



Full Length Research Paper

Statistical Investigation of Groundwater system in Itakpe area, Kogi state

¹Akpah F.A, Ishaku J.M ² and Ameh E.G¹

¹Department of Earth Sciences, Kogi State University Anyigba, Nigeria

²Department of Geology, Modibbo Adama University of Technology Yola, Nigeria

*Corresponding Author E-mail: jmishaku@yahoo.com

ABSTRACT

Statistical investigation of groundwater system in Itakpe area was carried out. The objective of the present work is using the multivariate statistical techniques to obtain information about the ground water quality status of Itakpe area and the processes responsible for the modification of the groundwater chemistry. Analytical results of 17 groundwater samples indicate that the cations based on their mean values are in the order of abundance as $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Mn}^{2+} > \text{Fe}^{2+}$ and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$ for the anions. The principal component analysis indicates factors 1, 2 and 3 which account for 71.51% of the total variance. Factor 1 is interpreted as reverse cation exchange indicated by Ca-Cl facies. Factor 2 is ascribed to anthropogenic pollution while factor 3 is interpreted as mineral dissolution. Cluster analysis identified two clusters. Cluster 1 is interpreted as rock-water interaction or natural mineralization and cluster 2 is interpreted as anthropogenic pollution. A predictor model developed with five dominant chemical parameters of groundwater to perceive an estimation of TDS has been developed for the study area. The R square between TDS, Ca^{2+} , Na^+ , Cl^- , Mg^{2+} and EC of 1.00 indicates a perfect relationship, and therefore suggests a common source. Rock-water interaction diagrams suggest precipitation induced chemical weathering along with the dissolution of rock forming minerals as responsible for the modification of groundwater chemistry. It is recommended that regular groundwater quality will ensure the well-being of the ever-increasing population of the area.

Keywords: Multivariate, Groundwater, Rock-water, Predictor model, Itakpe.

INTRODUCTION

Groundwater resource is an important component of the hydrologic cycle and contributes to the well-being of the ever-increasing population of the world. Sustainable socio-economic development of every community depends much on the sustainability of the available water resources (Belkhiri et al., 2010). The assessment of groundwater quality status is important for socio-economic development of any region of the World (Ishaku, 2011). Groundwater quality parameters are controlled by many factors such as rainfall, composition of aquifer material, topography, hydrologic fluctuation and climate (Mohapatra et al., 2011). The major problem with groundwater is that once it is contaminated, it is difficult to restore its quality (Bajpayee et al., 2012). Despite its importance, contamination from natural and man-made

sources has affected groundwater quality as a source for human consumption (Ishaku et al., 2012). Rock-water interactions that occur in the mixing zone can lead to changes in the chemical composition of groundwater, the mineralogical composition of the bed rock, and the porosity and permeability of the aquifer (Wicks and Troester, 1998). Indiscriminate waste disposal practice, application of chemical fertilizers and industrial activities are responsible for the degradation of groundwater quality (Ishaku et al., 2012). Hence, there is a need and concern for the protection and management of groundwater quality (Bajpayee et al., 2012).

Due to the complex hydrogeological setting and geological history of the study area, the use of multivariate statistical analyses including the principal

