM2		.090	.757**	.429	.980**	.762**	.169	.723**				
PM1	TSS	-.239	-.573*	-.698**	-.461	-.622**	-.278	-.628**	-.604**	1		
PM2		-.095	-.476*	-.395	-.529*	-.546*	-.208	-.543*	-.529*			
PM1	TS	-.021	.730**	.673**	.926**	.840**	.225	.799**	.993**	-.508*	1	
PM2		.079	.728**	.386	.961**	.718**	.141	.676**	.983**	-.366		
PM1	F	-.196	.723**	.600**	.615**	.577*	.064	.518*	.714**	-.440	.708**	1
PM2		-.177	.646**	-.102	.466	.495*	-.100	.410	.483*	-.370	.450	1

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

Factor Analysis
(a)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.1

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

PM1					
Principal Components	Communalities	Principal Component Loadings		Rotated Component Matrix	
		VF1	VF2	VF1	VF2
Temperature	0.591	0.708	0.299	0.662	0.391
pH	0.849	0.007	0.921	-0.116	0.914
EC	0.718	0.839	-0.120	0.847	-0.007
Salinity	0.902	0.902	-0.297	0.933	-0.174
TS	0.922	0.954	-0.104	0.960	0.023
TDS	0.955	0.976	-0.041	0.973	0.089

TSS	0.656	-0.696	-0.415	-0.634	-0.504
Eigen value		4.367	1.226		
Percentage variance		62.382	17.508		
Cum. Per.variance		62.382	79.890		
PM2					
Principal Components	Communalities	Principal Component Loadings		Rotated Component Matrix	
		VF1	VF2	VF1	VF2
Temperature	0.811	0.877	0.203	0.855	0.284
pH	0.912	0.100	0.950	0.010	0.955
EC	0.725	0.829	-0.196	0.843	-0.118
Salinity	0.935	0.958	-0.130	0.966	-0.040
TS	0.873	0.929	-0.096	0.934	-0.009
TDS	0.954	0.976	-0.044	0.976	0.047
TSS	0.482	-0.657	-0.223	-0.634	-0.283
Eigen value		4.633	1.059		
Percentage variance		66.184	15.125		
Cum. Per. variance		66.184	81.309		

(a)Chemical parameters

Fig.3 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 60.75% of the total variance and it was positively correlated with TH, CH, MH, F and TA. This varifactor revealed that water has hardness, alkaline nature and cause for fluorosis. The Eigen value for the first varifactor was 3.037. The second varifactor, on the other hand, accounted for 21.142 % of the variance with an Eigen value 1.057 and strong positive correlation with MH and moderate correlation with TH. This varifactor can be termed as factor responsible for hardness.

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

PM1					
Principal Components	Communalities	Principal Component Loadings		Rotated Component Matrix	
		VF1	VF2	VF1	VF2
TH	.942	.938	.251	.700	.673
CH	.832	.912	-.033	.814	.412
MH	.887	.456	.824	.001	.942
TA	.679	.761	-.317	.819	.090
F	.755	.735	-.463	.867	-.050
Eigen value		3.037	1.057		
Percentage variance		60.746	21.142		
Cum.Per.variance		60.746	81.887		
PM2					
Principal Components	Communalities	Principal Component		Rotated Component	

		Loadings		Matrix	
		VF1	VF2	VF1	VF2
TH	.970	.984	.037	.731	.660
CH	.936	.943	.217	.583	.772
MH	.583	.529	-.551	.759	-.083
TA	.667	.686	-.443	.811	.101
F	.891	.419	.846	-.221	.917
Eigen value		2.784	1.264		
Percentage variance		55.671	25.276		
Cum.Per.variance		55.671	80.947		

In the PM2 season, only two varifactors were sorted. The first varifactor (VF-1) accounted for 55.67% of the total variance with an Eigen value 2.784. This varifactor has high positive connection with CH & TH, moderate correlation with MH, TA and low association with F. This varifactor (VF-1) can be termed as factor responsible for hardness. The second varifactor (VF-2) was positively correlated with F. The second varifactor explained 25.28% of the percentage variance and both the varifactors together accounted for 80.95% of the total variance with Eigen values 2.784 and 1.264 and 1.108 for VF-1 and VF-2 respectively. PCA scatter plots for physical parameters in the PM1 and PM2 seasons are presented in Fig.2. PCA scatter plots for chemicalparameters in the PM1 and PM2 seasons are presented in Fig.4.

