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Interpretation of Groundwater Quality for Drinking Purpose in Nsuta Anomakokrom Using a Multivariate Statistical Technique, Western Ghana

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Abstract:- The study was to interpret the groundwater quality for drinking purpose in Nsuta Anomakokrom, Western Ghana. Water samples from 10 hand dug wells were collected and analyzed using factor analysis, cluster analysis and regression. Results obtained from factor analysis revealed that groundwater in the study area was controlled by carbonate mineral dissociation and silicate mineral weathering. Two clusters were developed, cluster (A) have higher electrical conductivity, total hardness, slightly acidic and appreciable amount of nitrate. The nitrate concentrations could be attributed to leachate from fertilizer application by farming activities within the study area. Cluster (B) have electrical conductivity (EC), total hardness (TH) within the permissible limit of the World Health Organization guideline for drinking water. The R^2 value of 0.7992 obtained for HCO_3 against Ca^{+2} suggest a strong relationship between bicarbonate and calcium. This could be explained that as the carbonate minerals undergoes a dissociation, much calcium ions are released into the groundwater. The R^2 value of 0.7689 obtained for HCO_3 against pH suggest an effects of the carbonate mineral dissociation on the pH of the groundwater of the study area. Based on the studies the groundwater quality of the study area has been affected by the geological formation (Thus the carbonate minerals dissociation and silicate mineral weathering process has affected the pH, Electrical conductivity and the Total hardness of the groundwater). Although the groundwater is safe for drinking, but limited to some hand dug wells within the study area.

Keywords:- *Groundwater, Quality, Nsuta Anomakokrom, Multivariate Statistical Technique*.

I. INTRODUCTION

Groundwater resources is of a major concern in water quality assessment, since it is a vital resources that contribute much to both domestic and industrial usage. In Ghana, majority of the rural population depend on groundwater which forms about 74% of the rural population by (Ghana Statistical Services, 2000). The availability of water resources in quantity and quality is a prerequisite in dealing with the sustainability of the resource. Over the past decades, a growth in population has yielded much stress on all other resources including surface and groundwater. Nevertheless, the quality of water has imposed much challenges worldwide on livelihood. This treat has kept various governmental organizations, stakeholders and researchers to rest not. In dealing with water quality assessment, many researchers have proposed theories and models to reveal any hidden danger related to surface and groundwater quality for drinking purposes. In Ghana, the sustainability of quality water is a major priority to both government, researchers and other stakeholders. In an attempt to characterized surface and groundwater quality, different methods have been employed by researchers to catalogue the hydrochemistry of both surface and groundwater resources. In 1944, Piper used diagram as a means of predicting water quality based on ionic anomalies. Despite all attempt made in revealing the best outcome of water quality based on various models and theories, there is always a flaw to catalogue the real hydrochemistry of water. In view of this, an attention has been drawn to most recent technique known as the cluster and factor analysis, which has played a significant role in assessing the quality of groundwater by various researchers. Ashley and Lloyd [14] used factor and cluster analysis to interpret the groundwater chemistry in Birmingham, Great Britain within the Santiago Basin and the Derbyshire Dome. Their studies recommended cluster and factor analysis as an important tool that could be used to figure out basic hydrochemistry features or patterns. The factor analysis was seen as a tool that could help reduced a large data sets into smaller form, unlike the traditional methods which works perfectly for some datasets and the type of data they could handle. Therefore, factor and cluster analysis were suggested as an effective technique in interpreting groundwater chemistry. Belkhiri et al. [15] investigated the groundwater hydrochemistry data obtained from the Ain Azel aquifer, Algeria using the multivariate techniques (Hierarchical Cluster Analysis and Principal Component Analysis). Their studies which aimed at extracting the control factors that were contributing to the hydrochemistry of the aquifer within the area under investigation were revealed. They concluded that based on their results obtained, the use of multivariate technique using both Cluster and Principal Component Analysis is an effect tool in interpreting groundwater hydrochemistry. Similar studies have been replicated in Ghana by

