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INCORPORATING FACTOR ANALYSIS IN GIS FOR ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION USE

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ABSTRACT

The study was conducted to assess the quality of groundwater in 35 wells in the Dusi Mamandur tank command area which is located in Thiruvanamalai district of Tamilnadu, using Factor analysis, Cluster analysis and Spatial Techniques. The physiochemical parameters exhibited wide variability. Since most of the groundwater sample lie at thelower triangle part of the diamond in the Piper diagram, therefore the quality of water is ALKALI CARBONATE in nature .Factor analysis indicated the data is a four component system explaining 80% of the total variance. Factor 1 explains 31.754% of the total variance and shows higher positive loadings for K^+ (0.772), Na+(0.625). The contribution of Na^+ and K^+ can be attributed to cation-exchange processes at Soil-Water interface and dissolution of Sodium Bearing Minerals. Factor-2 explains 23.29% of the total variance and shows moderate loadings for four parameters Na^+(0.335), K^+(0.456), HCO_3^-(0.498) and CO_3^{2-} (0.467). This component can be considered to explain the Water Type (i.e. Alkali carbonate in nature). It is analogous with the Piper diagram.Factor-3 has higher loading for pH (0.677) and Ca^{2+} (0.443). The pH of water is mainly governed by the dissociation of H_2CO_3 (H^+) and by the hydrolysis of bicarbonate (OH^-). Conversion of Adenosine into kaolinite present in Clay soil would account for moderate loading of Ca^{2+}. Factor-4 has higher loading for Mg^{2+} (0.841), the reason can be attributed to Base Exchange reaction.Cluster analysis categorized the sampling locations into four spatially dissimilar groups. The natural hydrochemistry of the groundwater appears to explain much of variability of the data. Spatial plot of Cluster-3 and Factor score-1 helped in narrowing down the area with moderate Sodic hazard which could be treated by appropriate management practices.

Key words: Hierarchical agglomerative cluster analysis (HACA), Factor analysis (FA), Geographical Information system (GIS).

INTRODUCTION

The surface water resources are inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to surface water, but rapid increase in

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urbanization and industrialization leads to deterioration in groundwater quality. Thereby groundwater is under constant threat of either salinity or sodic or toxicity hazard, which seems to have become a worldwide concern. The suitability of groundwater for irrigation depends upon many factors including the quality of water, soil type, salt tolerance characteristics of the plants, climate and drainage characteristics of the soil. Groundwater always contains small amount of soluble salts dissolved in it. The kind and quality of these salts depend upon the sources for recharge of groundwater and the strata through, which it flows. These geochemical processes determine temporal and seasonal variations (Matthess 1982). The application of various Chemometric techniques (correlation, factor analysis, graphical plots) were used to study the dependence of ions on each other and their geochemistry.

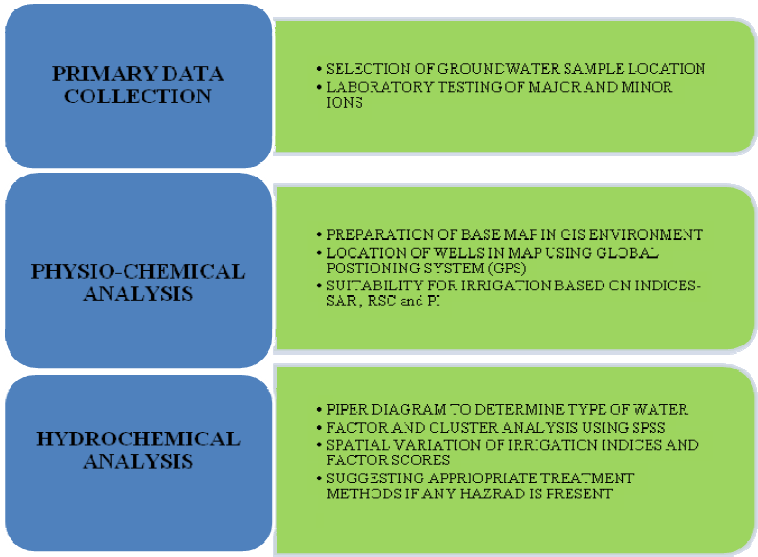
Factor analysis is a method for elucidating the structure of data by defining the correlations between variables. Factor analysis outlines the entire data into a few dimensions by constricting a large number of variables into a smaller set of latent variables or factors. (Dawdy and Feth 1967; Mahloch 1974). In FA, the original variables are defined as Linear combination of the factors. Its aim is to explicate the covariance or correlation between the variable. It helps to understand what constructs underlie the data. (Douglas and Leo 1977; Dalton and Upchurch 1978; Ashley and Lloyd 1978). Hierarchical Agglomerative Cluster analysis (HACA) is data analysis technique which is highly explorative in nature. Its objective is to sort data into groups which display very high internal homogeneity within the group and external heterogeneity among the group. It helps in narrowing down significant variable and source of pollution for felicitous alleviation. In a manner it minimizes the loss associated with each grouping, and to quantify that loss in a form that is readily interpretable (Romesburg 1984)

Objectives of the study

- To measure physical and chemical parameters to determine major cations and anions
- To assess the suitability of Groundwater for irrigation based on indices (SAR, RSC and PI)
- To perform multivariate analysis (FA & HACA) and to integrate the results with GIS to identify hazardous zones.