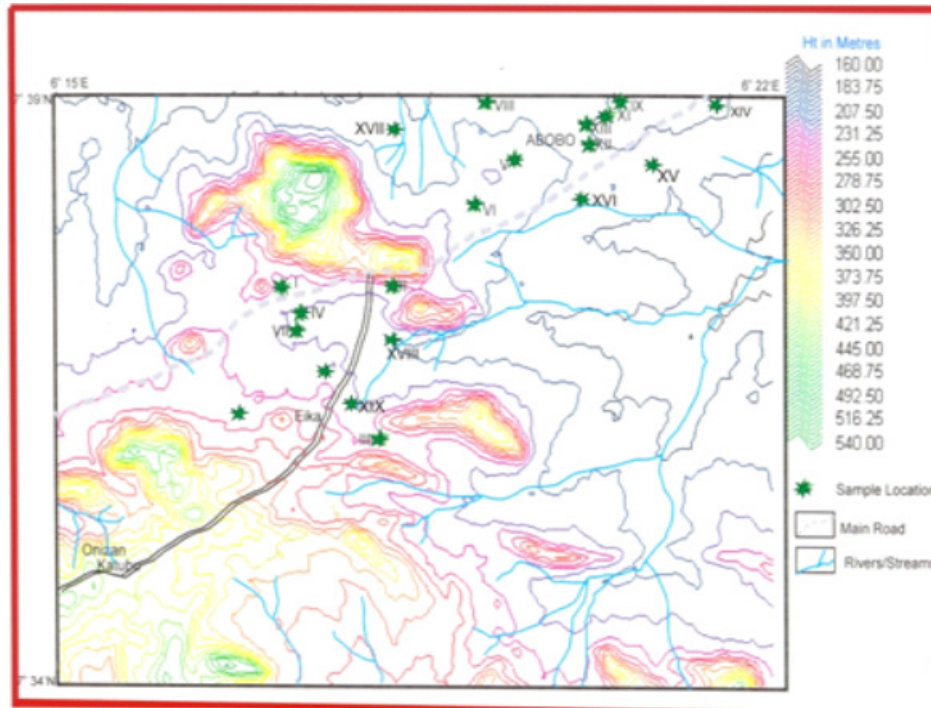


Figure 1. Topographic map of the study area showing access route and sample locations

component analysis (PCA), Hierarchical cluster analysis (HCA), correlation and regression analysis is aimed at distinguishing respective roles of geological and anthropogenic factors in the degradation of groundwater quality and processes responsible for the modification of groundwater chemistry. The multivariate statistical analyses such as PCA and 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 (Mohapatra et al., 2011). These techniques permit identification of the possible factors that influence the water systems and cause variations in water quality (Wu and Kuo, 2012). Multivariate statistical analysis is a useful tool to find the regularity among the complicated factors in an environment system so that complex phenomena can be simplified to excerpt important relevant information for analyzing and discriminating test result to propose effective, response management and policies (Wu and Kuo, 2012).

The objective of this paper is to discuss the water quality status of groundwater in Itakpe area and to identify the processes responsible for the modification of the groundwater chemistry from the view point of multivariate statistical analysis.

DESCRIPTION OF THE STUDY AREA

The study area is Itakpe; it is located between latitudes 7°35'N to 7°39'N and longitudes 6°15'E to 6°30'E. The

area is covered by sheet 246 (Kabba) on a scale of 1:100,000. The area is characterized by distinct dry and rainy season period, the rainy season commences from late April to October while the dry season is from November to March. The average daily temperature is about 28°C in the morning hours and 37°C during mid day to about 4:00 pm. The area is characterized by numerous streams which are seasonal in nature. The area is characterized by gentle to highly undulating topography with elevations ranging from 160 m to 540 m above mean sea level (Figure 1).

The area is underlain by the Precambrian basement complex rocks which consist mainly of gneisses, migmatites and quartzites as reported by Ajibade et al in Kogbe (1980), Akinrisola and Adekeye (1993), Nigerian Steel Development Authority (1976) and Olade et al., (1978). Figure 2 indicates that the area is underlain by older granites and charnokites, Hornblende-Biotite granite, Ferruginous Quartzites and Melanocratic Banded gneiss. The older granites and charnokites underlie the extreme corner of the southwestern part of the study area while the ferruginous quartzite underlies the southern portion of the area. The hornblende-biotite granite underlies the eastern corner. The dominant rock type in the area is formed by the melanocratic banded gneiss and this underlies most parts of the study area.

