An Application of Statistical Analysis to Hydrogeochemical Study of Groundwater in and Around Neyveli Lignite Mine Area, Cuddalore District, Tamilnadu.

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Abstract

Groundwater geochemistry is largely a faction of mineral composition of aquifer through which water flows thus, differences in aquifer composition and reflected as difference in groundwater chemistry. To understand water quality, multivariate importance in combining chemical variable and organizes voluminous data and group into variables of similar characters. R mode factor analysis in used in the field of hydrogeochemistry to decipher complex hydrogeological process. A total of 168 samples representing four seasons were analysed correlation and correlation coefficient was identified along with estimation of factor loading, principal component method was adopted for parameter estimation. Factor score is projected to demarcated zone of representation of each factor. Statistical packages for social sciences (SPSS) version 9 used to perform correlation and factor analysis. In general groundwater in study area is primarily influenced by leaching of secondary salts, anthropogenic impact and agricultural impact along with chemical weathering.

Key word: Geochemistry, Correlation, Factor analysis, Factor score.

Introduction

Statistical analysis is a very useful tool for identifying groundwater quality of the region (jay Kumar and siraz, 1996). Stistical association does not establish any cause and effect relationship but relationship of cause and effect can be figured out (Lawrance and Upchurch 1982). Statistical data has better representation than graphical representation due to finite number of variables, variables are limited by convention to major ions, and superior relationship may be introduced by using certain procedures (Razak m, Dazy J 1990).

The study area is Neyveli and adjoining region, which is located in Cuddalore district of Tamilnadu. The area is bounded between north latitudes 11º40´ and 11º25´ and east longitudes 79º20´ and 79º40´ (Fig 1). It falls in survey of India toposheet 58 M/6, M/7, M/10 and M/11, with a total area of about 835km2. It includes taluks of Vriddhachalam, Panruti and Chidambaram. There are two lignite mines in the proposed study area. 1st and 2nd mine, which extends from South of Neyveli Township to North of Vellar River.

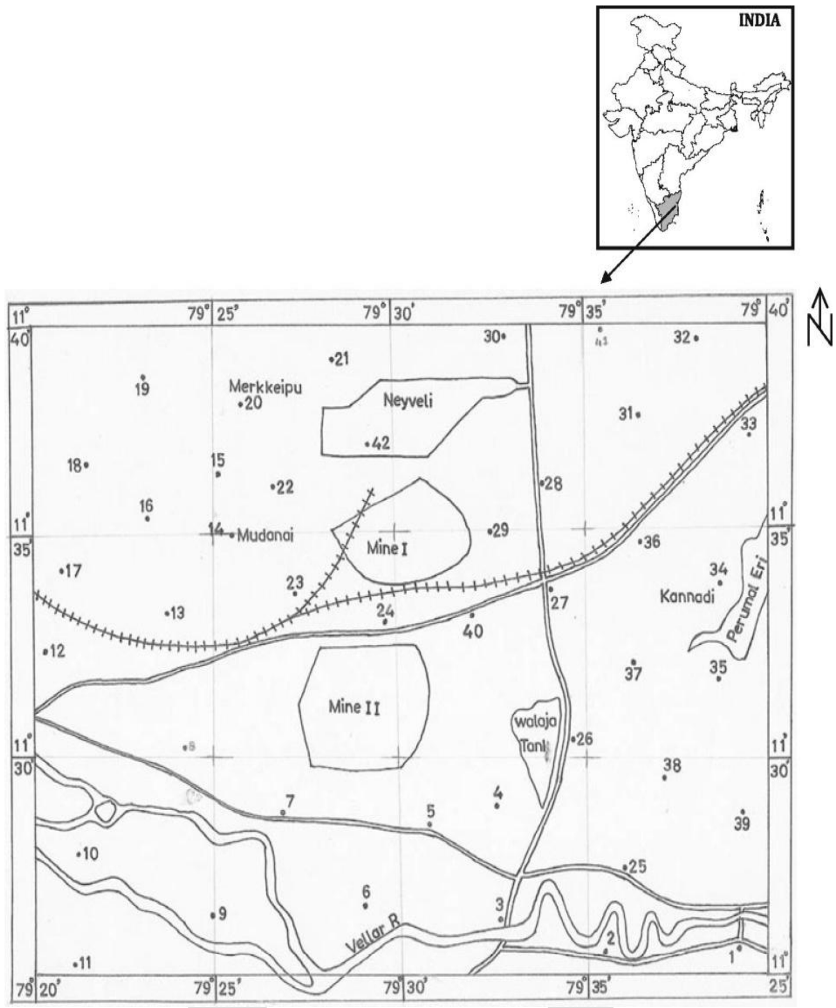

FIG. 1. LOCATION MAP OF THE STUDY AREA.