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Yidana et al. [1] they employed the use of factor analysis and regression models in identifying the key processes in the hydrochemistry of two Basins, mainly the Tarkwaian and the Birimian located at the Western part of Ghana. In their milestone of studies, they reported; that factor analysis made it possible to reveal the impact of a particular process within the study area which was affecting the water chemistry within the Basins studied. In Ghana, few or less has been done on assessing the groundwater quality using the most recent technique such as factor and cluster analysis, although other techniques have been employed by various researchers. Therefore, this studies seeks to assess the groundwater quality for drinking purpose in Nsuta Anomakokrom, Western, Ghana using a multivariate technique such as factor analysis, cluster analysis and regression model to ascertain the control parameters of the groundwater within the study area.

II. THE STUDY AREA

The study Area is called Anomakokrom, a suburb within Nsuta the in the Western Region of Ghana. It lies between 05° 17’ 9.0’’N and 001° 58’ 55.0’’W. Nsuta is well-known town in Ghana due to the exploitation of manganese. It is one of the major manganese deposits and is located in the south-west Ghana.

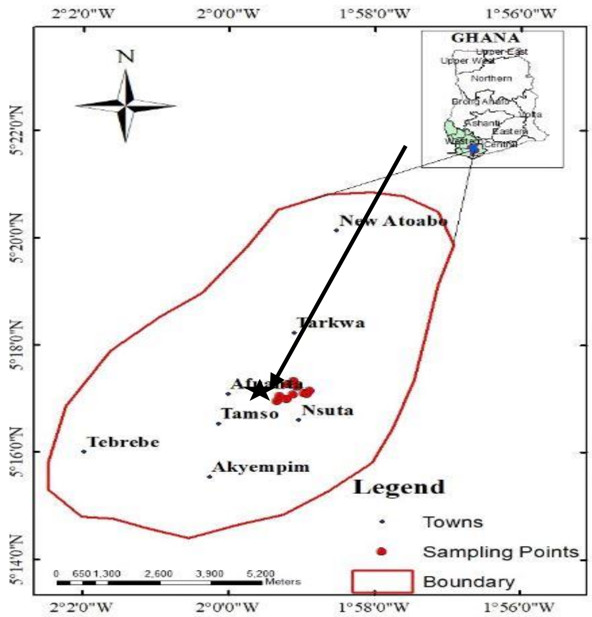

Fig 1:- Location of Study Area

III. GEOLOGY OF THE STUDY AREA

The rock deposits in the area occurs within the Birimian Series, which consist of isoclinally folded metamorphosed sedimentary rocks intercalated with metamorphosed tuff and lava (Dapaah-Siakwan and Gyau-Boakye, [6]). The Birimian Supergroup is divided into the lower and the upper Birimian. The sediments are predominant in the lower part of the Supergroup. These sediments have been metamorphosed to schist, slate phyllite and also there are some tuff and lava. The upper part of the System is dominantly of volcanic and pyroclastic origin (Kesse, [3]). The rocks consist of bedded groups of green lava. Lava and tuffs are dominant. Several bands of phyllite occur in this zone and are magniferous. The project site is underlain by rocks of complex folded upper Birimian. The Birimian Supergroup is separated by basins containing pyroclastic and meta-sedimentary units. The unweathered Greenstones include metamorphosed lavas and pyroclastic, predominantly in the andesitic-basaltic range.