MATERIALS AND METHODS

A total of 17 groundwater samples were collected from

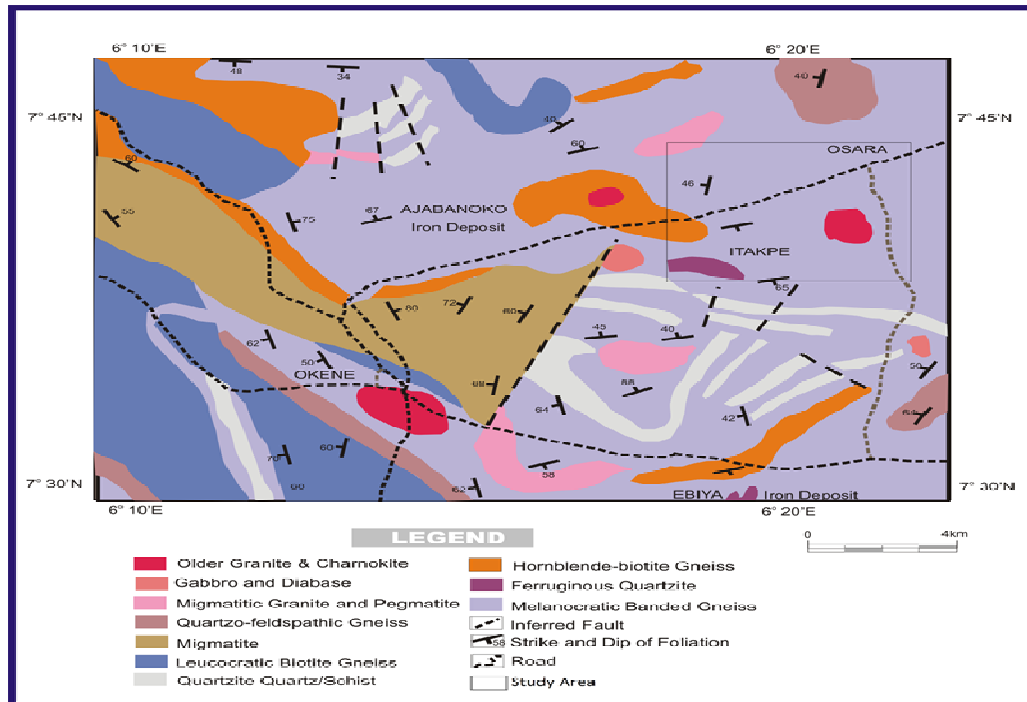


Figure 2. Geologic map of the study area (modified from Adegbuyi, 1981)

hand-dug wells and boreholes (Figure 1). The sample containers were rinsed twice with the samples to be collected according to Barcelona et al., (1985) method. Before the sample collection, field parameters such as pH, Temperature, EC and TDS were determined in the field using HANNA pH meter and TDS/conductivity meter (HACH KIT) (Model 44600). The samples for cations analysis were acidified with Trioxo nitrate (v) acid to prevent the cations from adhering to the wall of the container. The positions of the sampling points were determined in the field using the Global Positioning System (GPS). All the samples were analyzed chemically within 48 hours of collection using Induced Coupled Plasma (ICP) Optical Emission Spectrometer, mercury (II) nitrate, turbidity and calorimetric methods. The results obtained were analyzed statistically and displayed as minimum, maximum, mean and standard deviation. The results were further subjected to multivariate statistical analysis such as principal component analysis and Hierarchical cluster analysis. All the statistical analyses were performed using SPSS version 15.0

Multivariate Statistical Analysis

Principal Component Analysis (PCA)

The principal component analysis (PCA) is a multivariate statistical technique employed for the purpose of data reduction with a view to determining the sources of elements and their controlling factors (Ishaku et al.,

2012). PCA is defined as an orthogonal linear transformation that transforms the 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 (Subyani and Al Ahmadi, 2010). The aim of PCA is construction of new variables called principal components out of a set of existing original variables (Mohapatra et al., 2011). The total number of factors generated from a typical factor analysis indicates the total number of possible variation in the data. The first factor has the highest eigen vector sum and represents the most important source of variation in the data. The last factor is the least important process contributing to the chemical variation (Belkhiri et al., 2010). Factor loadings are interpreted as correlation coefficients between the variables, a high loading was defined as greater than 0.75, and moderate loading was defined as 0.40-0.75. Loadings of less than 0.40 were considered insignificant (Evans et al., 1996).