Geology

In study area detail mapping of Cretaceous and Tertiary deposits was initiated by (Arogiaswamy, 1967; Sundaram, 1979). The exploratory work carried out by Oil and Natural Gas Commission (ONGC) and agencies like, Neyveli Lignite Corporation (NLC) etc., was also significant. In study area (Fig.2), the basement Archean rocks consist predominantly of bluish grey granites and gneisses, this older formation are overlain by Cretaceous and Tertiary Sediment towards East. Southern part of study area is underlain by recent alluvium of 50m thick. Cuddalore formation of Mio-Pliocene age consists chiefly of sandstone and extensive clay layers with a thick band of lignite seam crops out in middle of study area, striking Northeast and Southwest and dipping towards Southeast.

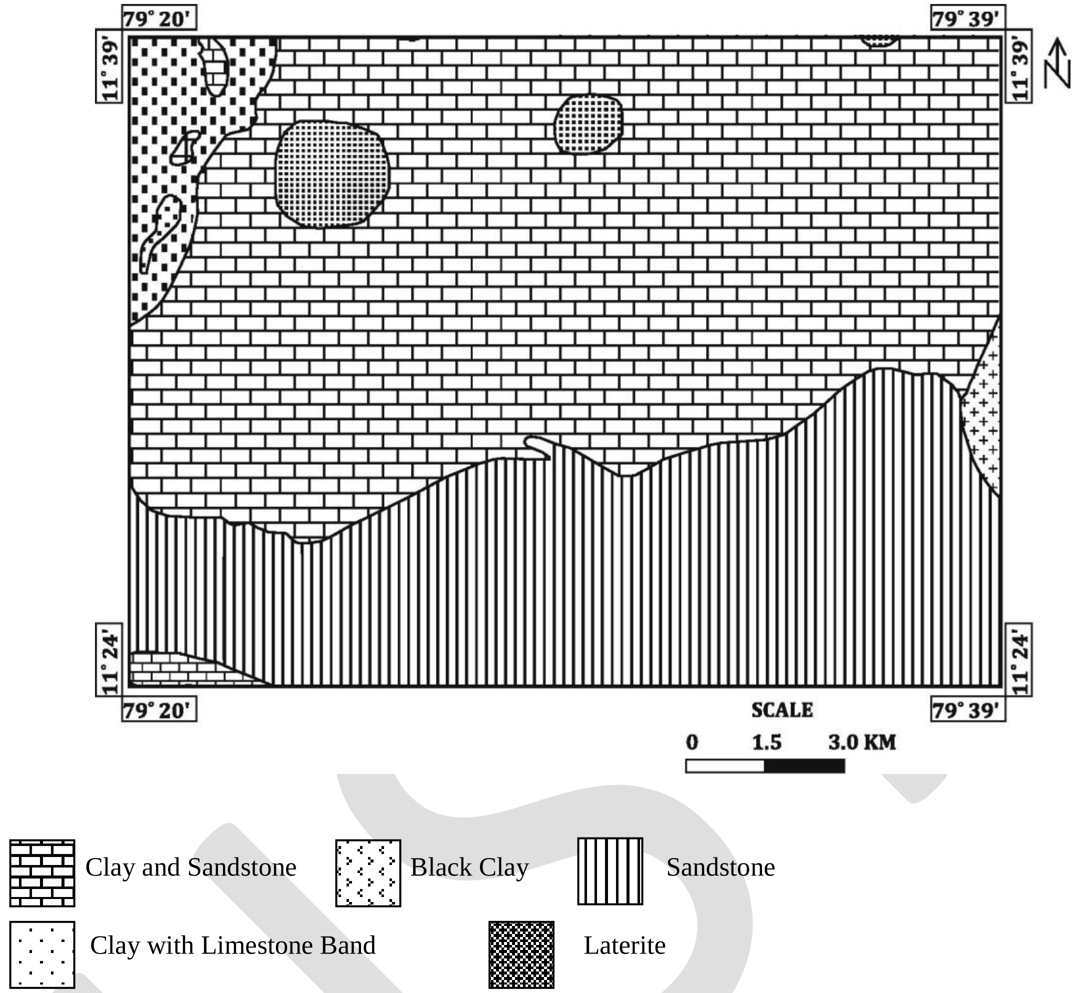

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FIG. 2. GEOLOGY MAP OF THE STUDY AREA.