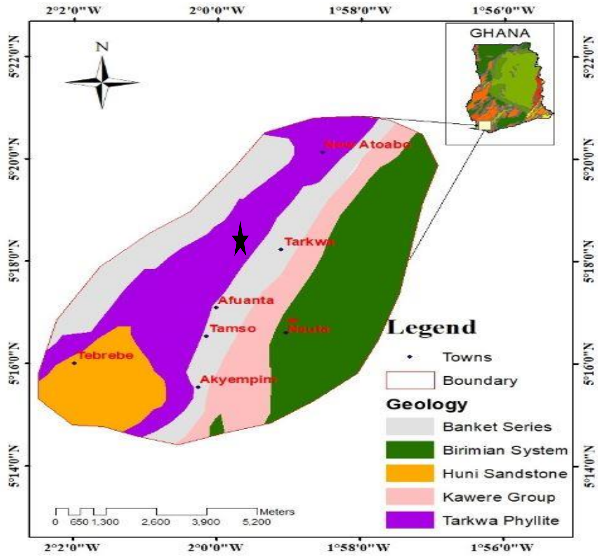

Fig 2:- Geological Map of the Study Area

IV. METHODOLOGY

The groundwater sampling was done in accordance with the sampling protocol. A total of 10 hand dug wells groundwater samples were collected for the analysis of the hydro-chemical parameters. The samples were collected using 5 Acid washed polyprolene containers after about 15 minute pumping. This was done to remove stored groundwater in the well. The samples were filtered immediately on site and filtrate for major ions were transferred into 100 mL polyethylene bottle and acidified to pH<2. Site parameters such as the electrical conductivity (EC), temperature and pH were recorded using the WTW multi-line P4 universal meter. The bottles were preserved in an ice chests and transported within 24 hours for laboratory analysis. The concentrations of major ions such as (Na^+, Ca^+, Mg^+, K^+, HCO_3^- Cl^- SO_4^{-2} and NO_3^- were determined using double column Dionex DX- 120 ion chromatography. To ensure consistency in the concentrations of the major ions, the results obtained were subjected to the charge balance error equation (Appelo and Postma, [4]).

$$\frac{\sum cations - \sum anions}{\sum cations + \sum anions} \times 100\% \qquad (1)$$

The 10 samples collected were consistent since the concentrations of the major cations and anions were within ±5% of each other.

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➢ *Normality Test*

The datasets were subjected to normality test, to verify the nature of the distribution curve using SPSS. From the analysis, most of the parameters were highly deviated according to the distribution curve. Hence, the datasets were log-transformed to normal distribution and were also standardized to their corresponding z-scores.

V. TEST PROCEDURES AND RESULTS

The datasets were subjected to the following test procedures factor analysis, cluster analysis and regression using the SPSS 16.0, Minitab 16 and Excel 2013.

A. Factor Analysis

Factor analysis is a multivariate statistical technique that can be used to examine the underlying relations for a large number of variables. Principal component analysis (PCA) is the most frequently used technique in analysing large data set. Principal component analysis is defined as an orthogonal linear transformation that transforms the variables to a new coordinates such that the greatest variance by any forecast of the variable comes to lie on the first coordinate (known as the first principal component), the second greatest variance on the second coordinate and continues. To determine the number of components to extract, the data sets obtained were used as variable inputs. The datasets were subjected to factor analysis using principal components as the extraction method and Kaiser [5] normalization. The varimax rotation was employed to optimize the differences of factors resulting from the factor analysis (Yidana et al. [1]). The Kaiser criterion applied on the datasets help in the data reduction. It reduces the number of factors in the model based on their eigenvalues which is less or equal to 1. Parameters that were significant to the studies were extracted from the factors loadings. Table (1) shows a summary of results obtained from the factor analysis.

Parameters	**Component Loading**		
	Factor 1	Factor 2	Factor 3
pH	**0.724**	-0.535	0.124
Temp	0.590	-0.037	-0.554
TDS	**0.891**	0.103	-0.383
EC	**0.891**	0.103	-0.382
TH	**0.866**	0.127	0.417
Calcium	**0.844**	-0.460	-0.048
Magnesium	0.585	0.540	0.573
Potassium	**0.800**	-0.120	0.339
Sodium	**0.705**	-0.172	0.462
Bicarbonate	**0.865**	-0.339	0.062
Chloride	0.415	**0.873**	0.201
Nitrate	0.418	0.814	-0.268

Table 1:- Factor Loadings from Factor Analysis

➢ *Extraction Method: Principal Component Analysis*

Component	Initial Eigenvalues			Extraction Sums of Squarred Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.289	52.061	52.061	7.289	52.061	52.061
2	2.593	18.523	70.584	2.593	18.523	70.584
3	1.76	12.571	83.156	1.76	12.571	83.156
4	1.336	9.54	92.695			
5	0.784	5.598	98.293			
6	0.152	1.089	99.382			
7	0.056	0.401	99.783			
8	0.026	0.185	99.968			
9	0.005	0.032	100.000			