Methodology

Study area: This tank is situated close to Dusi and Mamandur villages of Cheyyar taluk, Thiruvanamalai District. The Longitude is 79°41'02"E and Latitude is 12°45'00"N.



Command area details

The administrative boundary consisting of 18 villages, which comes under the Dusi-Mamandur tank irrigation is taken as the study area. The tank has a water spread area of 13 sq.kms, when it looks like an ocean and can store nearly 180 million cubic feet of water at its full water level of 30 feet. The catchment area of the tank is 297 sq.km and commands an area of 1667 hectares spread over 18 villages. The catchment area receives its water mostly during the north east monsoon.

Table 1: Name of the villages with area under cultivation

Name	Area (Km^2)	Area under cultivated (Km^2)
Pallavaram	2.571672	1.634584
Mamandur	6.082631	4.00554
Kuranganilmuttam	1.484866	0.72828
Dusi	7.487261	1.808562
vagai	2.502833	0.261776
Kanikilluppai	0.787892	0.449106
Alinjalpattu	2.15918	0.056644

Cont…

Name	**Area (Km^2)**	**Area under cultivated (Km^2)**
Valavandal	1.466437	0.95081
Elacheri	4.291215	1.327088
Bagavandapuram	1.244737	0.432922
Seniyanallur	1.105414	0.416738
Sodiyambakkam	2.390275	0.54621
Poonaithangal	1.427003	0.594762
Girijapuram	1.39481	0.477428
Menallur	2.593147	0.66759
Kilnaickenpalayam	2.128693	1.023638
Narasamangalam	1.784182	0.449106
Vadakalpakkam	2.126208	0.934626
Total	44.02846	16.76541

Sampling design

Sampling is used when we are unable to count or measure the entire population. Random sampling is used where an equal chance of being selected is needed. If the data are rare and patchily distributed then we must consider adaptive sampling for estimation. If a gradient exists in the data community then we must prefer Systematic sampling.

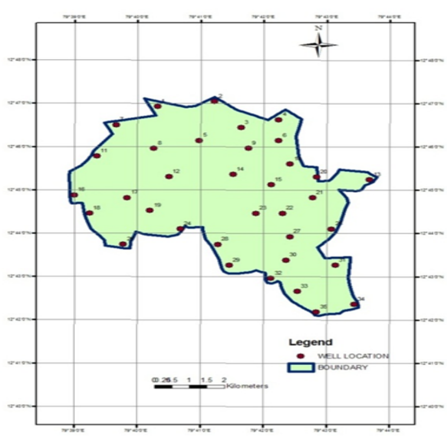


Fig. 1: Location of sampling points

Table 2 : Water quality parameter analysed

Well No.	pH	EC (µS/cm)	TDS (ppm)	Na^+ (me/L)	Ca^{2+} (me/L)	Mg^{2+} (me/L)	CO_3^{2-} (me/L)	HCO_3^- (me/L)	K^+ (me/L)	Cl^- (me/L)	SO_4^{2-} (me/L)
1	7.4	1295	848.75	15	1	3.1	3.333	2.583	2.1	1	0.625
2	7.9	1498	872.7	11	4	2	4.044	3.135	4	9.5	2.292
3	8.1	1898	1308.7	8	4	1.4	3.52	2.728	5	7.9	1.25
4	7.8	1997	1319.05	8	4	1.5	3.572	2.769	4.7	12	0.208
5	7.9	1698	1101.7	10	3.5	1.6	3.504	2.716	4.5	9	1.042
6	7.8	1897	1378.05	15	3.5	3	4.587	3.555	4	11	0.208
7	8.1	1478	885.7	10	1	1.7	2.25	1.744	3	7.45	0.625
8	7.8	1478	944.7	8	3.5	1.7	3.415	2.647	2	5	0.104
9	8.2	1775	1155.75	16	3.5	1.7	3.978	3.083	4.5	9	2.083
10	7.1	1695	1233.75	12	3	1.7	3.435	2.663	4	8	0.313
11	7.5	1515	1039.75	9.6	1	1.8	2.274	1.763	2.5	7	2.5
12	7.5	1585	1111.25	12	3	1.8	3.488	2.703	2	3	1.146
13	8.2	2915	1878.75	21.1	2.7	0.5	3.292	2.552	7.9	7	1.563
14	8.1	2215	1523.75	23	1.95	1.25	3.425	2.655	5	11	0.729
15	8.5	1497	1014.05	24.5	1.9	1.55	3.662	2.838	3	10	1.875
16	7.8	1397	861.05	13	3	1.85	3.584	2.778	3.2	11	1.667
17	7.9	1398	998.7	15	2.8	1.9	3.646	2.826	4.1	11	0.521
18	7.8	1789	1167.85	12	2.5	1.9	3.279	2.541	1.5	3.9	0.417

