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Application of Multivariate Statistical Techniques for the Interpretation of Groundwater Quality in Gombe and Environs, North-East Nigeria

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Abstract A total of 50 groundwater samples were collected from Hand dug Wells and Bore holes in Gombe area and environs and were analyzed for their physio-chemical characteristics aimed at interpreting the groundwater quality. Multivariate statistical methods, namely: the hierarchical cluster analysis (HCA), and the principal component analysis (PCA) were used to study the spatial variations of the most significant water quality variables and to determine the dominant processes affecting the water quality. Principal Component Analysis (PCA) on the data indicates three factors which explain about 61.004% of the total variance, and suggests temporary hardness of water, salinity of the groundwater and dissolution of bedrock material as the dominant processes affecting the water quality in the study area. Whereas hierarchical cluster analysis HCA indicate two clusters, and suggests salinity of the groundwater, natural mineralization, bedrock dissolution, Temporary Hardness and anthropogenic contamination as the dominant processes affecting the water quality parameters in the study area.

Keywords: *hierarchical cluster analysis (HCA), principal component analysis (PCA), groundwater chemistry, physio-chemical, and Gombe*

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1. Introduction

Groundwater is the most vital natural resource, which forms the core of the ecological system. It has become the major source of water supply for drinking, domestic, household, agricultural, industrial, recreational, and environmental activities etc. The usefulness of water for particular purpose is determined by its quality. Good quality water will enhance the sustainability of socio-economic development, by significantly bringing down government’s expenditure towards combating outbreaks of water borne diseases due to consumption of contaminated groundwater. Groundwater quality is mainly controlled by the range and type of human influence as well as geochemical, physical and biological processes occurring in the ground [1,2]. Groundwater quality depends, to some extent, on its chemical composition [3] which may be modified by natural and anthropogenic sources. Rapid urbanization, especially in developing countries like Nigeria, has affected the availability and quality of groundwater due to waste disposal practice, especially in urban areas. Variation in groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by natural processes such as geological formations and anthropogenic activities. Multivariate statistical techniques can be an effective means of managing, interpreting, and representing data about groundwater constituents and geochemistry [4].

Multivariate statistical analyses such as principal component analysis (PCA) and hierarchical cluster analysis (HCA) have been used to provide a quantitative measure of relatedness of water quality parameters and to suggest the underlying natural and anthropogenic processes in groundwater aquifers. Multivariate statistical analysis comprises a number of statistical methods or a set of algorithms that may be applied to several fields of empirical Investigation. These methods are also giving a better understanding of the physical and chemical properties of the groundwater system in space as well as in time [5]. Recent studies have confirmed the usefulness of multivariate analysis techniques for (i) evaluation and interpretation of groundwater quality data sets [6] (ii) providing insight into the processes [7] (iii) identifying critical water quality issues and possible sources of pollution/polluting processes [8,9].