Methodology

A total of 168 representative samples were collected from bore wells representing entire stretch of the study area for four different season viz., southeast, southwest, northwest and northeast monsoon and analysed using standard analytical procedures (Apha 1995; Ramesh and Anbu 1996). Average chemistry of groundwater for all seasons is represented in (Table 1).

Representation

Statistical analysis is a very useful tool for identifying groundwater quality of a region. Statistical association does not establish any cause and effect relationship but relationship of cause and effect can be deduced. Correlation of factor analysis is generally used in parametric classification of modelling studies (Balasubramanian and others 1989). Factor analysis and cluster analysis were used in groundwater chemistry interpretation by Ashley and Lloyd (1978).

TABLE 1. MAXIMUM, MINIMUM, AND AVERAGE OF GROUNDWATER SAMPLES IN ALL SEASON.

		pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K	TDS
	Max	8.6	6621	487.44	60	347.6	610	1.8	5	1.5	30	30	20	936	38	2205
NEM	Min	6.9	155	8.86	0	67.1	15	0.03	0.5	0.05	1.6	4	0	3	1	138.7
	Avg	7.9	970.43	130.31	15.1	137.7	176	0.467	2.308	0.26	22.409	16.1	6.15	211	9.547	666.3
	Stdv	0.4	1085.8	117.34	10.6	69.42	152	0.538	0.884	0.25	7.888	6.08	6.16	229.0	8.163	509.2
		pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K	TDS
	Max	7.9	2970	458	24	384.2	368	8.8	13	0.72	147.5	42	52	365	43	1313
	Min	5.7	118	8	0	12.2	0.01	0.01	0.01	0.01	8	3	1	22	1	125.5
SEM	Avg	7.1	795	141.02	5.14	123.4	114.	2.089	1.366	0.15	35.9880	16.5	9.46	147.1	8.380	554
	Stdv	0.5	651.85	114.32	7.12	89.86	95.7	2.949	2.050	0.15	25.0489	9.34	11.3	100.0	8.941	348.6
		pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K	TDS
	Max	8.3	5680	584	18	312	197	1.75	6	0.82	183	60	42	345	74	1347
POM	Min	5.1	215	17	0	12.2	5	0.01	0.01	0.01	18	1	1	21	1	201.3
	Avg	6.7	974.61	155.63	3.85	85.24	81.5	0.295	2.122	0.23	72.666	25.6	10.5	131.1	14	547.2
	Stdv	0.5	1027.1	128.18	4.92	57.85	46.3	0.396	1.724	0.19	24.522	13.4	9.89	79.60	14.87	255.1
		pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K	TDS
	Max	8.2	2180	895.21	24	250.1	341	1.4	2.5	1.1	84	48	53	781	28	1993
SUM	Min	5.9	102	17.73	0	6.1	25	0.001	0.5	0.01	10	1	0	20	0	143.7
	Avg	6.9	795.02	171.01	5	81.45	131	0.436	1.892	0.16	41.163	15.6	7.58	196.0	6.380	623.9
	Stdv	0.4	578.49	190.18	7.60	51.74	80.6	0.348	0.395	0.17	18.85	8.22	9.23	176.9	5.648	450.3

In view of the limitations of the existing graphical methods an increasing number of chemical parameters now being measured in groundwater hydrogeochemical studies, there is a need for wide ranging statistical analysis of the data. Delineating relationship between geochemical water types is difficult, while it is almost impossible to visualise the impact of both the physical and chemical variables on the water chemistry (Melloul and Collin, 1992). Statistical methods especially factor and correlation analyses are often used to achieve the above objectives.