Cont…

Well No.	pH	EC (μS/cm)	TDS (ppm)	Na^+ (me/L)	Ca^{2+} (me/L)	Mg^{2+} (me/L)	CO_3^{2-} (me/L)	HCO_3^- (me/L)	K^+ (me/L)	Cl^- (me/L)	SO_4^{2-} (me/L)
19	7.7	1875	1225.75	24.7	1.6	1.6	3.545	2.748	1.6	3.95	0.729
20	8.1	1898	1218.7	24.7	1.6	1.6	3.545	2.748	4.5	10	2.083
21	8.3	1995	1213.75	22.5	1.65	1.5	3.364	2.608	7	9	2.292
22	7.9	2397	1643.05	19	2.2	2	3.667	2.842	4.6	8	0.25
23	7.7	3998	2710.7	24.5	1.5	1.5	3.426	2.656	4.5	9	0.625
24	7.9	2105	1333.25	15.5	5	2	4.883	3.785	4	9	2.292
25	8.5	2400	1491	24	1.1	2	3.444	2.669	7.5	10	1.25
26	7.9	2085	1319.25	15	2	2.1	3.333	2.583	1.25	4	0.208
27	7.7	2104	1314.6	24.1	1.5	1.1	3.189	2.472	4.3	4.3	1.042
28	7.8	3105	1942.25	23	2.1	1.8	3.791	2.939	5.5	7.8	0.208
29	7.5	2998	1847.7	21.1	1.9	1.95	3.631	2.815	6	4	0.625
30	7.7	3105	1943.25	20.95	1.9	2.4	3.856	2.989	5	13	0.104
31	7.8	2350	1487.5	18	3	1.5	3.753	2.909	7.5	9.5	2.083
32	7.9	2918	1915.7	21	3.1	2.1	4.33	3.356	8	10	0.313
33	8.1	2450	1684.5	17.5	1.8	2.9	3.822	2.963	8	8	2.5
34	8.4	2314	1610.1	15	1.69	2.02	3.129	2.426	6.5	7	1.146
35	8.9	2696	1852.4	20.5	1.5	2.7	3.772	2.924	8.3	9	1.563
Mean	7.92	2108.943	1382.784	16.979	2.428	1.849	3.565	2.763	4.601	7.98	1.099
Minimum	7.1	1295	848.75	8	1	0.5	2.25	1.744	1.25	1	0.104
Maximum	8.9	3998	2710.7	24.7	5	3.1	4.883	3.785	8.3	13	2.5
Std-deviation	0.347	618.405	407.339	5.587	1.020	0.517	0.492	0.381	2.030	2.811	0.797

In this study systematic sampling is used because since there is no periodicities in data thereby there is no chance of biased estimates of means and confidence limits. Systematic Sampling is adopted by dividing the entire study area into 1 min grid interval and 2 samples per grid were chosen. In all totally 35 samples was collected. Collected samples were transported to the laboratory and testing started within 24 hrs of collection.

Water sample testing

The samples were tested in the Wet Chemistry Laboratory of Centre for Water Resources. The testing procedure adopted is as per APHA (1995) 'Standard Methods for the examination of water and wastewater', 19^{th} Edition.

Table 3: Table showing the methods used for testing

Parameter	Instrument/Method Used
pH	pH meter
EC and TDS	Pocket meter
Sodium (Na^+) and Potassium (K^+)	Flame photometer
Calcium (Ca^{2+}) and Magnesium (Mg^{2+})	Complex titrimetry using EDTA
Chloride(Cl^-)	Titrimetry method using $AgNO_3$
Carbonates (CO_3^{2-}) and Bicarbonates (HCO_3^-)	Titrimetry using HCl
Sulphate (SO_4^{2-})	Spectrophotometer

RESULTS AND DISCUSSION

Descriptive analysis of groundwater

The electrical conductivity gives a rough estimate of Ionic Concentrations. Salts present in water exist in ionic form and by nature they conduct current. Thereby conductivity is a good indicator to assess groundwater. Its values vary depending on temperature, concentration and types of ion present (Hem, 1985). EC readings, ranged from 1295-3998 $\mu S\ cm^{-1}$ during post monsoon season of December 2014. The maximum (24.7 me/L and 13 me/L) and mean (16.979 me/L and 7.98 me/L) values of sodium and chloride during post monsoon season of December 2014 exceeded the IS 11624-1986 standards (9 me/L and 5.63 me/L). Out of 35 samples, 31 samples had Na^+ concentration more than standards prescribed by IS 11624-1986. Chloride Ion was partially preponderant in these waters with 10 samples exceeding the IS limit. Na^{+} contamination in the groundwater of study area might be attributed to the geology of the rocks.

The groundwater quality in this region falls in the range of hard to very hard range depicting a permanent hardness being vested with the water in study area. None of the samples have hardness value lesser than 75 mg/L or 75 mg/L to 150 mg/L to be classified as soft or moderately soft water. All the sampling well has hardness value ranging from 413 mg/L to 1053 mg/L.The major cation are in the order $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ and anions in the order $CO_3^{2-} > HCO_3^{-} > SO_4^{2-} > Cl^{-}$.