Table 2:- Variances Explained by the Various Factors

Parameters	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
pH	5.6	6.73	6.24	0.32
Temp	22.2	23.7	22.85	0.51
EC(µS/cm)	84	694	235.1	190.13
TDS(mg/L)	46	382	129.4	104.67
TH	29	136	67.6	35.50
Calcium(mg/L)	6.4	28	15.28	7.18
Magnesium(mg/L)	1.94	28	7.61	7.69
Potassium(mg/L)	7.5	17.5	10.44	3.07
Sodium(mg/L)	4.5	87.5	48.15	21.56
Nitrate(mg/L)	0.01	7.1	2.44	2.76
Bicarbonate(mg/L)	10	130	59.6	38.36
Chloride(mg/L)	11	59	21.4	14.39

Table 3:- Statistical Summary of the Groundwater parameters from the Study Area

B. Cluster Analysis

Cluster analysis is a group of multivariate techniques used to group objects based on similarities or characteristics they possess. With programmed selection criterion, the cluster analysis classifies objects so that each object is similar to the others in the clusters. These clusters of objects should display high internal (within-clusters) homogeneity and high external (between-clusters) heterogeneity. In this study the Hierarchical agglomerative clustering approach was performed on the normalized data sets by means of Ward's method using squared Euclidean distances as a measure of similarity, which is the most common approach that provides intuitive similarity relationships between any one sample and the data sets (Shrestha and Kazama, [10]). The Ward's method uses an analysis of variance approach to estimate the distances between clusters in effort to minimize the sum of squares of any two clusters that could be formed at each step. This is usually represented by Dendrogram (tree diagram) [Shrestha and Kazama, [10]; Kim et al., [7]; Otto et al, [8]). The Dendrogram gives a visual display of summary of the clustering process, presenting an image of the groups and their proximity, with a reduction in dimension of the original data. The Euclidean distance depicts the similarity between two samples and a distance could be represented by the difference and analytical values from the samples (Otto et al. [8]). The chemical variation of the data set was examined according to the groups, using box plots (also known as box-and-whisker plots). The individual variables were plotted. The whiskers are the lines that extend from the bottom and top of the box to the lowest and the highest observations. The asterisks are known as (outliers). A summary of the results are presented below in fig (3, 4).

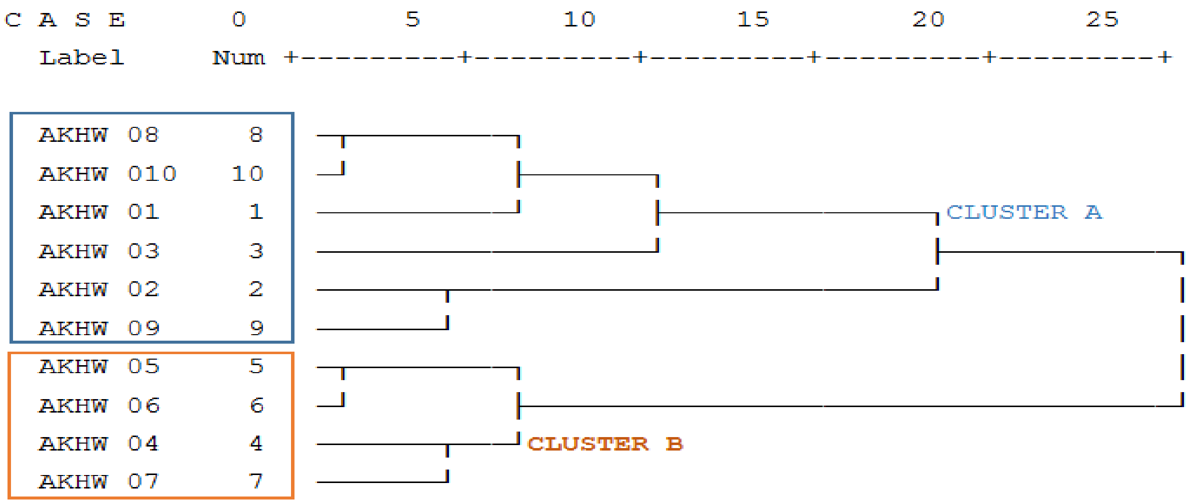

Fig 3:- Dendrogram for Groundwater grouping in the Study Area based on Similarities