In the study area multivariable statistical method has been used. Correlation analysis was perfumed to identify chief ions controlling water chemistry. Correlation coefficient, measures of interrelationships for all pairs of constituents was determined along with estimation of factor loading. Principal component method was adopted for parameter estimation to transform a set of observed independent variables into orthogonal set variables called principal compounds. Each principal compound accounts for as much as possible for residual variance not accounted for by all the previous principal compounds. Kaiser scheme called Verimax rotation is used in this study. Factor score is estimated to find out spatial variation, zone of representation of each factor (Balasubramanian and others 1989). Spatial variation by musing factor score values by all factors. Statistical packages for social sciences (SPSS) version 9 used to perform correlation and factor analysis.

Results and Discussion

Correlation

The correlation analysis of groundwater of Neyveli region (Table 2) shows that in SWM good to excellent correlations are observed between Cl-HCO_3, Cl-SO_4, Cl-Na, Cl-Mg, SO_4-Na, SO_4-Mg, SO_4-F, Mg-Cl,Mg-HCO_3, Mg-SO_4, Mg-Na. Poor correlation exists between H_4SiO_4,NO_3, PO_4 and F with other ions. The same trend is followed in northeast and POM (Table 3) season. In SUM (Table 4) good to excellent correlation observed between Cl-HCO_3, Cl-SO_4, Cl-Na, SO_4-Na, SO_4-Cl, Na-HCO_3, Na-Cl and Na-SO_4. Poor correlation exhibits between F, Ca, PO_4 and NO_3. In general SWM good positive correlation between anions are well established and with a meagre correlation in cation between Mg and Na. In general NEM (Table 5) good correlation in cations (Ca, Mg, and Na) anions (Cl, HCO_3, SO_4) and between them both. Apart from this there is a set of correlation between the minor ions PO_4 – H_4SiO_4 and F. In POM season shows good positive correlation between cation (Mg, Ca and Na) and anion (SO_4, Cl and HCO_3). Good correlation is also established between cation and anion the relationships of minor ions are maintained in this season (PO4, H_4SiO_4 and F) as that of Notheast monsoon. In SUM, correlation could be established only between few ions and that to mainly between anion (Cl, HCO_3, F and SO_4) and in cation only Na is correlated with few anions. Other cations lack correlation.

The overall view of correlation analysis indicates that the relationship between Cl, HCO_3 and SO_4 remains the same irrespective of the season, hence they form the spinal species (Srinivasamoorthy, 2005, Chidambaram 2010, Chidambaram and others 2014) of the water chemistry of the region. Other species like (Ca, Mg, K, PO_4 and NO_3) are all having only seasonal relationship and they form the seasonal species.

It’s very clear that the anions trend to form the spinal species of the water chemistry. The relationship of the cation to these spinal species varies according to the relative mobility of cation present in water as it varies according to the season. It’s also evident that the cation establishes more relationship during the NEM and POM than in SUM and SWM. This may be due to the impact of rainfall over the relative mobility of the cation in the study area.

The correlation analysis shows that the weathering and leaching of secondary precipitate salts might be the major sources for these ions followed by agriculture and anthropogenic. This has been further examined by factor analysis.

Factor Analysis

The aim of the factor analysis of hydrogeochemical data is to explain the observed relation in simple terms expressed as new varieties called factors (Singaraja and others 2015). The factor analysis model is assumed to represent adequately all the variance of the data set and the structure expressed in the pattern of variance and