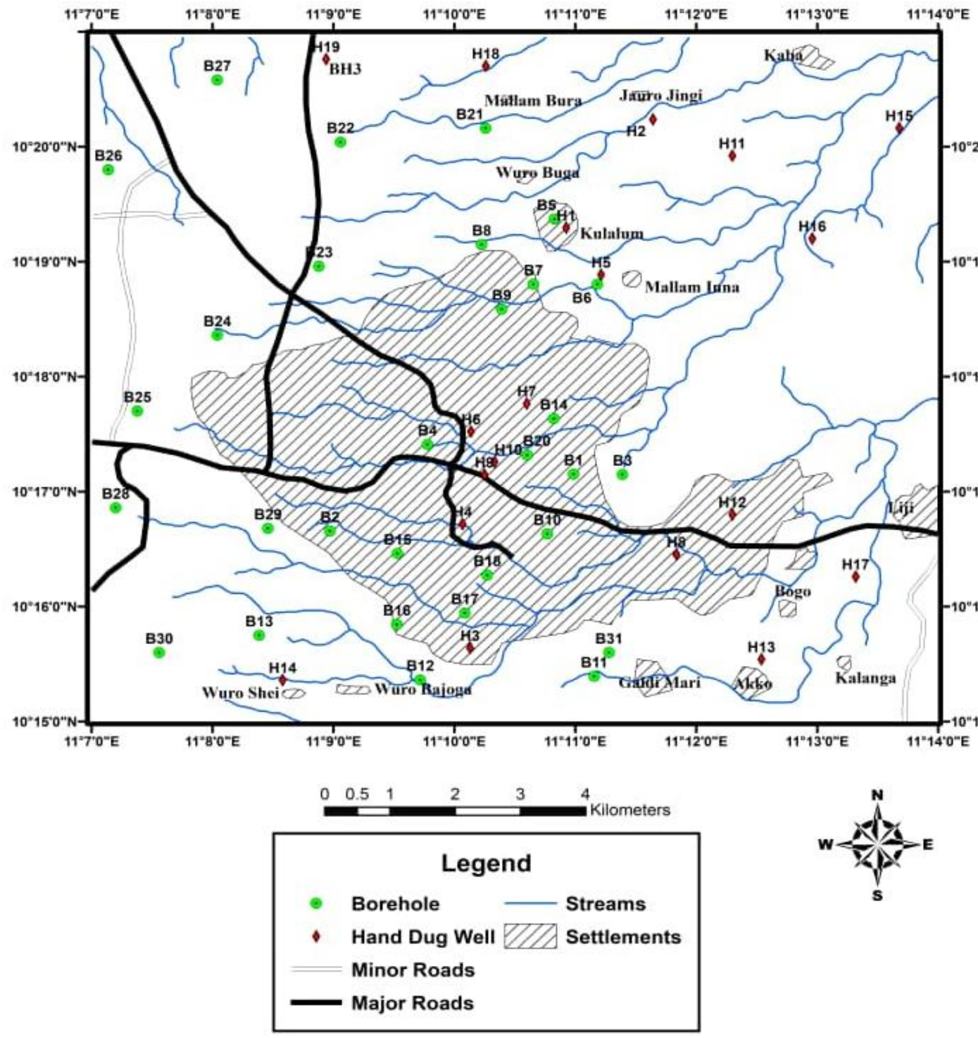

Figure 1. Topographic map of the study area showing groundwater sampling points

1.1. Study Area

Gombe Area and Environs is the study area, located in the North-eastern part of Nigeria, and lies between longitudes $11^{0}7'0''$E to $11^{0}14'0''$E and latitudes $10^{0}15'0''$N to $10^{0}21'0''$N covering about 136.08km^2. The area is accessible through numerous interconnected footpaths, motarable tarred and untarred roads linking all parts of the study area. The topography of the area is generally hilly with an elevation ranging from about 400m to 600m (Figure 1) above sea level and falls within the Upper Benue Basin, The outcrops generally consist of rocks which are made up of sandstones. The climatic condition in the study area is characterized by two seasons; a rainy season, which starts in May and ends in October and the dry season, which normally spans between October and April. Surface drainage systems in the study area comprise numerous streams formed in the direction of the river basin towards the southeast. Most of the streams are seasonal overflowing their banks during rainy season.

2. Methodology

The groundwater samples were obtained from 50 sampling points (hand dug wells and boreholes) in June 2017. The sample collection was done according to [10] method, and the coordinates of each well and boreholes were recorded using GPS (Model Garmin eTrex HC Series). The water samples were analyzed for physico-chemical parameters. Field parameters such as: pH, Temperature, Turbidity, Conductivity, bicarbonate, and Total dissolve Solids were measured immediately after sampling, using appropriate equipments. All other parameters such as Potassium (K^+), Calcium (Ca^{2+}), Copper (Cu^{2+}), Sodium (Na^+), Magnesium (Mg^{2+}), Chloride (Cl^-), Nitrate (NO_3^-), Fluoride (F^-), Sulphate (SO_4^{2-}), were determined in the laboratory.

The variables (water quality parameters) were standardized using z-score: Z= yi-y^/s, where 'y^' is the average value of a parameter in a data set and 's' is its standard deviation to avoid the problem of difference in scale, i.e., range of values and variances. The Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were carried out on the standardized data sets. The software SPSS Statistics 20 version was used for data standardization, PCA and HCA

2.1. Principal Component Analysis

PCA is defined as an orthogonal linear transformation that transforms variables to a new coordinate system such that the greatest variance by any projection of the variables comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. PCA is theoretically the optimum transform for a given data in least square terms [11]. To determine the number of components to extract, data obtained from laboratory and field analysis were used as variable inputs. Prior to the analysis, the data were standardized to produce a normal distribution of all variables [12]. The weights of the original variables in each factor are called loadings, each factor is associated with a particular variable. Communality is a measure of how well the variance of the variable is described by a particular set of factors [5].