Table 4: Descriptive Statistics of Samples collected

Parameter	Min	Max	Mean	Desirable	Exceeding the limit
pH	7.10	8.900	7.920	6.5-8.5	1
EC (µS/cm)	1295	3998	2108.943	-	-
TDS (mg/L)	848.7	2710.7	1382.784	2000	1
Na^{+} (me/L)	8.00	24.7	16.979	9	31
Ca^{2+} (me/L)	1	5	2.428	10	NIL
Mg^{2+}(me/L)	0.5	3.1	2.763	8.33	NIL
CO_3^{2-} (me/L)	2.25	4.883	3.565	-	-
HCO_3^{-}(me/L)	1.74	3.785	2.763	5	NIL
K^{+} (me/L)	1.25	8.3	4.601	-	-
Cl^{-}. (me/L)	1	13	7.980	5.63	10
SO_4^{2-} (me/L)	0.104	2.5	1.099	8	NIL

Graphical plot of hrydrochemical data

Piper (1944) tri-linear diagram is used for expressing hydrochemical facies of water. Piper divided water into four types according to their placement near the four corners of the diamond. The water plots at the top of the diamond is high in both ($Ca^{2+} + Mg^{2+}$) and (Cl^{-} + SO_4^{2-}), which is the region of permanent hardness. The water plots at the right hand corner of the diamond is high in both ($Ca^{2+} + Mg^{2+}$) and (HCO_3^{-}), which is the region of salinity. Water plotted at lower plot of the diamond is primarily composed of Alkali carbonates (Na^{+} + K^{+}) and ($HCO_3^{-} + CO_3^{2-}$). Water lying at left hand side of the diamond is ($Na^{+} + K^{+}$) and ($Cl^{-} + SO_4^{2-}$).

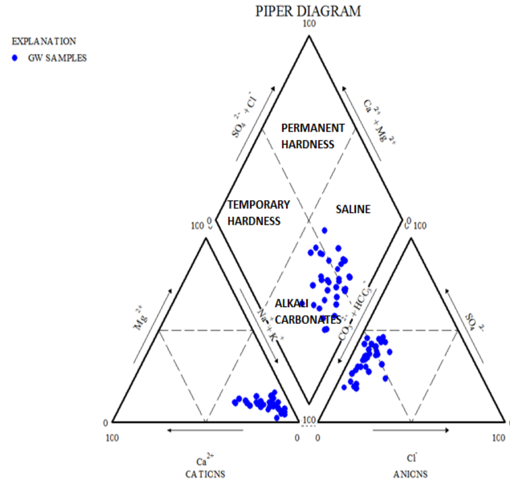


Fig. 2: Graphical Representation of Piper Diagram

Since most of the groundwater sample lie at the lower part of the diamond, therefore the quality of water is Alkali Carbonate in nature ($Na^+ + K^+$) and ($HCO_3^- + CO_3^{2-}$).

Data analysis using correlation matrix

In statistics, dependence between two random variables or two sets of data is the key source for information extraction. Correlation matrix quantifies the extent to which two quantitative variables go together. Correlation matrix was studied using Pearson product-moment correlation to point out whether any association between the observed parameters exist so as to explain component loadings during PCA extraction of Factor analysis. The linkage between the variables was studied at a significance level of $P < 0.05$. Parameters showing $r > 0.7$ are considered to be strongly correlated whereas r between 0.4 and 0.7 shows moderate correlation.

The Pearson Correlation matrix generated shows EC having strong correlation with Na^+ (0.577) and K^+ (0.584) indicating the most of the ions are involved in physiochemical reactions such as oxidation-reduction, ion exchange and also indicating their origin from the same source (Subha Rao 2002). TDS-K^+ (0.576), Na^+-K^+ (0.396) and Ca^{2+}-CO_3^{2-} (0.522) showed, moderate correlation might be due to impact of fertilizers used for growing paddy crops. High correlation between minerals Mg^{2+}-SO_4^{2-} (0.706) indicates a possible ion exchange process. pH-K^+ (0.496), pH-Cl^- (0.35) and pH-SO_4^{2-} (0.365) are mere mathematical relationship since pH is the negative log of the hydrogen ion concentration in an aqueous solution and thereby it cannot be attributed to any physiochemical reaction, geological effect, seasonal effects or point or non-point source of pollution.

Suitability based on irrigation indices

SAR can indicate the degree to which irrigation water tends to enter into cation-exchange reactions in soil. Sodium has the ability to replace adsorbed calcium and magnesium, thereby it makes the soil structure intact and impervious to movement of water (Raju, 2006).

$$SAR = Na^{+} / ((Ca^{2+} + Mg^{2+}/2)*0.5)$$

Table 5: SAR Classification as per code IS 11624-1986

Type	SAR (me/L)
Low	< 10
Medium	10-18
High	18-26
Very high	> 26

The analysis of groundwater samples are compared with the IS 11624-1986 standards for irrigation purpose. Out of 35 samples, 7 samples have SAR value more than 18, suggesting the indication of sodic hazard , i.e. the concentration of sodium ions compared to other ions are more in number. Out of total 44 km^2 nearly 2.41 km^2 of the total study area is prone to high sodic hazard. If water contains carbonate and bicarbonate in excess of calcium and magnesium, then it is likely to detach calcium displayed by exchange reactions. The result is an increase in sodium hazard of water. This excess quantity of carbonate and bicarbonate is denoted by Residual Sodium Carbonate.