TABLE 2. CORRELATION MATRIX FOR THE CHEMICAL COMPOSITION OF GROUNDWATER DURING SWM

	pH	**EC**	**Cl**	**CO_3**	**HCO_3**	**SO_4**	**PO_4**	**NO_3**	**F**	**H_4SiO_4**	**Ca**	**Mg**	**Na**	**K**	**TDS**
pH	1														
EC	-0.06	1													
Cl	-0.222	0.49	1												
CO_3	0.017	0.228	0.354	1											
HCO_3	-0.166	0.36	0.62	0.66	1										
SO_4	-0.201	0.730	0.771	0.43	0.697	1									
PO_4	0.037	-0.06	0.064	0.13	0.036	0.148	1								
NO_3	-0.082	0.126	0.41	0.45	0.401	0.419	0.200	1							
F	-0.209	0.136	0.36	0.639	0.61	0.528	0.1734	0.502	1						
H_4SiO_4	-0.318	0.18	0.158	0.13	0.134	0.322	0.069	0.306	0.214	1					
Ca	-0.178	0.458	0.822	0.70	0.83	0.72	0.120	0.390	0.526	0.1670	1				
Mg	-0.166	0.09	0.348	0.18	0.337	0.29	0.1077	0.1178	0.309	0.112	0.35	1			
Na	-0.185	0.29	0.45	-0.133	0.175	0.25	-0.0479	0.1335	-0.039	-0.1423	0.23	0.238	1		
K	-0.190	0.281	0.61	0.107	0.45	0.60	-0.035	0.207	0.212	0.363	0.45	0.331	0.02	1	
TDS	-0.217	0.583	0.909	0.602	0.83	0.88	0.1216	0.4478	0.548	0.2418	0.94	0.384	0.31	0.5	1

TABLE 3. CORRELATION MATRIX FOR THE CHEMICAL COMPOSITION OF GROUNDWATER DURING POM

	pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K	TDS
pH	1														
EC	0.185	1													
Cl	0.188	0.82	1												
CO_3	0.616	0.088	0.269	1											
HCO_3	0.21	-0.19	-0.16	-0.056	1										
SO_4	0.225	0.394	0.428	0.135	0.1816	1									
PO_4	-0.169	-0.09	-0.09	-0.11	-0.0547	0.058	1								
NO_3	-0.167	-0.09	-0.001	-0.11	0.1549	0.004	-0.225	1							
F	0.010	0.232	0.217	-0.18	-0.0506	0.112	0.034	0.1051	1						
H_4SiO_4	-0.003	-0.01	-0.05	0.104	-0.179	-0.32	-0.23	-0.006	0.100	1					
Ca	0.180	0.644	0.593	0.074	0.0096	0.44	-0.149	0.105	0.033	-0.143	1				
Mg	0.22	0.698	0.841	0.235	-0.1004	0.24	-0.163	-0.030	0.307	0.04	0.55	1			
Na	0.278	0.761	0.903	0.27	0.0791	0.62	-0.034	-0.030	0.239	-0.123	0.47	0.68	1		
K	0.092	0.600	0.676	0.051	-0.2047	0.35	0.015	0.073	0.147	-0.002	0.52	0.634	0.54	1	
TDS	0.280	0.791	0.940	0.273	0.0786	0.64	-0.091	0.025	0.229	-0.060	0.62	0.78	0.96	0.6	1

TABLE 4. CORRELATION MATRIX FOR THE CHEMICAL COMPOSITION OF GROUNDWATER DURING SUM

	pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K
pH	1													
EC	0.49	1												
Cl	0.21	0.65	1											
CO_3	0.40	0.46	0.31	1										
HCO_3	0.47	0.78	0.61	0.33	1									
SO_4	0.46	0.82	0.56	0.32	0.62	1								
PO_4	0.07	0.42	0.10	0.10	0.23	0.33	1							
NO_3	0.28	0.20	0.14	0.26	0.31	0.11	-0.02	1						
F	0.16	0.35	0.12	0.43	0.51	0.13	0.13	0.27	1					
H_4SiO_4	0.06	0.16	0.05	0.13	0.16	0.06	0.16	0.03	0.12	1				
Ca	0.32	0.20	0.03	0.09	0.06	0.35	0.07	0.03	0.00	-0.24	1			
Mg	0.02	0.31	0.27	0.05	0.20	0.28	0.01	-0.29	0.09	0.29	-0.2	1		
Na	0.34	0.82	0.93	0.39	0.76	0.74	0.20	0.18	0.25	0.06	0.10	0.25	1	
K	0.15	0.25	0.04	0.01	0.34	0.28	0.12	0.06	0.35	-0.06	0.11	-0.1	0.16	1
TDS	0.356	0.828	0.94	0.387	0.762	0.772	0.212	0.178	0.23	0.116	0.13	0.30	0.99	0.17