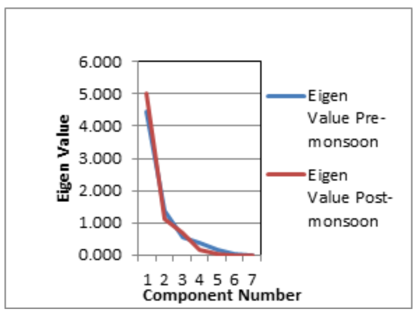


Figure1Scree plot for physical parameters of water samples

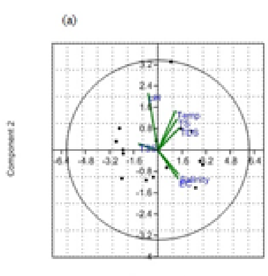
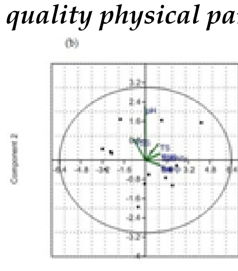


Figure2PCA scatter plots of water quality physical parameters in (a) pre- monsoon season



(b) post- monsoon season

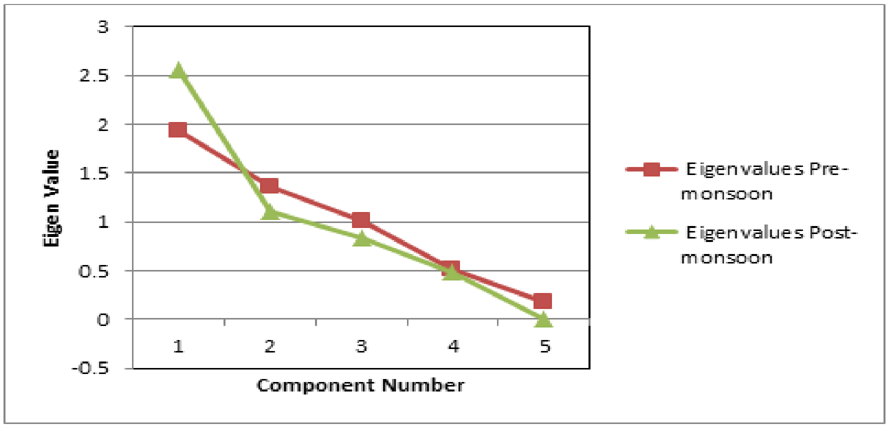


Fig.3 Scree plot for chemical parameters of water samples

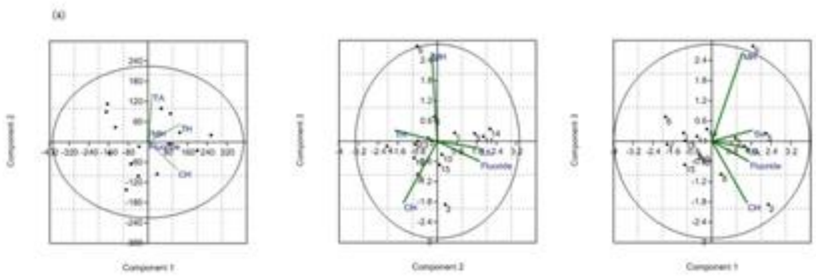
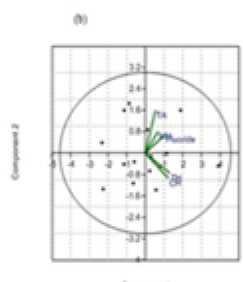


Figure 3 PCA scatter plots of water quality chemical parameters in (a) pre- monsoon



(b) post-monsoon season

Cluster Analysis

The majority of physico-chemical parameters assessed in groundwater samples complied with the standards set by the World Health Organization. The HCA is a data classification technique is applied in Earth sciences and used in the classification of hydrogeochemical data [29],[30],[31],[32]&[22]. However, certain villages exhibited elevated levels of hardness and fluoride content in their water, highlighting the need for treatments such as softening and defluoridation before considering it safe for drinking. Analysis of correlations among water quality parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), salinity, calcium hardness (CH), and fluoride (F), revealed significant associations among them. Factor analysis (FA) revealed distinct seasonal variations, with certain physical parameters such as temperature, total solids (TS), and total dissolved solids (TDS) exhibiting higher loadings during specific seasons, indicating potential sources of contamination like agricultural runoff and industrial discharges.

Chemical parameters like fluoride (F) and total alkalinity (TA) displayed notable loadings during certain seasons, suggesting the influence of carbonate and bicarbonate ions from interactions with soil and rocks. Moreover, factors with high loadings of total hardness (TH), calcium hardness (CH), and fluoride (F) indicated the presence of fluorospar (CaF_2) in the soil or rock within the study area. Employing Ward's method of cluster analysis (CA), the study identified five clusters during both seasons for physical parameters, even reflecting distinct trends in groundwater quality [30],[31],[32],[33],[34],[35].This research illustrates the application of multivariate statistical techniques in assessing the hydrochemical characteristics of the EdappadiTaluk, offering valuable insights for future investigations and monitoring efforts focused on groundwater quality in the region.
CA was used to identify the similarity between the sampling sites.