Hierarchical Cluster Analysis (HCA)

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 (Mary et al., 2011). It is a technique that identifies natural groupings among objects to decipher hidden structures present in the data set. In HCA, clusters are formed

Table 1. Statistical Summary of Ground water Chemistry data

	Minimum	Maximum	Mean	Std. Deviation
Temp	28.00	36.50	30.1294	2.33607
pH	6.03	9.30	6.4394	.76737
EC	1660.00	4220.00	2601.7647	892.51915
TDS	1079.00	2743.00	1690.9706	580.06224
TH	10.00	182.50	88.8664	57.94068
Sodium	1.54	38.64	13.2969	12.11414
Potassium	.85	49.74	10.4971	14.85115
Calcium	3.75	64.57	23.8879	15.65942
Magnesium	.04	16.70	8.2614	6.22956
Iron	.00	1.63	.3364	.55840
Manganese	.00	69.89	13.7113	24.17935
Chloride	37.09	70.34	46.6875	9.58890
Sulphate	.19	64.34	35.6888	21.00791
Bicarbonate	.03	6.21	2.3644	1.92423
Nitrate	.02	4.27	.4019	1.07074

Table 2. Rotated Component Matrix

	Component		
	1	2	3
Temp	.002	-.106	.956
pH	.110	.105	.914
EC	.841	-.340	.121
TDS	.841	-.340	.121
TH	.902	.122	.220
Sodium	.588	.278	.496
Potassium	.015	-.679	-.061
Calcium	.775	.146	-.017
Magnesium	.654	.452	.415
Iron	-.221	.766	-.160
Manganese	-.473	-.773	-.141
Chloride	.512	-.005	-.257
Sulphate	.251	.936	.055
Bicarbonate	.014	.717	.352
Nitrate	-.296	.551	-.167
Eigen value	4.30	3.91	2.52
% Variance explained	28.66	26.08	16.77
% Cumulative	28.66	54.74	71.51

sequentially, starting with the most similar pair of variables and forming higher clusters step by step (Mohapatra et al., 2011). A low distance shows the two objects are similar or close together whereas a large distance indicates dissimilarity (Avdullahi et al., 2013). Hydrochemical data with similar properties are clustered in a group (Lu et al., 2011). The results of the analysis are presented in form 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 (Wu and Kuo, 2012). In this study, cluster analysis was performed using Ward's method with squared Euclidean distances as a measure of similarity for linkage (Jiang-Qi et al., 2013).

Correlation and Multiple linear regressions analyses

Pearson correlation is commonly used to measure and

establish the strength of a linear relationship between two variables or two sets of data (Bajpayee et al., 2012). The author further stated that correlation coefficient is always between -1 and +1, and strong negative correlation range between $r = -1$ to -0.7 ; strong positive correlation between $r = +0.7$ to $+1.0$; $r = -0.7$ to -0.3 as weak negative correlation; $r = +0.3$ to 0.7 as weak positive correlation, and $r = -0.3$ to $+0.3$ as negligible or no correlation.

Regression analysis is a practical model that predicts for dependent variable whenever there is change in independent variable (Ishaku and Abdulkakeem, 2010). The authors went further to show the equation representing multiple linear regressions as;

$$\hat{Y} = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \dots \quad (1)$$

Where: a = constant, b = slope or rate of change of the independent variable x .

Table 3: Correlations Coefficient of some Groundwater Chemistry data

	Temp	pH	EC	TDS	TH	Sodium	Potassium	Calcium	Magnesium	Iron	Manganese	Chloride	Sulphate	Bicarbonate	Nitrate
Temp	1														
pH	.594	1													
EC	-.075	.261	1												
TDS	-.075	.261	1.000	1											
TH	.212	.325	.677	.677	1										
Sodium	.426	.527	.465	.465	.521	1									
Potassium	.012	-.203	.396	.396	-.182	-.284	1								
Calcium	.023	.179	.531	.531	.886	.236	-.247	1							
Magnesium	.297	.442	.534	.534	.644	.812	-.167	.350	1						
Iron	-.303	.022	-.314	-.315	-.198	.052	-.377	-.130	.213	1					
Manganese	.060	-.239	-.117	-.117	-.598	-.494	.507	-.517	-.680	-.294	1				
Chloride	-.163	-.158	.262	.262	.270	.473	-.092	.200	.210	-.148	-.260	1			
Sulphate	-.139	.184	-.029	-.029	.378	.349	-.541	.352	.592	.644	-.910	.068	1		
Bicarbonate	.099	.267	-.067	-.067	.177	.286	-.298	.045	.509	.417	-.636	-.189	.717	1	
Nitrate	-.135	-.058	-.263	-.264	-.387	-.033	-.177	-.179	.092	.655	-.054	-.175	.239	.210	1