2.2. Hierarchical Cluster Analysis

In this study, HCA with Ward's method of linkages with squared Euclidean distance as dissimilarity measure was applied to detect multivariate similarities and to group parameters into clusters based on their similarities. Hierarchical Cluster analysis groups a system of variable into clusters on the basis of similarities or dissimilarities such that each cluster represents a specific process in the system [13]. It is a technique that identifies natural groupings among objects to decipher hidden structures present in the data set. In HCA, clusters are formed sequentially, starting with the most similar pair of variables and forming higher clusters step by step [14]. A low distance shows the two objects are similar or close together whereas a large distance indicates dissimilarity [15]. Hydrochemical data with similar properties are clustered in a group [16]. The results of the analysis are presented inform of dendrogram. The dendrogram provides a visual summary of the clustering processes by presenting a picture of the groups and their proximity with a dramatic reduction in dimensionality of the original data [17].

3. Results and Discussion

3.1. Hydrogeochemical Characteristics of Groundwater

Table 1 show the values of physico-chemical results of ground water from the study area. Based on the mean values of the chemical parameters the order of abundance of the cations concentration is in the order of $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while those of the anions are $HCO_3^{-}>SO_4^{2}>Cl^{-}>CO_3^{2-}$. Temperature range from 20.4° to 27.2 ℃ with average of 25.85°. pH in the area range from 5.81 to 8.1mg/l with average value of 6.53mg/l which indicate moderately acidic to neutral water [18]. Electrical Conductivity (EC) in the study area range from 189 to 369 with a mean of 286.92 μS/cm and thus indicates less mineralized water [18]. Total Hardness (TH) 46.62 – 73.12mg/l, with average of 59.93mg/l, thus indicate soft to moderately hard water. Total Dissolved Solids (TDS) in the area range from 110 to 251mg/l with average of 188.40mg/l and be regarded as fresh water [19]. Turbidity in the area range from 0.005 to 1.053 with average of 0.356 and standard deviation of 0.359. Calcium (Ca^{2+}) in the study area is between 30.1 and 53mg/l with average of 40.64 and standard deviation of 5.07. Magnesium (Mg^{2+}) range from 7.49 to 31.27 with average of 18.88. Magnesium is an important contributor to water hardness. The sources of magnesium in natural water are dolomites and mafic minerals (amphibole) in rocks. Sodium (Na^{+}) in the study area range from 0.78 to 2.93mg/l with average of 1.43mg/l. Potassium (K^{+}) range from 4.2 to 13.1mg/l with average of 6.81mg/l. Sulphate (SO_4^{2-}) range from 23.42 to 29.66mg/l with average of 27.002. Chloride (Cl^{-}) in the area is between 14.49 and 30mg/l with average of 20.81mg/l. Nitrate (NO_3^{-}) range from 7.58 to 38.42mg/l with average of 14.98mg/l. Bicarbonate (HCO_3^{-}) in the area range from 90 to 241mg/l with a mean of 166.83. Carbonate (CO_3^{2-}) concentrations in all the water samples are extremely low (0 – 3.2mg/l) Fluoride (F^{-}) range from 0.33 to 0.92mg/l with mean of 0.59. Iron (Fe^{2-}) range from 0.22 to 1.02mg/l with mean of 0.53, Copper (Cu) (0.2 – 1.2mg/l, mean of 0.757mg/l).

3.2. Principal Component Analysis

Principal Component Analysis (PCA) on chemical data indicates three factors which explain about 61.004% of the total variance (Table 2). For factor loadings, a high loading was defined as greater than 0.75, and a moderate loading was defined as 0.40-0.75. Loadings of less than 0.40 were considered insignificant [20].

Factor 1 account for about 26.03% of total variance and is characterized by strong positive loading with respect to pH, TH, and K. pH and TH have loadings of 0.801 and 0.832 respectively. This factor is interpreted as temporary hardness of water attributed by the strong loadings of K and moderate loadings of Mg and Ca. The association of these elements to this factor may be attributed to leaching of bed rock materials, weathering and rock-water interaction [21]. Hardness of water is caused by calcium and magnesium ions and can be tied to bedrock geochemistry [22]. The positive loadings of K, Cl, and NO_3, (0.775, 0.702, and 0.503 respectively) is interpreted as diffused form of contamination due to application of chemical fertilizer such as NPK, Potash, and Manure [23].

