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Research Paper

Statistical Characterization of Groundwater Quality in Port Harcourt, Southern Nigeria.

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ABSTRACT

This study attempts to analyze hydrochemical data and determine the chemical characteristics, the most relevant controls on the water quality, and the dominant chemical processes which control the groundwater composition using multivariate statistical approach. The study reveals that the highest correlation exist between EC and TDS which is 0.816 .This means the statistical relationship between EC and TDS is strong and direct because of the positive sign that the result portrays. The level of significance is 0.000 at 95% confidence level and this is less than 0.005 of the standard significant level meaning that TDS which is taken as independent variable influences EC and this explains the 66.6% of the level of concentration of EC in the study area. . The total variance explained reveals the amount of variance in the original variables accounted for by each component. The cumulative % column of the extraction sums of squared loading reveals that the extracted component explained about 78% of the variability in the original 26 variables, which considerably reduces the complexity of the data set by using this component, with only about 21% loss of information. Generally, the study provides the basic tool for sustainable groundwater management in the context of quality assessment. The methodology illustrated in the study allows the incorporation of hydrochemical information (variables) into a statistical model that takes into consideration all possible interactions between the variables. This study has provided a method to characterize groundwater quality using statistical analyses and modeling of hydrochemical data to explain the groundwater chemistry origin in the area. Generally, the study provides the basic tool for sustainable groundwater management in the context of quality assessment.

Key words: Groundwater, hydrochemistry, statistical analysis, water quality, Port Harcourt.

INTRODUCTION

Groundwater resources are considered to be significant and economical water resources (Izadi et al., 2012). The comprehensive recognition and proper utilization of this valuable resource, especially in Port Harcourt, Nigeria, has an important influence on the sustainable development of social and economic activities. Groundwater quality concept seems to be clear, but the way of how to study and evaluate it still remains tricky (Chenini and Khemiri, 2009). The chemical composition of groundwater is controlled by many factors that include the composition of precipitation, mineralogy of the watershed and aquifers, climate and topography. These factors can combine to create diverse water types that change in composition spatially and temporally (Nwankwoala, 2013; Ukandu et al., 2011).

In recent times, multivariate statistical methods have been employed to extract significant information from hydrochemical datasets in compound systems. These techniques can help resolve hydrological factor such as aquifer boundaries, groundwater flow paths, or hydrochemical components (Syehan et al., 1985; Suk and Lee, 1999; Locsey and Cox, 2003), identify geochemical controls on composition (Reeve et al., 1996; Adams et al., 2001; Alberto et al., 2001). Different techniques have been used in attempt to evaluate water quality, essentially based on chemical ions correlation (Piper, 1944). Since the data obtained in this study is multivariate and correlative in nature, Principal Component Analysis (PCA) methods were used for the interpretation of the data. Multiple Linear Regression (MRL), based on chemical groundwater properties is given as an accurate tool to evaluate groundwater quality, since it generates a minimum data set of indicators (Doran and Parkin, 1996).

In Port Harcourt, the study area, groundwater is facing enormous pressure due to high population and rapid industrial growth. The area lies approximately between latitudes 04043'N and 05000'N and longitudes 06045'E and 07006'E (Fig.1). The chemical constituents of groundwater is known to cause some health risks, so supply cannot be said to be safe if specific information on water quality is lacking. The hydrochemical processes and characteristics of the aquifer systems in the area are generally not well known due to scanty hydrologic and hydrogeologic data. Large uncertainties also exist in the understanding of the main processes controlling the evolution of groundwater in the area.

In the study area, studies on comprehensive approaches to the understanding of groundwater involving chemical indicators and hydrochemical evolution of groundwater using chemical data from the standpoint of environmental geochemistry are relatively few. Moreso little is done to assess and understand the quality of groundwater especially within the different aquifer systems, hence the importance of this study which aims at quantifying the relationship between several independent or predictor variables and a dependent variable. This method is successfully used by different authors to establish statistical model (Ghasemi and Saaidpour, 2007).