Table 4. Analysis of Variance

Source	Degree of freedom	Sum of squares	Mean square	F value	p- value
Model	5	4564545.630	912909.126	12127757.581	0.00
Error	8	0.602	0.075		
Corrected total	13	4564546.232			

Table 5. Parameter estimation

Parameters	Estimate	Std Error	t-value	p-value
Intercept	-0.624	0.447	-1.396	0.200
Calcium	-0.004	0.006	-0.718	0.493
Sodium	-0.019	0.013	-1.451	0.185
Chloride	0.014	0.009	1.477	0.178
Magnesium	0.026	0.024	1.080	0.312
EC	0.650	0.00	5882.217	0.000

RESULTS AND DISCUSSION

The statistics of the physical and chemical parameters of groundwater samples are presented in Table 1. The groundwater samples reveal pH values ranging from 6.0 to 9.3 which indicate that the groundwater condition is acidic to alkaline in nature. TDS and EC range from 1079

mg/l to 2743 mg/l and 1660 $\mu\text{S}/\text{cm}$ to 4220 $\mu\text{S}/\text{cm}$ with mean values of 1691 mg/l and 2601.8 $\mu\text{S}/\text{cm}$, respectively. Total hardness ranges from 10 mg/l to 182.5 mg/l with mean of 88.9 mg/l. The cations reveal ranges and mean values as Na^+ (1.5-38.6 mg/l) 13.3 mg/l; K^+ (0.9-49.7 mg/l) 10.5 mg/l; Mg^{2+} (0.04-16.7 mg/l) 8.3 mg/l; Ca^{2+} (3.8-64.6 mg/l) 23.9 mg/l; Mn^{2+} (0.0-69.9 mg/l) 13.7 mg/l and Fe^{2+}

(0.0-1.6 mg/l) 0.3 mg/l. The anions indicate the ranges and mean values as: SO_4^{2-} (0.2-64.3 mg/l) 35.7 mg/l; Cl^- (37.1-70.3 mg/l) 46.7 mg/l; HCO_3^- (0.03-6.2 mg/l) 2.4 mg/l and NO_3^- (0.02-4.3 mg/l) 0.4 mg/l. Based on their mean values, the cations are in the order of abundance as $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Mn}^{2+} > \text{Fe}^{2+}$ and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$ for the anions.