Factor 2 accounts for about 20.8% of total variance and is characterized by strong positive loadings of EC and TDS (0.93 and 0.831 respectively) with moderate positive loading of SO4 (0.588). Strong loadings of EC and TDS control the overall mineralization [24]. This component is interpreted as salinity of the groundwater.

Factor 3 account for about 14.17% of total variance and is characterized by moderate loading of Na (0.748) and moderate loading of Mg (0.567), this factor is interpreted as dissolution of bedrock material. Sodium could be derived from the weathering of plagioclase feldspar, atmospheric dust washed by rain water and also through cation exchange process while magnesium is derived from the weathering of mafic minerals.

3.3. Hierarchical Cluster Analysis

The results of cluster analysis are presented in Figure 2 and indicate two clusters. Cluster 1 is subdivided into two sub clusters, and sub cluster 1 comprises of EC, TDS, SO_4 and F^{-}. This cluster is also related to factor 2 and the cluster is interpreted as salinity of the groundwater controlled by SO_4 and F^-. The second sub-cluster comprises of Temperature and HCO_3 and is ascribed to as natural mineralization. Cluster 2 is also subdivided in to two sub clusters; first sub cluster shows similarities between pH, K and Ca and is interpreted as bedrock dissolution. The second sub cluster shows close similarities between TH, Mg, Cl and $N0_3$ with Na loosely bounded to the cluster. This sub cluster is related to component 1 and interpreted as Temporary hardness of the water and the presence of Cl and NO_3 indicate anthropogenic contamination.

Table 1. Physico-Chemical Constituents of groundwater Samples from the Study Area