TABLE 5. CORRELATION MATRIX FOR THE CHEMICAL COMPOSITION OF GROUNDWATER DURING NEM

	pH	EC	Cl	CO_3	HCO_3	SO_4	PO_4	NO_3	F	H_4SiO_4	Ca	Mg	Na	K
pH	1													
EC	0.2165	1												
Cl	0.143	0.941	1											
CO_3	0.560	0.235	0.23	1										
HCO_3	0.335	0.849	0.78	0.188	1									
SO_4	0.303	0.68	0.67	0.176	0.563	1								
PO_4	-0.428	-0.01	0.03	0.008	-0.088	-0.28	1							
NO_3	-0.030	-0.07	-0.1	-0.05	-0.154	-0.02	-0.2	1						
F	0.355	0.20	0.25	0.152	0.161	0.257	0.03	-0.21	1					
H_4SiO_4	0.0278	0.07	0.11	0.150	-0.033	-0.06	0.45	-0.16	0.561	1				
Ca	0.233	0.58	0.59	0.190	0.570	0.27	0.16	-0.04	0.170	-0.006	1			
Mg	0.188	0.803	0.74	0.118	0.758	0.455	0.2	-0.21	0.20	0.037	0.68	1		
Na	0.213	0.811	0.86	0.22	0.701	0.877	-0.2	-0.05	0.18	0.013	0.44	0.515	1	
K	0.086	0.313	0.35	0.01	0.246	0.227	0.01	-0.08	0.144	-0.070	0.48	0.262	0.273	1
TDS	0.2632	0.919	0.94	0.248	0.814	0.858	-0.1	-0.11	0.288	0.095	0.55	0.695	0.95	0.33

covariance between the variables and the similarities between the observations (Davis 1986). The contribution of a factor is said to be significant when the corresponding Eigen value is greater than unity (Briz-Kishore and Murali 1992). In general factor I will be related to the largest Eigen vale and will explain the greatest amount of variance in the dataset. In the aquifer, the proportion of the total variance explained by the extracted factors of the data set 80% and 89%. The communality of the variable are generally with Eigen value >1. So the factor model is assumed to represent adequately the overall variable of the data set. The factor analysis for waters is given in the table.

In SWM (Table 6) factor I is dominated by Cl, HCO_3, SO_4, Na and Mg indicating the leaching of secondary salts after monsoon. Factor II is represented by CO_3, HCO_3, PO_4, NO_3, F and Na indicating the dominance of anthropogenic impact and ion exchange. Factor III is represented by H_4SiO_4 and Mg indicating the dominance of lithological influence along with leaching. In NEM (Table 7) factor I is dominated by Cl, HCO_3, SO_4, Mg and Na

TABLE 6. FACTOR ANALYSIS FOR CHEMICAL COMPOSITION OF GROUNDWATER DURING SWM

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
pH	-0.02	-0.05	-0.65	-0.38
Cl	0.79	0.22	0.14	0.39
CO_3	0.42	0.76	-0.14	-0.23
HCO_3	0.68	0.55	0.02	0.11
SO_4	0.84	0.28	0.24	0.12
PO_4	-0.21	0.51	0.02	0.18
NO_3	0.23	0.61	0.19	0.03
F	0.27	0.78	0.16	0.00
H_4SiO_4	0.15	0.14	0.82	-0.23
Na	0.76	0.51	0.01	0.18
K	0.13	0.32	0.21	0.58
Ca	0.30	-0.17	-0.15	0.79
Mg	0.58	0.02	0.52	0.07
Total	4.53	2.87	1.61	1.51
% of Variance	30.21	19.15	10.72	10.08
Cumulative %	30.21	49.37	60.09	70.16

TABLE 7. FACTOR ANALYSIS FOR CHEMICAL COMPOSITION OF GROUNDWATER DURING NEM

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
pH	0.15	0.08	-0.04	0.93
Cl	0.87	0.37	0.17	0.02
CO3	0.07	0.17	0.16	0.72
HCO3	0.75	0.43	0.02	0.15
SO4	0.89	-0.07	-0.08	0.19
PO4	-0.23	0.36	0.64	-0.44
NO3	-0.05	-0.14	-0.44	-0.01
F	0.23	-0.12	0.66	0.40
H4SiO4	0.03	-0.17	0.89	0.06
Ca	0.34	0.81	0.08	0.14
Mg	0.59	0.61	0.20	-0.01
Na	0.95	0.09	-0.03	0.11
K	0.16	0.61	-0.05	0.08
Total	5.27	2.17	1.96	1.85
% of Variance	35.14	14.49	13.10	12.35
Cumulative %	35.14	49.63	62.73	75.08