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Table 6: RSC Classfication as per code 11624-1986

Type	RSC (me/L)
Low	< 1.5
Medium	1.5-3.0
High	3.0-6.0
Very high	>6.0

The permeability index is given by –

$$PI = (Na^+ + K^+ + (HCO_3^-)*0.5) \text{ X } 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$$

Out of 35 samples, 12 samples have RSC value more than 2.50, suggesting the indication of sodic hazard, i.e. the concentration of carbonate and bicarbonate is in excess of calcium and magnesium, then it is likely to perceptible calcium displayed by exchange reactions. Out of total 44 km^2 nearly 14.843 km^2 of the total study area is prone to high concentration of $HCO_3^- + CO_3^{2-}$

Thus from the analysis of spatial plots of SAR and RSC it can concluded the villages of Kilnaickenpalaym, vadakalpakkam, sodhiyambakkam and bagavandapuram are prone to Alkali and excess of carbonate and bicarbonate.

Table 7: SAR, RSC and PI values for 35 wells

Well No.	SAR	RSC	PI
1	10.476	1.816	86.740
2	6.351	1.179	72.730
3	4.869	0.848	70.033
4	4.824	0.841	69.318
5	6.262	1.120	77.998
6	8.321	1.642	73.823
7	8.607	1.294	89.163
8	4.961	0.863	72.286
9	9.923	1.862	81.752
10	7.828	1.398	77.133
11	8.113	1.236	88.320
12	7.746	1.391	79.022
13	16.681	2.643	92.294
14	18.183	2.881	93.203
15	18.654	3.050	92.626
16	8.348	1.512	80.746

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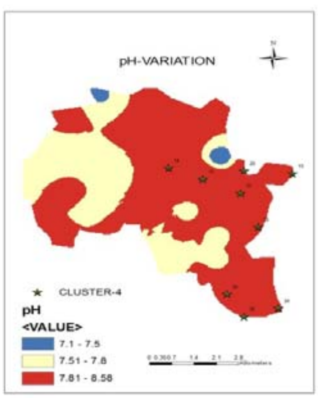
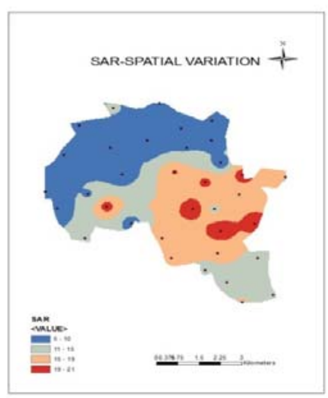
Well No.	SAR	RSC	PI
17	9.785	1.773	82.592
18	8.090	1.420	81.548
19	19.527	3.093	93.455
20	19.527	3.093	93.204
21	17.928	2.822	93.259
22	13.111	2.309	87.620
23	20.004	3.082	95.973
24	8.285	1.669	74.820
25	19.277	3.013	93.327
26	10.476	1.816	85.005
27	21.137	3.061	95.765
28	16.471	2.830	90.734
29	15.208	2.596	90.559
30	14.288	2.545	88.731
31	12.000	2.162	87.458
32	13.024	2.486	85.807
33	11.416	2.085	84.292
34	11.013	1.845	87.985
35	14.146	2.496	88.589





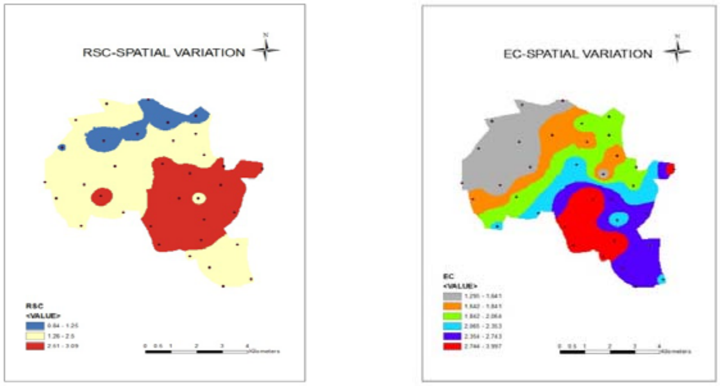


Fig. 3: Spatial variation of irrigation indices- (a) SAR (b) RSC (c) pH and (d) EC