Sample Locations	Water source	Temp (℃)	pH	EC (µs/cm)	TDS (mg/l)	Turbidity (NTU)	TH mg/l	HCO_3^- mg/l	Ca^{2+} mg/l	K^+ mg/l	Cu^{2+} mg/l	Na^{2+} mg/l	Mg^{2+} mg/l	Fe^{2+} mg/l	SO_4^{2-} mg/l	F^- mg/l	Cl^- mg/l	NO_3^- mg/l	PO_4^{2+} mg/l
ARAWA	BH1	26.83	5.92	309	205	0.11	47.54	118.7	36.84	5.33	1.09	0.96	10.11	0.83	28.01	0.61	20.42	10.43	1.02
WURO BIRIJI	BH2	26.73	6.44	341	226	1.053	46.62	220	34.42	5.6	0.8	1	11.01	0.49	28.08	0.5	16.88	13.2	0.94
RAILWAY	BH3	26	6.41	289	190	0.25	59.84	200	46	5.53	0.99	1	14.01	0.83	27	0.47	23.07	9.66	0.86
BYE PASS	BH4	26.97	6.25	268	177	0.075	54.05	191.11	41.67	5.3	1.1	0.94	12.61	0.77	26.57	0.67	17.63	12.08	1.04
PANTAMI	BH5	26.12	6.22	297	196	0.105	64.97	196.1	43.23	4.77	1	1.14	18.11	0.63	29.66	0.56	18.53	9.88	1.01
JEKA DA FARI	BH6	25.92	6.37	298	200	0.005	54.66	192.5	41.08	5.1	1.09	0.9	12.82	1.02	26.99	0.68	20.18	10.42	0.97
BOLARI	BH7	26	6.44	340	227	0.066	51.27	90	43.37	7	0.97	0.9	7.49	0.8	27.55	0.44	16.83	8.62	1
JAURO KUNA	BH8	27.01	6.23	287	190	0.108	53	174	43.13	4.83	0.9	0.89	8.97	0.7	26.77	0.82	21	9.18	0.83
MAIN MARKET	BH9	27.05	5.97	255	169	0.027	47.48	102	38.11	6.9	1.04	0.78	8.55	0.6	26.84	0.83	19.4	7.58	0.71
IDI QUARTERS	BH10	26	6.65	297	199	0.042	52.89	188	37.01	5.38	1.2	0.86	16.42	0.59	27.9	0.92	16.57	8.63	0.85
KUNDULUM	BH11	26.81	6.31	348	231	0.029	55.98	201.4	40	4.88	0.8	0.88	16.73	1	28.01	0.6	18.93	9.77	1
TAURA	BH12	26.91	6.21	311	210	0.125	52.09	186.4	38.87	4.2	0.73	0.98	12.44	0.67	28.11	0.33	17.67	8.73	1.1
WURO KESA	BH13	27.11	6	353	237	0.95	47.67	190.8	37.73	5.4	0.69	1	9.08	0.55	28.73	0.73	17.88	12	1.06
WURO JULI	BH14	26.64	6.6	314	209	0.028	59.12	205	39	6.1	0.78	1	19.83	0.5	27.01	0.49	16	9.07	0.88
NEW GRA	BH15	25.7	6.48	274	184	0.035	52.6	133	38.93	6.6	1.11	0.8	14.4	0.78	26.81	0.44	23.11	11.52	1
GABUKKA	BH16	27.03	6.18	269	179	0.091	50.24	109	40.83	4.9	1.1	0.84	8.87	0.43	26.11	0.5	21.43	10.55	0.9
STATE LOWCOST	BH17	27.2	6.2	317	210	0.15	53.94	166.73	42.84	4.8	0.67	0.8	11.47	0.92	27.11	0.61	15.93	9.4	1
T/WADA PANTAMI	BH18	26.9	6.2	273	181	0.511	49.05	124	39.66	6.6	0.91	0.91	9.16	0.39	27.41	0.37	19.53	7.93	0.78
WURO BOGGA	BH19	26.87	6.1	284	188	0.907	50.97	108.6	38.55	6	1.02	0/91	12.83	0.6	29	0.77	22	11	0.95
MKTTAKO	BH20	25.99	6.09	285	191	0.315	55.95	211.4	44.42	6.42	1.03	0.92	11.73	1	25.93	0.48	16.87	9.91	0.96
MALAM BURRA 1	BH21	27.1	6	217	134	1.02	59.11	193	37.81	6.61	0.73	2.44	21.07	0.27	23.42	0.39	24	23.66	0.43
MALM BURRA 2	BH22	27	6.12	212	129	0.65	62.28	187	40.66	6.42	1.01	2.81	21.44	0.52	24.81	0.48	21.1	19.48	0.59
CBN	BH23	26.81	6.33	284	251	0.55	70.17	198	41.92	4.93	1	2.73	27.12	0.49	24.66	0.64	16.5	20.48	0.81
LEGISLATIVE QUARTERS	BH24	26.12	6.17	271	241	0.41	68.84	191	39.73	5.1	0.67	1.66	27.91	0.44	25.92	0.44	20.1	19.68	0.75