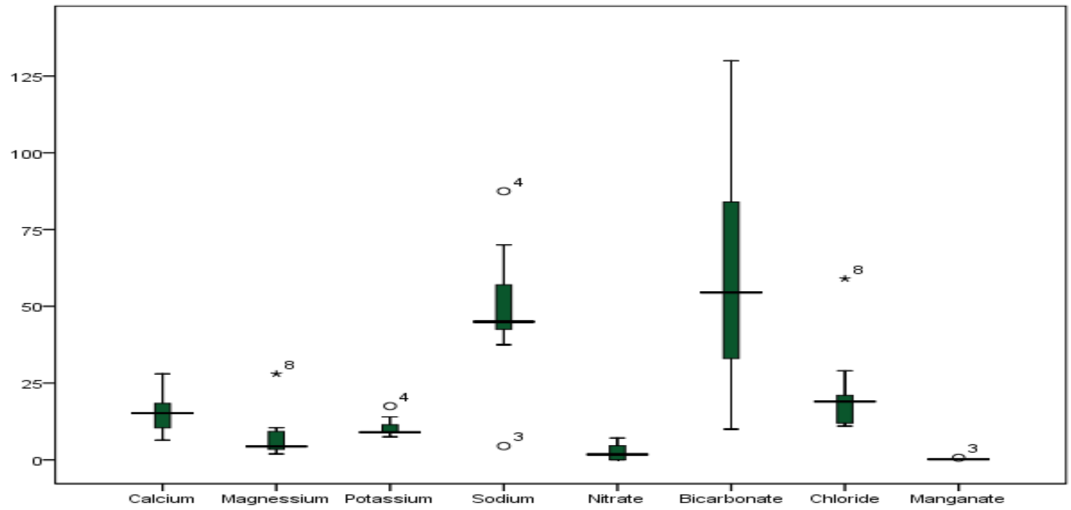

Fig 4:- Box-plots (Box and Whisker) of the major ions of the Study Area

A correlation matrix was plotted to validate the relationships between the hydro-chemical parameters within the study area.

	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO^-_3	Cl^{--}	$MnO^2{}_4^-$	pH	Temp	TDS	Cond.	Salinity	TH
Ca^{2+}	1.000												
Mg^{2+}	0.234	1.000											
K^+	0.632	0.544	1.000										
Na^+	0.592	0.502	**0.810**	1.000									
HCO^-_3	**0.894**	0.390	**0.817**	0.558	1.000								
Cl^-	-0.096	**0.820**	0.314	0.273	0.051	1.000							
MnO^{2-}	-0.282	0.175	-0.226	-0.665	-0.041	0.209	1.000						
pH	**0.874**	0.271	0.607	0.481	**0.877**	-0.152	-0.070	1.000					
Temp	0.430	-0.029	0.540	0.241	0.572	0.120	-0.083	0.292	1.000				
TDS	**0.745**	0.366	0.481	0.435	0.660	0.389	-0.132	0.565	0.615	1.000			
COND	**0.745**	0.366	0.481	0.436	0.659	0.389	-0.133	0.565	0.615	1.000	1.000		
TH	**0.708**	**0.850**	**0.735**	0.686	**0.762**	0.525	-0.023	0.674	0.186	0.642	0.642	0.596	1

Table 4:- Correlation Matrix of Groundwater Parameters within the Study Area

C. Regression

Regression analysis was examined between some key parameters to forecast their impact on other independent parameters. The coefficient of determination (R^2) obtained were used to predict the effects of one dependent parameter on the other independent parameter. The summary of the results are presented in fig (5, 6, 7 and 8).