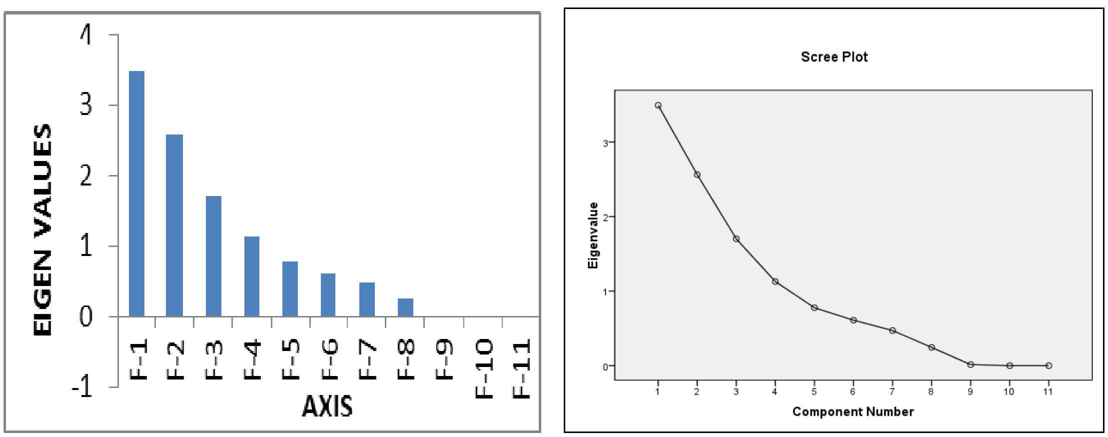


Fig. 4: Scree plot for choosing appropriate number of EIGEN VALUES

Table 8: Correlation matrix for routine analysis parameter for 35 samples

	pH	EC	TDS	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-
pH	1										
EC	0.116	1									
TDS	0.115	0.984	1								
Na^+	0.292	**0.577**	0.546	1							
Ca^{2+}	-0.14	-0.2	-0.19	-0.505	1						

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	pH	**EC**	**TDS**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Cl^-**	**SO_4^{2-}**	**CO_3^{2-}**	**HCO_3^-**
Mg^{2+}	-0.033	-0.056	-0.019	-0.118	-0.116	1					
K^+	**0.496**	**0.584**	**0.576**	**0.396**	-0.051	-0.018	1				
Cl^-	**0.35**	0.175	0.187	0.111	0.27	-0.042	**0.431**	1			
SO_4^{2-}	**0.365**	-0.19	-0.211	0.07	0.03	**0.706**	0.271	0.145	1		
CO_3^{2-}	0.014	0.089	0.094	0.042	**0.522**	0.207	0.126	0.297	0.122	1	
HCO_3^-	0.011	0	-0.005	0.006	0.215	0.285	0.126	0.249	0.256	**0.471**	1

Table 9: Factor loadings for various parameters

	Factor -1	**Factor- 2**	**Factor -3**	**Factor -4**
pH	0.312	-0.164	**0.677**	0.21
EC	0.216	-0.313	-0.349	-0.171
TDS	0.211	-0.295	-0.365	-0.156
Na^+	**0.625**	**0.335**	-0.022	0.17
Ca^{2+}	0.08	0.069	**0.443**	-0.443
Mg^{2+}	0.172	0.289	-0.283	**0.841**
CO_3^{2-}	0.235	**0.467**	-0.147	0.117
HCO_3^-	0.265	**0.498**	-0.147	0.117
K^+	**0.772**	**0.456**	0.314	-0.028
Cl^-	0.287	0.261	0.381	-0.216
SO_4^{2-}	0.078	0.059	0.187	0.151
Eigen value	3.493	2.562	1.7	1.128
Percentage of variance	31.754	23.29	15.459	10.2502
Cumulative % variance	31.754	55.044	70.503	80.755

Principal component extraction of Factor analysis was performed on the matrix of hydro-geochemical data. The statistical analysis was performed using SPSS software package.

Correlation matrix must be used to calculate the principal components if variables are measured by different scales and if we need to standardize them or if the variances differ widely between variables. Else we can use covariance or correlation matrix in all other situations. Correlation matrix was used to calculate the principal components since variables are measured by different scales i.e. EC in microsiemens/cm, ions in me/l and TDS in mg/L.

Factor score-1

Factor 1 explains 31.754% of the total variance and shows higher positive loadings for K^+ (0.772), Na + (0.625). The higher loading of Na^+ and K^+ can be attributed to Cation-exchange processes at Soil-Water interface and dissolution of Sodium Bearing Minerals. (Guo H and Wang Y 2004). The spatial plot of factor score-1 shows negative loading (-1.422 to -0.6) in the villages of Dusi, Vagai, Kurangimuttam and Mamandur (Fig. 5) and very high positive loading (0.919 to 2.631) in the villages of Vadakalpakkam, Kilnaikapalayam, Sodhiyapakkam and Bagavandapuram.

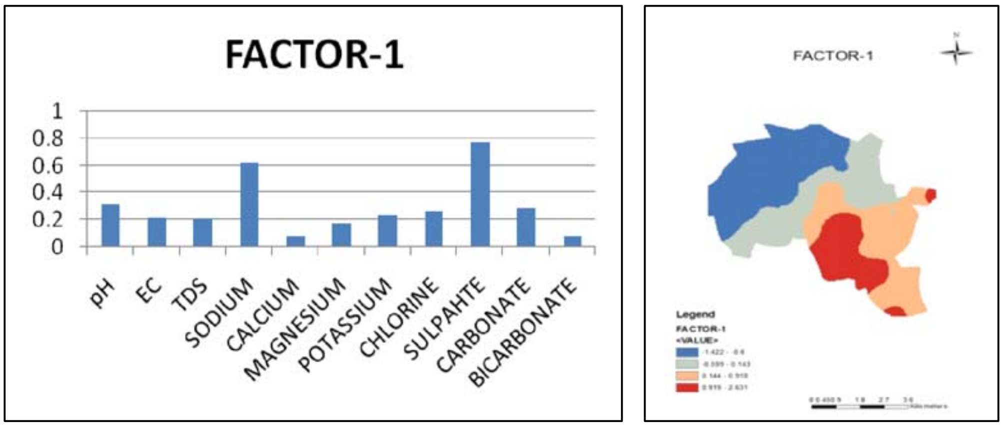

Fig. 5: PCA Loading of factor Scores-1 with its spatial plot

Factor score-2

Factor-2 explains 23.29% of the total variance and shows moderate loadings for four parameters Na^+ (0.335), K^+ (0.456), HCO_3^- (0.498) and CO_3^{2-} (0.467) (Fig. 6). Therefore this component can be considered to explain the Water Type (Fig. 7) (i.e. alkali carbonate in nature) It is analogous to Piper Diagram. The quality of water is alkali carbonate in nature ($Na^+ + K^+$ and $HCO_3^- + CO_3^{2-}$).