JIYAMERE	BH25	24.93	6.16	255	149	0.112	62.91	207	41.1	5	0.7	1.47	23.42	0.4	26.6	0.59	16.5	19	1
SHONGO DIRANGO	BH26	26	6.53	189	118	1	73.12	200	44.87	4.99	0.4	1.88	31.27	0.37	26.1	0.6	20	18.97	0.63
DORAWA 2	BH27	26.53	6	200	110	0.215	53.92	178	37.08	6	0.51	2.93	19.79	0.22	27	0.34	17.5	20.55	1.04
NEW MILE 3	BH28	27.1	5.81	298	181	0.405	51.73	153	32.91	7.01	0.88	2.91	19.88	0.377	27.12	0.72	18.8	12.54	0.44
NEAR HOUSE OF ASSEMBLY	BH29	26.81	5.93	300	186	0.095	50.93	149	33.03	6.98	0.47	1.88	18.78	0.4	27.11	0.67	16.9	11.73	0.57
WURO SHIE 3	BH30	26.44	6.18	283	172	0.073	68.22	188	40.43	5.23	0.59	1.9	27.19	0.501	26.93	0.41	14.5	10.46	1.1
GALDIMARI	BH31	27.2	6.27	219	137	1.05	64.79	158	46.27	5.93	0.8	2.48	19.39	0.45	26.14	0.8	23.7	21.18	1.21
RIYAL QUARTERS	HDW1	23.67	8.1	321	210.5	0.063	64.11	107	39.73	8.6	0.37	1.14	23.59	0.56	28.72	0.9	22.97	16.73	0.43
YALANGURUZA	HDW2	24.28	7.6	331	216.5	0.095	67.51	121	48.91	13	0.72	1.01	17.55	0.601	26.15	0.82	30	20	1
WURO KESA 2	HDW3	24.08	7.81	301	196.7	0.205	71.08	101	47.88	10.4	0.39	1.34	22.88	0.4	28.09	0.79	29.72	38.42	0.56
ANGUWAN GANDU	HDW4	23.67	7.4	334	221	0.1	71	178.63	49	12.8	0.81	1.06	21.67	0.453	27.08	0.75	24.88	8.4	0.68
JAURO JINGI	HDW5	24	7.44	303	201.1	0.101	71.22	123.3	49.6	13.1	0.2	1.08	20.15	0.443	28.01	0.83	18.77	19.72	0.84
KUMBIYA KUMBIYA	HDW6	22.83	7.63	348	221	0.201	69.89	110.1	51.66	9.9	0.44	1.04	19.67	0.617	27.15	0.75	21.76	16.92	1.05
ANGUWAN FADA	HDW7	23.11	7.55	367.1	240	0.411	73.05	100	53	11.6	0.63	1.24	19	0.37	28.1	0.81	26.52	9.43	0.87
KUNDULUM	HDW8	23.42	7.9	309	214	0.152	66.93	188	44.11	10	0.6	1.31	23.42	0.411	26.15	0.51	21.67	15.62	0.77
BAYAN STADIUM	HDW9	23.92	7.48	369	244.5	0.927	57.85	120	37.28	9.1	0.52	1	20.85	0.49	28.1	0.64	19.4	14.93	0.72
HERWAGANA	HDW10	23.91	8	322	212.9	0.104	72	96.6	46.77	12.6	0.56	1.21	24.22	0.318	27.62	0.54	26.15	16	1.19
JAURO JINGI 2	HDW11	26.66	6.14	269	159	0.511	71.43	181	40.72	6.1	0.47	1.97	28.93	0.321	26.88	0.41	20.4	18.92	0.72
NASARAWO	HDW12	20.4	6.23	274	248	0.501	64.8	174	37.12	4.88	0.51	2.04	20.61	0.34	24.92	0.4	25	22.47	0.71
AKKO	HDW13	26	6.44	300	167	1.02	60.11	212	39.61	6.27	0.92	1.86	21.43	0.41	25.9	0.53	23.1	19.67	0.64
WURO SHIE 2	HDW14	25.93	6.51	260	149	0.45	59.82	199	30.1	5.91	1	1.09	27.11	0.48	26	0.47	19.6	11.1	1.02
KABA	HDW15	26.17	6.28	254	144	0.09	66.81	179	36.33	4.99	0.87	1.43	28	0.33	27.11	0.51	25.9	21.68	0.8
LIJI	HDW16	26.11	6.51	209	129	1.02	61.91	241	34.17	6.01	0.43	1.67	29.01	0.29	27.01	0.62	24.9	19.77	0.54
LIJI 2	HDW17	27	6.42	227	131	0.25	60	210	36.72	6.3	0.55	2.42	21.63	0.48	26.9	0.51	24.9	18	1.03
MALAM BURRA 3	HDW18	26.91	6.4	241	141	0.05	64	221	31.98	5.88	0.48	2.81	30.99	0.41	27.8	0.63	23.8	20.12	1
DORAWA 1	HDW19	26.84	5.98	270	167	1.005	57.21	168	36	7.1	0.61	1.09	19.53	0.33	27	0.67	21.4	24.11	0.69