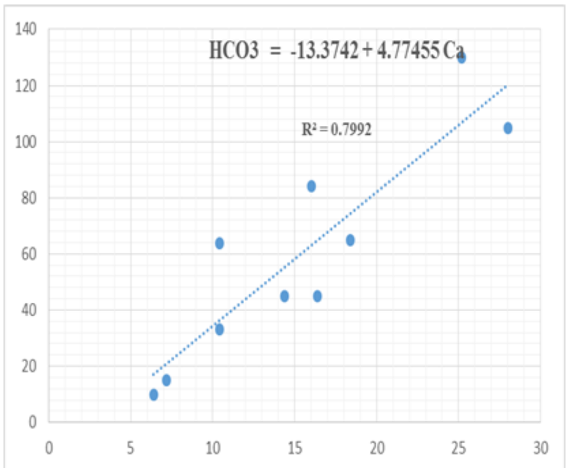

Fig 5:- A Plot of HCO_3^- against Ca^{+2}

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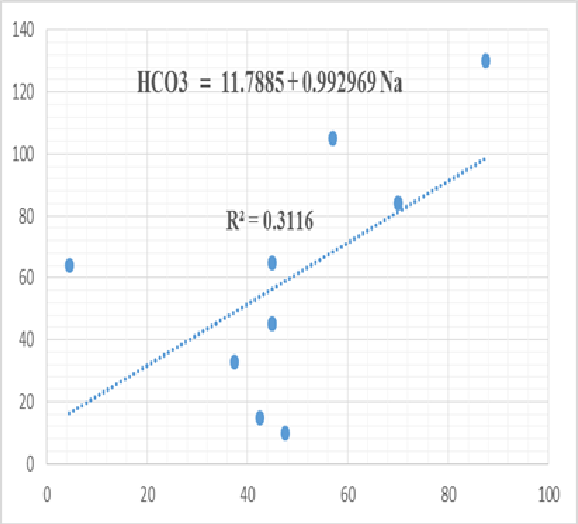