TABLE 8. FACTOR ANALYSIS FOR CHEMICAL COMPOSITION OF GROUNDWATER DURING POM

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
pH	0.13	0.85	0.15	0.02	0.05
Cl	0.95	0.13	-0.01	-0.01	0.08
CO_3	0.15	0.84	-0.10	-0.04	-0.19
HCO_3	-0.21	0.21	0.70	0.32	0.20
SO_4	0.52	0.12	0.62	-0.09	0.02
PO_4	-0.09	-0.25	0.23	-0.76	0.08
NO_3	0.02	-0.30	0.16	0.74	0.06
F	0.21	-0.14	-0.04	-0.01	0.90
H_4SiO_4	-0.07	0.19	-0.70	0.24	0.28
Na	0.73	-0.02	0.18	0.21	-0.23
K	0.83	0.16	-0.14	0.07	0.19
Ca	0.84	0.24	0.26	-0.06	0.20
Mg	0.79	-0.11	-0.07	-0.00	-0.04
Total	5.50	1.86	1.65	1.35	1.13
% of Variance	36.64	12.39	10.99	9.00	7.52

TABLE 9. FACTOR ANALYSIS FOR CHEMICAL COMPOSITION OF GROUNDWATER DURING SUM

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
pH	0.27	0.52	0.51	-0.04	-0.02
Cl	0.94	0.08	-0.09	0.01	-0.06
CO_3	0.28	0.65	0.17	0.21	0.01
HCO_3	0.70	0.32	0.13	0.13	0.42
SO_4	0.73	0.05	0.53	0.01	0.12
PO_4	0.09	-0.11	0.61	0.32	0.23
NO_3	0.09	0.78	-0.12	-0.16	0.11
F	0.12	0.45	-0.05	0.22	0.69
H_4SiO_4	-0.01	0.16	0.08	0.81	-0.04
Na	0.07	0.09	0.67	-0.51	-0.06
K	0.39	-0.33	-0.05	0.60	-0.00
Ca	0.97	0.15	0.08	0.02	0.09
Mg	0.11	-0.09	0.16	-0.18	0.85
Total	4.73	1.87	1.66	1.59	1.53
% of Variance	31.53	12.48	11.07	10.59	10.22
Cumulative %	31.53	44.00	55.08	65.66	75.88

which follows the same trend as in SWM and Factor II is dominated by Ca, Mg and K indicating the dominance by selective observation. Factor III is dominated by PO_4, F and H_4SiO_4 indicating the contribution of ions from fertilisers, and ion exchange with clay matrix. In POM (Table 8) factor I is dominated by Cl, SO_4, Ca, Mg, Na indicating recharge of the leached water and K and factor II is dominated by pH and CO_3 and factor III is dominated by HCO3 and SO4 which follows the same trend as in NEM. This trend shows the leaching of secondary salts precipitates along with anthropogenic impact like agriculture, mine effluent etc. In SUM (Table 9) factor I is dominated by Cl, HCO_3, SO_4 and Na and factor II by pH, CO_3 and NO_3 shows agricultural return flow from nitrate and factor III by pH, SO_4, PO_4 and Na. This shows the influence of Kunnankurichi, Flyash pond and Walaja tank.

The factor analysis shows the region is complex hydrogeochemical system with proportional interplay of ions from leaching of ions, ion exchange, agricultural return flow, stagnant waters (Kunnakurichi pond, flyash pond and Walaja tank), influence of mine waters and weathering of minerals. This interplay varies according to the season and spatial distribution of the source.

Conclusion

The overall view of correlation analysis indicates the relationship between Cl, HCO_3 and SO_4 remains the same irrespective of seasons; hence they form the spinal species of water chemistry in the study area. Other species like Ca, Mg, K, PO_4 and NO_3 are all having only seasonal relationship and they form the seasonal species. Factor analysis shows the region is complex hydrogeochemical system with proportional interplay of leaching of ions, ion exchange, agricultural return flow, stagnant waters, Flyash pond and Walaja tank, influence of mine water and weathering of minerals. This interplay varies according to season and spatial distribution of the source.

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