Table 2. Principal Component Analysis (PCA) component matrix

Parameters	Component 1	Component 2	Component 3
Temperature	-.719	-.350	-.192
pH	**.801**	.425	.118
Electrical Conductivity	.120	**.930**	-.089
Total Dissolve Solids	.120	**.831**	-.059
Total Hardness	**.832**	-.208	.187
Bicarbonate (HCO3)	-.135	-.413	.235
Calcium (Ca)	**.724**	.214	-.452
Potassium(K)	**.775**	.372	.088
Sodium (Na)	-.048	.065	**.748**
Magnesium (Mg)	.439	-.444	**.567**
Iron (Fe)	-.300	.367	-.635
Sulphate (SO4)	-.080	.588	-.108
Fluoride (F)	.316	.393	-.034
Chloride (Cl)	**.702**	-.164	.083
Nitrate (NO3)	.503	-.444	.433
Phosphates (PO4)	-.090	.101	-.641
Eigen Value	**4.165**	**3.328**	**2.267**
% of Variance explained	**26.032**	**20.801**	**14.171**
Cumulative %	**26.032**	**46.833**	**61.004**

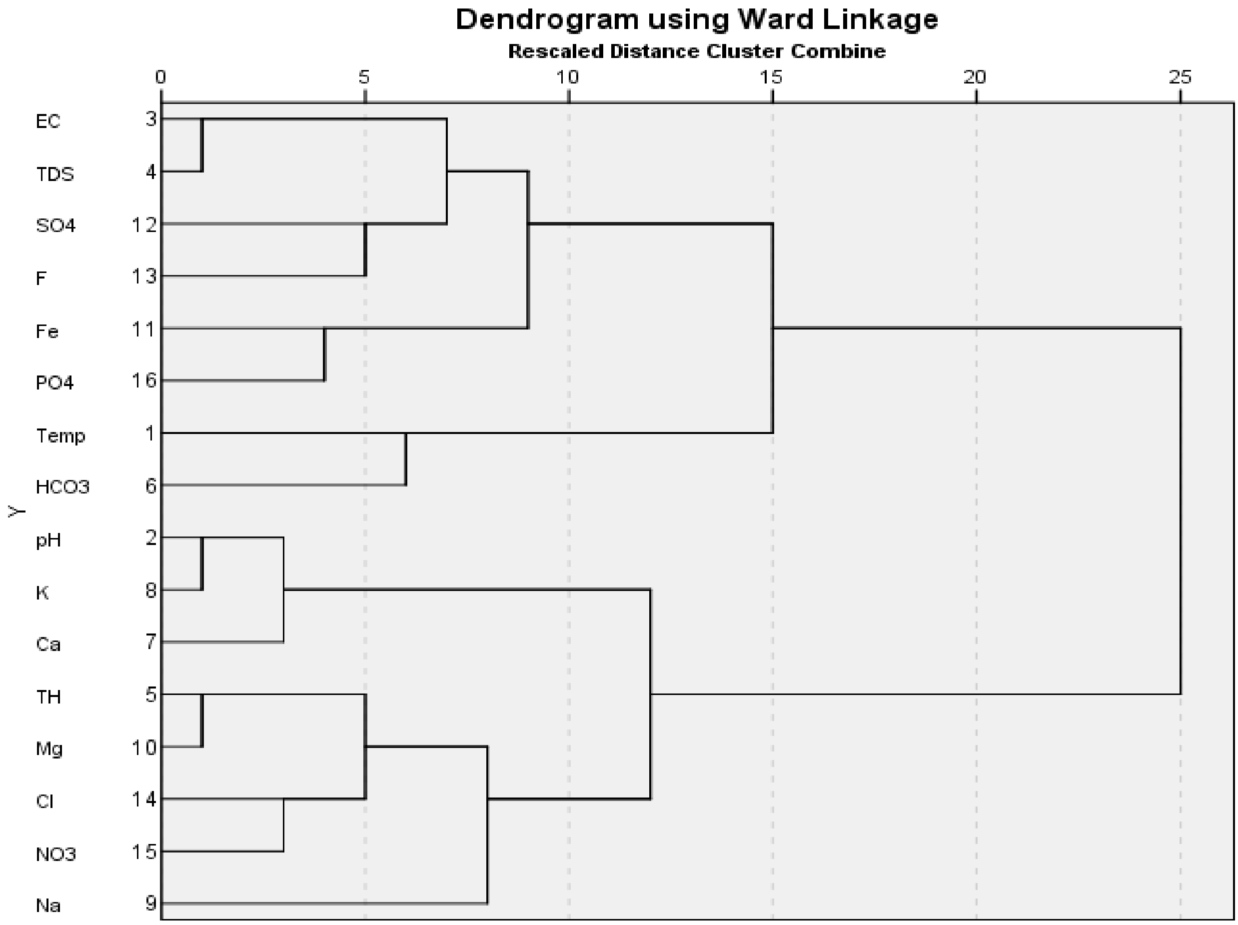

Figure 2. Dendrogram of hydrochemical data

4. Conclusion

The water quality data sets of parameters from the area were analyzed using two different multivariate statistical techniques namely PCA and HCA to understand dominant processes affecting the water quality parameters. From PCA 3 factors were obtained from the data set with varimax rotation. The rotated factors allowed interpretation of different geochemical processes. The processes inferred were temporary hardness of water, salinity of the groundwater and dissolution of bedrock material. From HCA with Ward's method, two (2) cluster were classified from the Dendrogram of the data sets. The variables in the clusters were similar to the variables from significant factor loadings of PCA factor groups. The HCA clusters confirmed most of the processes suggested from PCA factors and also suggest natural mineralization and anthropogenic contamination as other processes affecting the water quality in the study area.

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