Factor score-3 & 4

Factor-3 has higher loading for pH (0.677) and Ca^{2+} (0.443) (Fig. 7). The pH of water is mainly governed by the dissociation of H_2CO_3 (H^+) and by the hydrolysis of bicarbonate (OH^-). Since the study contains clay soil, Andesine present in the clay would have got converted into kaolinite, which would be the reason for the loading on Ca^{2+}. Factor-

4 has higher loading for Mg^{2+} (0.841), the reason can be attributed to Base Exchange reaction (Fig 8).

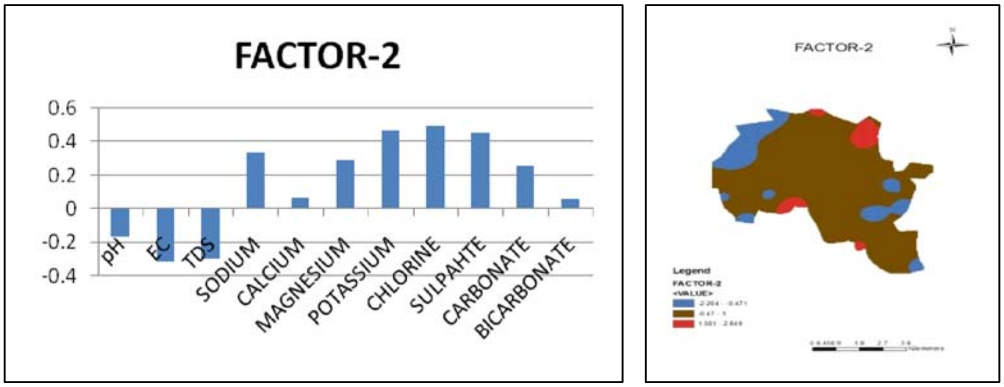

Fig. 6: PCA Loading of factor Scores-2 with its spatial plot

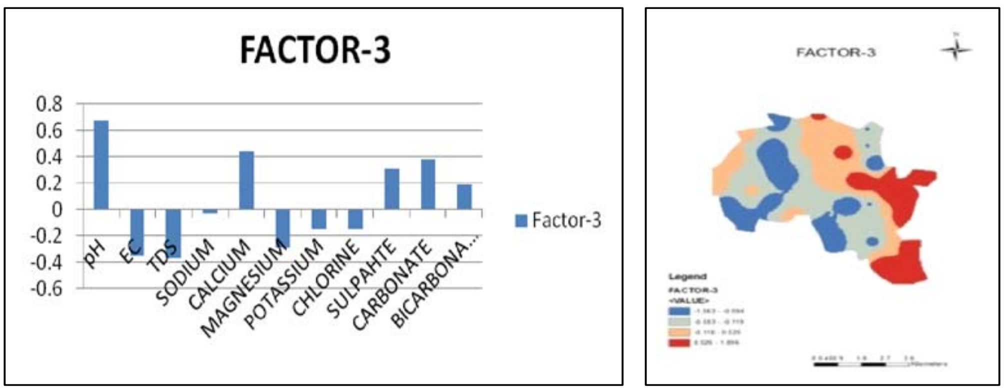

Fig. 7: PCA Loading of factor Scores-3 with its spatial plot

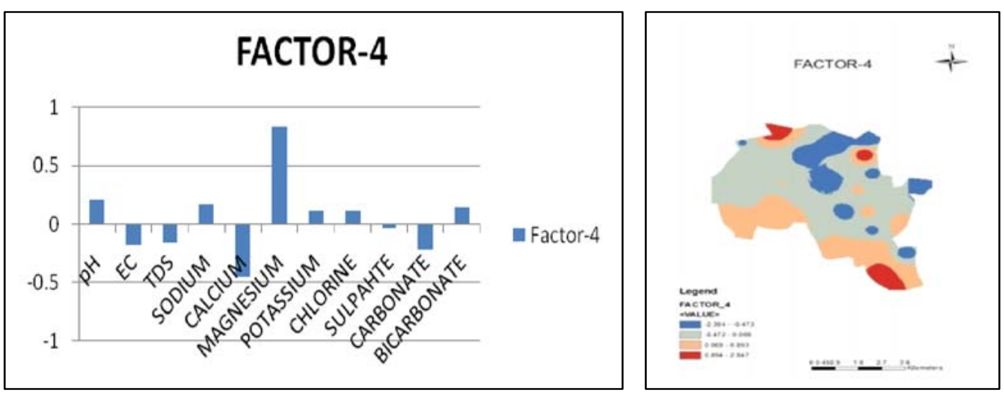

Fig. 8: PCA Loading of factor scores-4 with its spatial plot

Cluster analysis

Standardization of data was done before performing cluster analysis to ensure normality of data, to take into account of different weights variable, and removing the effect of measurement units (Noy-Meir I 1973). 35 sampling sites were clustered into four groups based level of similarity.