Dendrogram using Ward Method

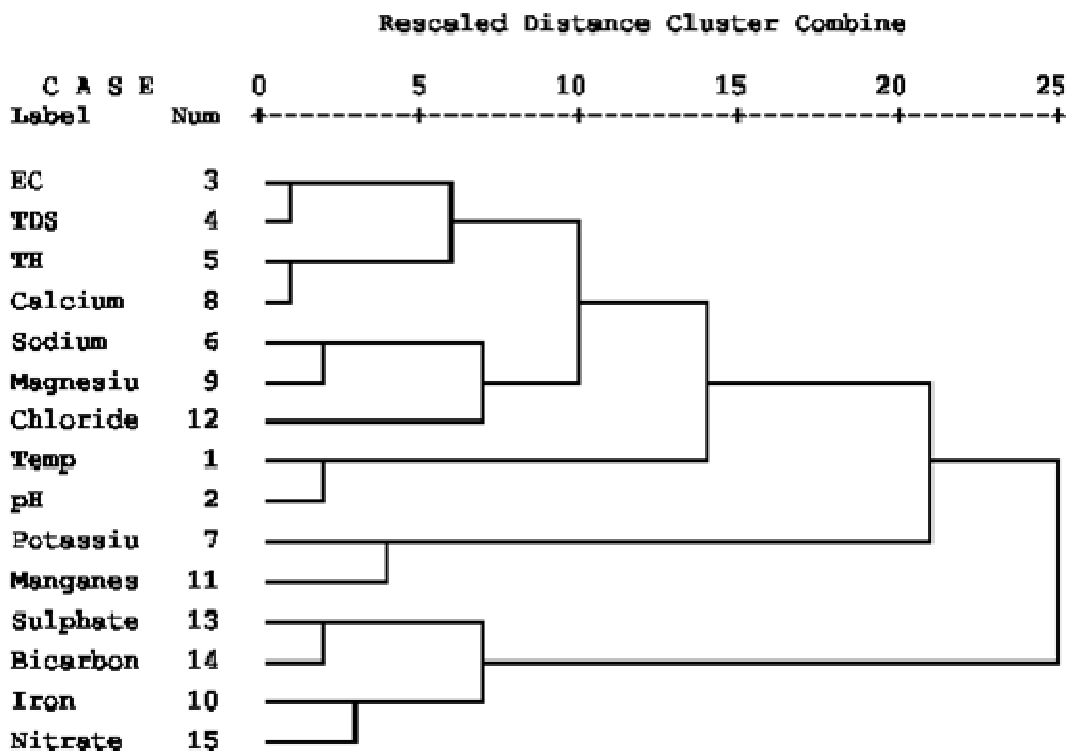


Figure 3. Dendrogram of Cluster Analysis of Groundwater Chemistry in the study area

The principal component analysis on chemical data indicates three factors which explain about 71.51% of the total variance (Table 2). The first factor accounts for about 28.66% of the total variance and is characterized by high positive loadings with respect to EC, TDS, TH and Ca while Mg and Cl have moderate loadings. Factor 1 indicates that EC and TDS are dominantly influenced by Ca followed by Mg and Cl. Also the hardness of the groundwater is influenced by Ca and Mg as revealed by high positive loading with respect to Ca and moderate loading for Mg. Factor 1 is interpreted as reverse cation exchange indicated by Ca-Cl facies. The water is characterized by intermediate composition which evolved between Ca-Mg-HCO₃ recharged water and Na-SO₄-Cl water type (Ishaku, 2011). At high salinities, the process of reverse cation exchange may create Ca-Mg-SO₄-Cl water due to the removal of Na out of solution for bound Ca (Adams et al., 2001). Factor 2 accounts for about 26.08% of the total variance and has high positive loadings for SO₄, Fe and HCO₃, and moderate loadings for Mg and NO₃. Factor 2 is ascribed to anthropogenic pollution. Factor 3 accounts for about 16.77% and is characterized by high positive loadings for temperature and pH, and moderate loading with respect to Na. Factor 3 is therefore interpreted as mineral dissolution. The different factors revealed by PCA can be summarized as follows: Factor 1 (EC, TDS, TH, Ca²⁺, Mg²⁺ and Cl⁻) Factor

2 (SO₄²⁻, Fe²⁺, HCO₃⁻, Mg²⁺ and NO₃⁻) Factor 3 (Temperature, pH and Na⁺).

The results of cluster analysis are presented as Dendrogram (Figure 3) and reveal two clusters. Cluster 1 comprises of EC, TDS, TH, Ca²⁺, Na⁺, Mg²⁺ and included Cl⁻, temp and pH in the same cluster. Cluster 1 is interpreted as rock-water interaction or natural mineralization. Cluster 2 shows close similarities between K⁺, Mn²⁺, SO₄²⁻, HCO₃⁻, Fe²⁺ and NO₃⁻. The cluster is interpreted as anthropogenic pollution. Table 3 shows correlation matrices for the 15 physico-chemical parameters, and indicate that high positive correlation exists between EC, TDS, TH, Ca, Mg and Na (r= 0.81 to 1.0). Strong to perfect correlation is an indication of common source. Regression analysis was considered in this study to derive the relationship between TDS and other chemical parameters. Based on the results of principal component analysis, hierarchical cluster analysis and Pearson correlation, TDS was found to be in close association with EC, Ca, Na, Mg and Cl. Therefore, the use of multiple linear regression model will be useful in predicting TDS based on the independent variables (EC, Ca, Na, Mg and Cl). The results of the model are presented in Tables 4 and 5. Based on the results presented in Table 5, the final model is formulated as follows:

$$TDS = -0.624 - 0.004Ca^{2+} - 0.019Na^{+} + 0.014Cl^{-} + 0.026Mg^{2+} + 0.650EC.$$