Fig 6:- A Plot of HCO_3^- against Na^+

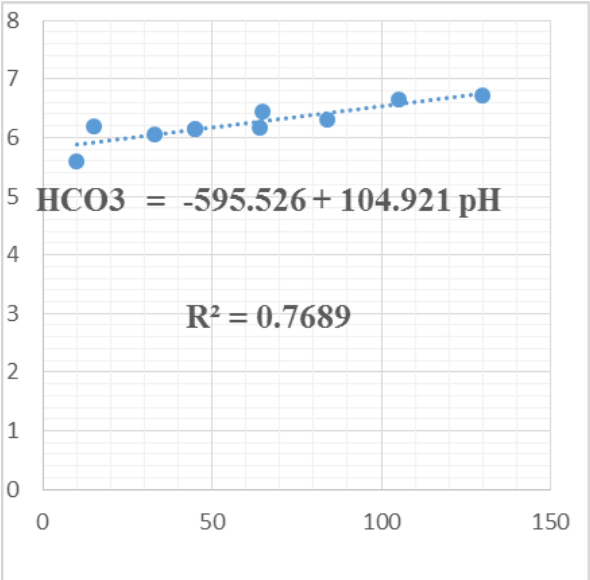

Fig 7:- A Plot of HCO_3^- against pH

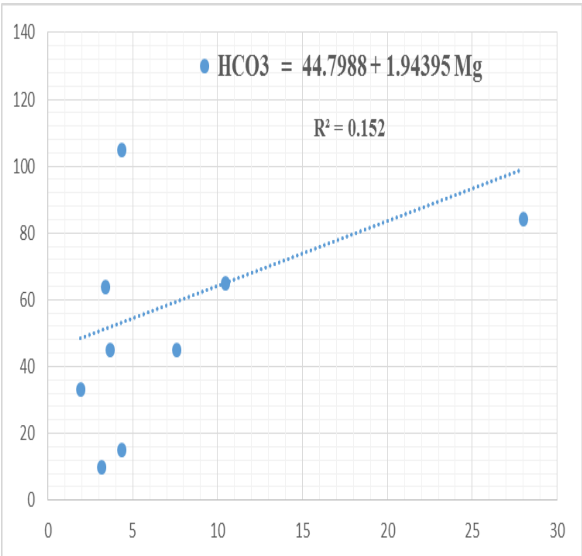

Fig 8:- A Plot of HCO_3^- against Mg^{+2}

VI. DISCUSSIONS

A. Factor 1 from the factor loadings accounts for 52.061% of the total variance. Liu et al.[2] applied the term 'strong', 'moderate' and 'weak' to a range of factors loadings values of > 0.75, 0.75 – 0.50 and 0.50 – 0.30 respectively. From the table (1a), the following parameters are highly loaded; pH, TDS, EC, TH, K^+, Na^+, Ca^{+2} and HCO^-_3. The pH of the groundwater in the study area is affected by carbonate mineral weathering processes. The dissociation of dominant carbonate minerals present in the rock formation (lithology) has released mobile Ca^{+2} which could contribute to total hardness (TDS) and electrical conductivity (EC) by natural movement of the groundwater in the study area. Other types of silicate minerals such as feldspars present in the study area may have released Na^+ and K^+ by hydrolysis.

B. Factor 2 accounts for 18.523% of the total variance with a high positive loadings on chloride (Cl^-). The underlain geology according to (Kesse, [3]; Junner et al.[11]); reported that Rocks of the upper Birimian consist of greenstones, tuffs and sediments with minor bands of phyllite bearing manganese ore. As the project site is within the upper Birimian, the phyllite might have contain appreciable concentrations of chlorides as major ions that could affect the groundwater in the study area.

C. From the correlation matrix, four (4) strong correlated groups were established. Group A consisted of (Ca^{+2} & HCO_3; Ca^{+2} & pH; Ca^{+2} & TDS; EC & Ca^{+2} ; TH & Ca^{+2}), Group B (Mg^{+2} & TH; Mg^{+2} & Cl^-), Group C (K^+ & TH) and Group D (HCO^-_3 & pH; HCO_3 & TH). From the correlation matrix, group A and B suggest a dissociation of silicate minerals by weathering process within the study area which affirms the factor loadings of factor 1. The possible groundwater type could be (Ca^{+2} – HCO_3) which is characterized by carbonate mineral dissociation. Group C and D suggest the movement of the dissolved ions through natural process as the carbonate minerals undergoes a dissociation, which affects both total hardness and pH.

D. From the boxplots, the order of major ion patterns within the study area are HCO^-_3 > Cl^- >NO^-_3 and Na^+ >Ca^{2+} > k^+ >Mg^{2+} which tells that the bicarbonate are dominated in the study Area.

E. Cluster A and B suggest the similarities and non-similarities between the parameters analyzed. Wells within cluster A have higher electrical conductivity, total hardness, slightly acidic and appreciable amount of nitrate. The nitrate concentrations could be attributed to leachate from fertilizers by minor farming activities within the study area. Cluster B have electrical conductivity (EC), total hardness (TH) within the permissible limit of the World Health Organization (WHO, [12]) guideline for drinking water.

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F. The coefficient of determination ($R^{2)}$ values were established between some dependent and independent parameters such (HCO_3 against Ca^{+2}; HCO_3 against Na+; HCO_3 against pH and HCO3 against $_{Mg}{}^{+2}$). The R^2 value of 0.7992 obtained for HCO_3 against Ca^{+2} suggest a strong relationship between bicarbonate and calcium. This could be explained that as the carbonate minerals undergoes a dissociation, much calcium ions are released into the groundwater. An increase in the concentration of the bicarbonate would result in an increased in the Ca^{+2} concentration. The R^2 value of 0.7689 obtained for HCO_3 against pH suggest an effects of the carbonate mineral dissociation on the pH of the groundwater of the study area. R^2 of 0.3116 established for HCO_3 and Na^+ could be attributed to the presence of other silicate minerals within the study area, which might have also undergone a weathering process.