Fig. 9: Location of clutsering wells

Cluster 1

Itcontains 10 well, which comes under the villages Vagai, Dusi, Mamandur and Alinjalpattu (Fig. 10), which happens to be located in north-western part of the study area. Similarity behind the clustering can be attributed to the fact that the PI (Permeability Index) value of these 10 samples is between 77.133 to 95.765 and groundwater is moderately polluted suggesting it can be categorized as fit and not so good for irrigation.

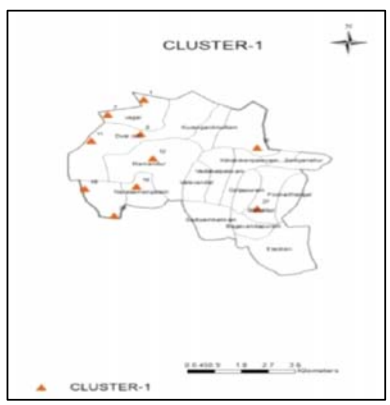

Fig. 10: Spatial plot of cluster-1

Cluster 2

It contains 10 wells out of which 6 wells cover north-eastern part of the study area, consisting of villages Kurangimuttam, Kilnaikapalayam and some parts of Dusi village. (Fig 11(a)) Clustering can be attributed to fact SAR values ranges form 4.824 to 12 and RSC values range from 0.8 to 1.5 suggesting the groundwater completely fit for irrigation.

Cluster 3

It contains 6 wells, which comes under the villages of Sodiyambakkam, Bagavndapuram, Vadakalpkkam and Girjapuram (Fig 11(b)). Factor score-1 and Cluster-3 are anonymous with each representing the Sodicity Hazard in the study area. As per IS 11624-1986, Well no 23 has SAR and RSC value more than prescribed value of 18 and 3, all other values are in medium class.

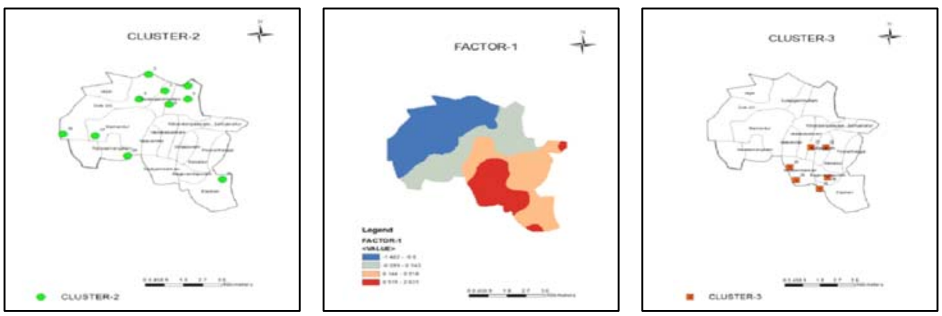

Fig. 11: Spatial plot of (a) Cluster-2(b) Cluster-3

Cluster-4

Similar to Cluster-2 all the wells have physical and chemical parameters are within the permissible limits and similarity can be attributed to pH, which is more than 8.2 showing the water is alkaline in nature.

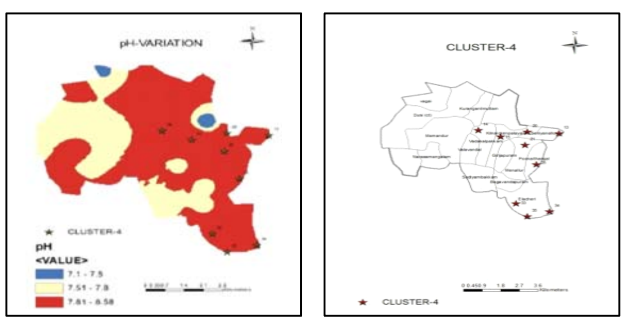

Fig. 10: Spatial plot of cluster-4

CONCLUSION

From the descriptive analysis, it was established the ions, which are more than prescribed limit was sodium and chlorine. The major cation are in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and anions in the order $CO_3^{2-} > HCO_3^- > SO_4^{2-} > Cl^-$. Piper diagram showed majority of the well contain sodium and carbonates in excess amounts. Using SAR and RSC as testing tool, it can concluded that Moderate Alkali Hazard is present and mainly due to Sodium ion. Cluster and Factor analysis helped in narrowing down the location of the wells. The groundwater collected from the villages of Sodiyambakkam, Bagavandapuram, Vadakalpkkam and Girjapuram contain Sodic hazard which has been proved from the result of cluster-3 and factor score-1. Since the hazard is moderately high and not too high and which can be rectified through both management practices and treatment methods. Food and agriculture organization (FAO) of the United Nations have released the following six treatment methods.

1. Application of amendments
2. Mixing with an alternate source of water
3. Irrigating more frequently
4. Growing crops with low water requirements
5. Growing tolerant crops
6. Organic matter applications

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