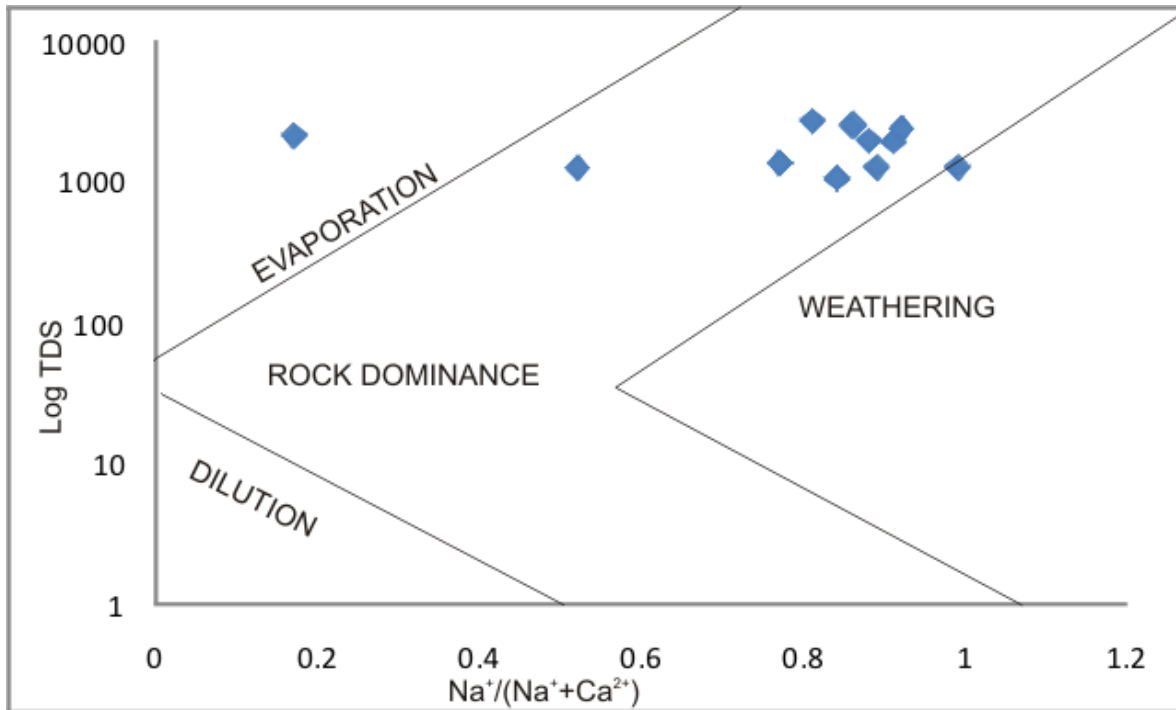


Figure 4. Rock-water interaction diagram for the study area

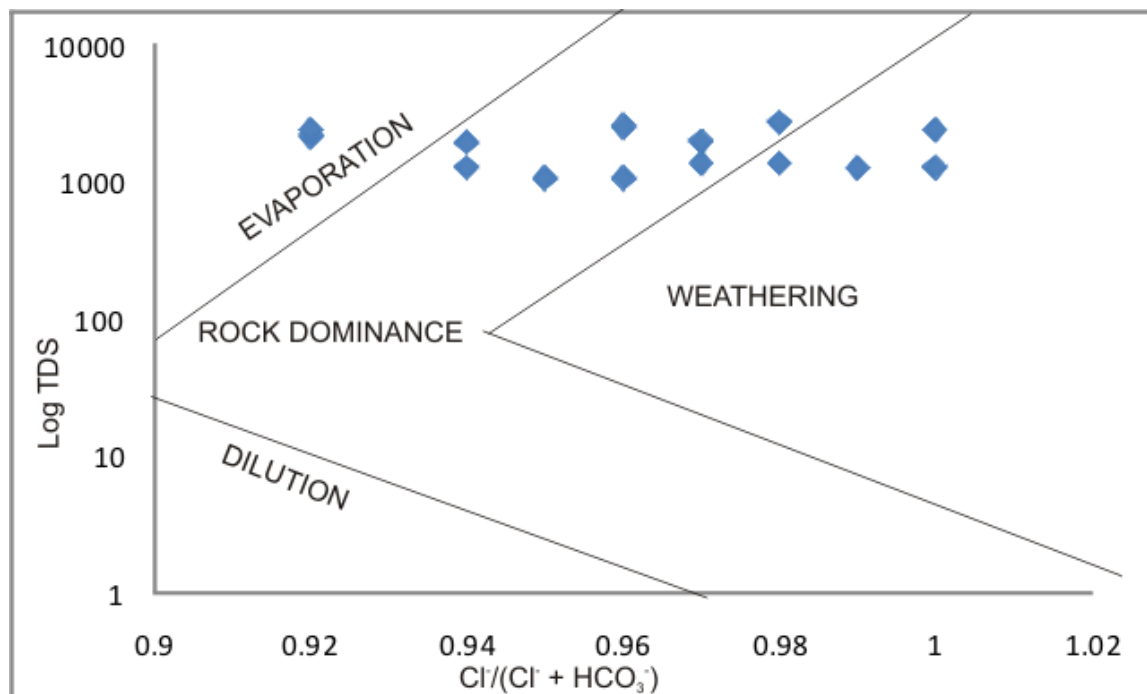


Figure 5. Rock-water interaction diagram for the study area

The R square between TDS, Ca^{2+} , Na^+ , Cl^- , Mg^{2+} and EC of 1.00 indicates a perfect relationship, and therefore suggests a common origin.

Rock-Water interaction

Rock-water interaction reflects the differences in

mineralogical composition of the aquifer, existence of fissures, faults and cracks which affect groundwater movement in the subsurface medium (Kumar et al., 2011). The use of scattered plots for TDS vs. $Na^+/(Na^+ + Ca^{2+})$ and TDS vs. $Cl^-/(Cl^- + HCO_3^-)$ (Gibbs, 1970) can be used to identify rock-water interaction processes (Nur et al., 2012). Figure 4 indicates that most points plotted in

the region of rock dominance, thus indicating samples derived from rock-water interaction. Figure 5 also indicates that most points plotted in the region of rock dominance, and few points plotted in the region of weathering. The rock-water interaction diagrams suggest precipitation induced chemical weathering along with dissolution of rock forming minerals is responsible for the modification of groundwater chemistry.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. Analytical results of 17 groundwater samples reveal that the cations based on their mean values are in the order of abundance as $\text{Ca}^{2+} > \text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Mn}^{2+} > \text{Fe}^{2+}$ and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^-$ for the anions.
2. The principal component analysis indicates factors 1, 2 and 3 which account for 71.51% of the total variance. Factor 1 accounts for 28.66% of the total variance and is interpreted as reverse cation exchange indicated by Ca-Cl facies. Factor 2 accounts for 26.08% of the total variance and is ascribed to anthropogenic pollution while factor 3 accounts for 16.77% of the total variance and is interpreted as mineral dissolution.
3. Cluster analysis identified two clusters. Cluster 1 is interpreted as rock-water interaction or natural mineralization and cluster 2 is interpreted as anthropogenic pollution.
4. A predictor model developed with five dominant chemical parameters of groundwater to perceive an estimation of TDS has been developed for the study area.
5. The R square between TDS, Ca^{2+} , Na^+ , Cl^- , Mg^{2+} and EC of 1.00 indicates a perfect relationship, and therefore suggests a common source.
6. Rock-water interaction diagrams suggest precipitation induced chemical weathering along with the dissolution of rock forming minerals is responsible for the modification of groundwater chemistry.
7. It is recommended that regular groundwater quality will ensure the well-being of the ever-increasing population of the area.

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