VII. CONCLUSIONS

The study involved different multivariate technique such as factor analysis, cluster analysis and regression model to assess the groundwater quality in Nsuta Anomakokrom, Ghana, West Africa. Results from the factor analysis and correlation matrix indicated that the groundwater in the study area is influenced by carbonate minerals dissociation and other silicate mineral weathering processes, which is a geogenic or natural process. The possible water type within the study Area could be (Ca^{+2} – HCO_3) which is characterized by carbonate mineral dissociation. The order of major ion pattern are HCO^-_3 > Cl^- >NO^-_3 and Na^+ >Ca^{2+} > k^+ >Mg^{2+} which tells that, bicarbonate are much hosted in the Rock formation within the study area. Two cluster groups were established (thus, cluster A and B). Parameters within cluster A have higher electrical conductivity, total hardness, slightly acidic and appreciable amount of nitrate. The nitrate concentrations could be attributed to leachate from fertilizers by minor farming activities within the study area. Cluster B have electrical conductivity (EC), total hardness (TH) within the permissible limit of the World Health Organization (WHO, [12]) guideline for drinking water. The R^2 value of 0.7992 obtained for HCO_3 against Ca^{+2} suggest a strong relationship between bicarbonate and calcium. This could be explained that as the carbonate minerals undergoes a dissociation, much calcium ions are released into the groundwater.

The R^2 value of 0.7689 obtained for HCO_3 against pH suggest an effects of the carbonate mineral dissociation on the pH of the groundwater of the study area. The results obtained from the study clearly shows that factor analysis, cluster analysis and regression is an effective tool that could be employed in interpreting groundwater quality.

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REFERENCES

[1]. Yidana, S.M., Banoeng-Yakubo, B. and Sakyi, P.A., 2012. Identifying key processes in the hydrochemistry of a basin through the combined use of factor and regression models. *Journal of earth system science*, *121*(2), pp.491-507.

[2]. Liu, C.W., Lin, K.H. and Kuo, Y.M. (2003), “Application of factor analysis in the Multivariate analysis”, *Environmental Earth Sci 59:1461-1473*, 7 April pp. 1-13.

[3]. Kesse G. O. (1985), *The mineral and rock resources of Ghana*;AA Balkema, Rotterdam, Boston.

[4]. Appelo C.A.J and Postma .D. (2005), *Geochemistry, Groundwater and Pollution*; 2nd edn, Balkerma, Netherlands.

[5]. Kaiser H. F. (1960), “The application of electronic computers to factor analysis”, *Educ. Psychol. Meas.* 20 pp. 141–151.

[6]. Dapaah-Siakwan, S. and Gyau-Boakye, P., 2000. Hydrogeologic framework and borehole yields in Ghana. *Hydrogeology Journal*, *8*(4), pp.405-416.

[7]. Kim, J.H., Yum, B.W., Kim, R.H., Koh, D.C., Cheong, T.J., Lee, J. and Chang, H.W.(2003) “Application of cluster analysis for hydrogeochemical factors of saline groundwater”,*Korea Institute of Geosciences*, December, 7(12), pp. 1-10.

[8]. Otto, M., Kellner, R., Mermet, J.M. and Widmer, H.M (1998), *Multivariate methods*.In *Analytical chemistry*. Wienheim Wiley-VCH

[9]. Piper, A.M. (1944) “A graphic procedure in the geochemical interpretation of water–analyses”, *Trans. Amer. Geophysical Union*25, 914–928.

[10]. Shrestha, S. and Kazama, F. (2006), “Assessment of surface water quality using multivariate *Statistical techniques”, Environmental modelling and software 22(200) 464-475*, 22 March, pp. 1-2.

[11]. Junner N. R, Hirst T and Service, H. (1942) Tarkwa Goldfield;*Memoir*, No. 6, *Gold Coast Geological Survey*.

[12]. Anon. (2011), World Health Organisation, Guidelines for drinking- water quality, Switzerland, WHO, Geneva. Accessed 14, March, 2019.

[13]. Ghana Statistical Services (2000) Population and housing census, Provisional results.

[14]. Ashley, R.P., Lloyd, J.W. (1978) “An example of the use of factor and Cluster analysis in groundwater chemistry interpretation”. Journal of Hydrology 39, 355–364.

[15]. Belkhiri, L. A. & Mouni, L., (2011). A Multivariate Statistical Analysis of Groundwater Chemistry Data. *International Journal of Environmental Resources*, 5(2), pp. 537-544.