The dendrogram (cluster tree) of water samples forthephysical parameters is shown in Fig.4. It can be classified into five groups based on the visual observation of the dendrogram namely, C1, C2, C3, C4 and C5.
C1, 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 C1,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.5 shows the dendrogram of water samples for chemical parameters 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 byhigh concentration of TSS and by low concentrations of pH, MH, TA and F. Samples from C3 are characterized by high concentrationsof Temperature, EC, Salinity, TS, TDS, TH, CH, MH, Fand by low concentration of TSS.

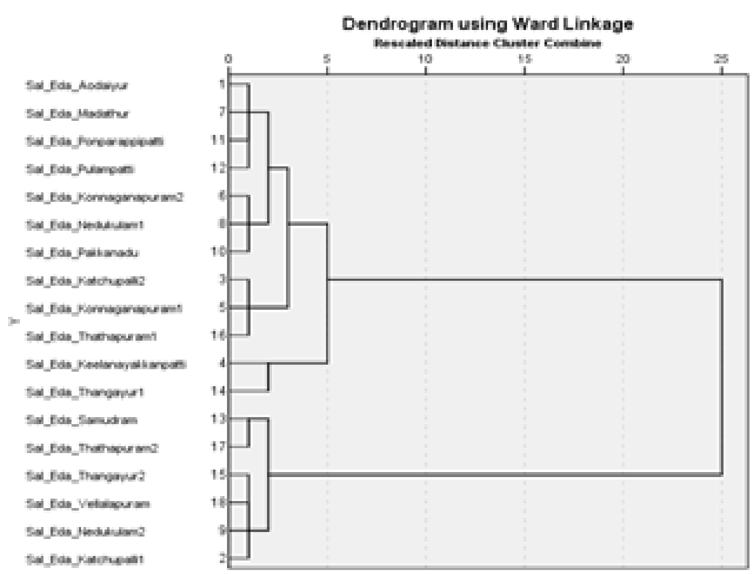


Figure. 4Dendrogram achieved by CA for water quality parameters in PM1 and PM2 (Physical)

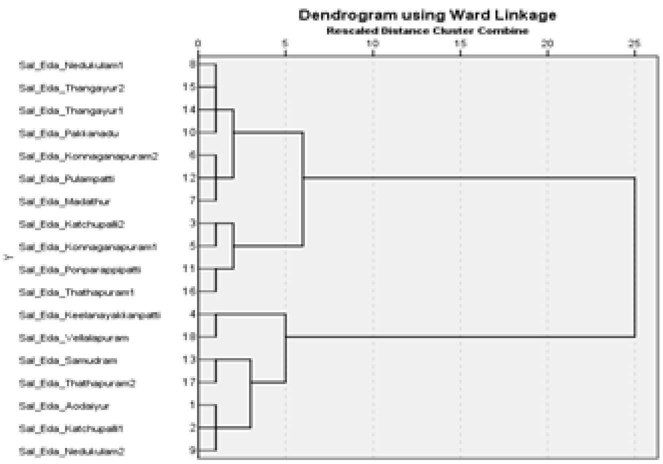


Figure. 5Dendrogram achieved by CA for water quality parameters in PM1 and PM2 (Chemical)

CONCLUSION

Most of the physico-chemical parameters measured in groundwater samples conformed to the World Health Organization's standards. However, certain villages exhibited elevated levels of hardness and fluoride content, indicating the necessity for treatment processes such as softening and defluoridation before utilizing groundwater for drinking purposes. Correlation analysis revealed significant associations among various water quality parameters including pH, EC, TDS, salinity, calcium hardness (CH), and fluoride (F). Factor analysis (FA) highlighted distinct seasonal variations, with certain physical parameters like temperature, total solids (TS), and total dissolved solids (TDS) exhibiting higher loadings during specific seasons, suggesting potential contamination sources such as agricultural runoff and industrial discharges. Chemical parameters such as fluoride (F) and total alkalinity (TA) displayed notable loadings in certain seasons, indicating the influence of carbonate and bicarbonate ions from soil and rock interactions.

Additionally, factors with high loadings of total hardness (TH), calcium hardness (CH), and fluoride (F) suggested the presence of fluorospar (CaF_2) in the soil or rock within the study area. By employing Ward's method of cluster analysis (CA), the study identified four clusters during one season and three clusters during another, reflecting distinct trends in groundwater quality. Overall, this research illustrates the utilization of multivariate statistical techniques to evaluate the hydrochemical characteristics of the EdappadiTaluk, providing valuable insights for future investigations and monitoring initiatives focused on groundwater quality in the region.

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