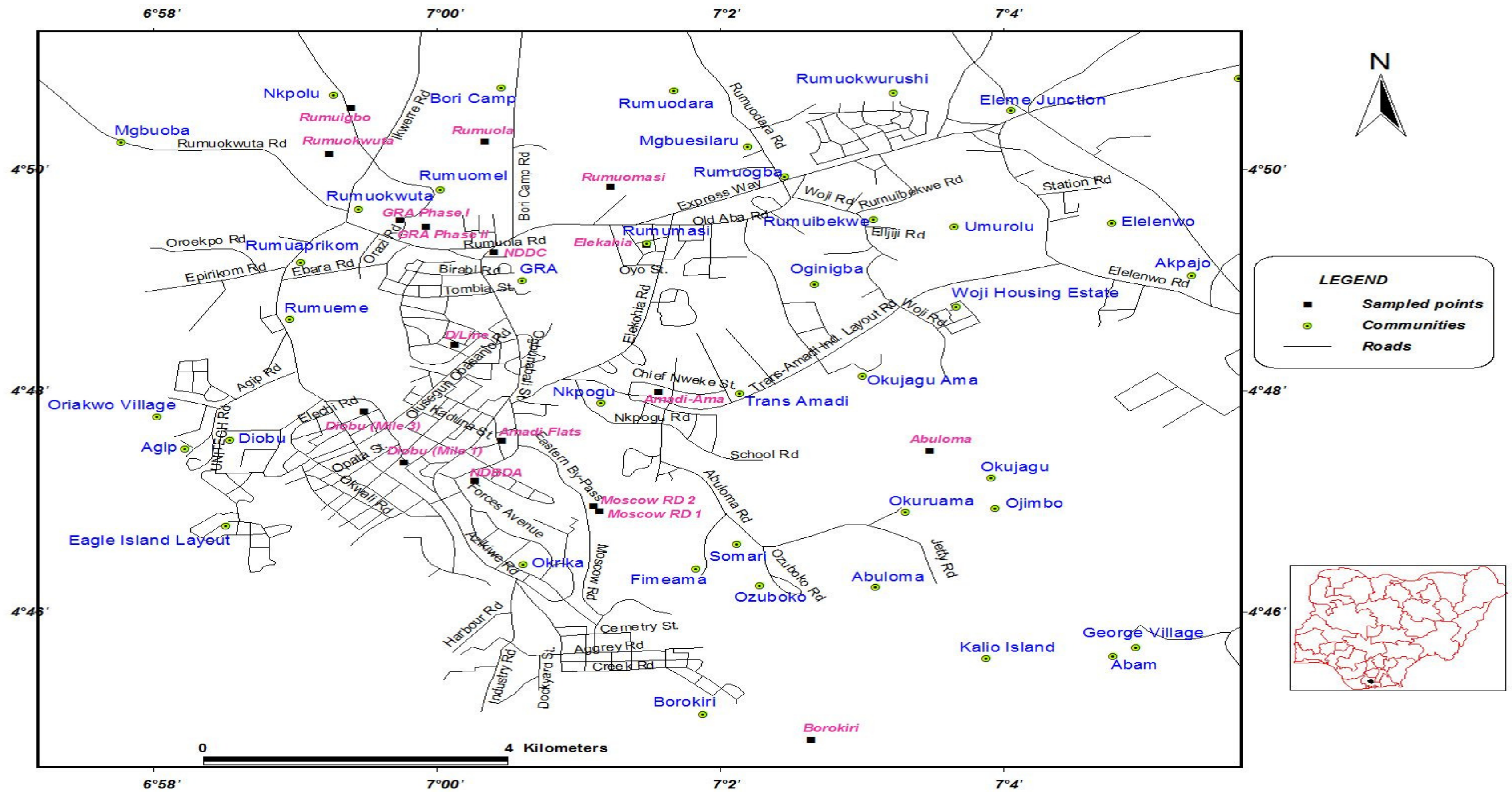

Figure 1: Map of Port Harcourt Showing Study Locations

METHODOLOGY

Since the data obtained in this study had multivariate nature and several of the variables were correlated, Principal component analysis (PCA) methods were used for the interpretation of the data. Multiple linear regression (MLR), based on chemical groundwater properties of an aquifer system is given as an accurate tool to evaluate groundwater quality, since it generates a minimum data set of indicators (Doran and Parkin, 1996). Therefore, the results of groundwater quality data analyses in a sequential fashion have been fully integrated to better constrain the interpretation in the process.

As a multivariate data analytic technique, PCA reduces a large number of variables to a small number of variables, without sacrificing too much of the information (Qian *et al*., 1994). More concisely, PCA combines two or more correlated variables into one variable. This approach has been used to extract related variables and infer the processes that control water chemistry (Helena *et al*., 2000; Hidalgo and Cruz-Sanjulian, 2001). The PCA method was performed using STATISTICA 6.0 statistical program. The general purpose of multiple linear regressions is to quantify the relationship between several independent or predictor variables and a dependent variable. This method is successfully used by different authors to establish statistical models (Ghasemi and Saaidpour, 2007). PCA was applied to the groundwater data set to examine relations between water properties analysed and to identify the factors that influence the concentration of each one.

RESULTS AND DISCUSSION

The total Variance Explained (Table 1) reveals the amount of variance in the original variables accounted for by each component. The cumulative % column of the Extraction Sums of Squared Loading reveals that the extracted component explained about 78% of the variability in the original 26 variables (Tables 2 and 3). This considerably reduces the complexity of the data set by using this component, with only about 21% loss of information. Table 1 shows the descriptive statistical results of analyzed parameters in the study area.

Table 1: Descriptive Statistical analysis of parameters analyzed in the study area

Parameters	Minimum	Maximum	Mean	SD
Temp ^{0}C	26.33	29.64	27.67	0.056
pH	3.84	7.72	7.73	0.44
EC (µS/cm)	28.00	717.40	245.76	0.53
TDS(mg/l)	12.60	401.00	145.49	0.84
TSS (mg/l)	0.00	14.00	4.63	0.42
Hardness(mg/l)	2.50	142.00	34.31	0.71
Cl^- (mg/l)	12.00	710.00	161.49	0.27
Eh (mV)	26.44	197.00	131.68	0.53
SO_4^{2-}(mg/l)	9.70	230.11	68.76	0.04
Fe (mg/l)	0.00	1.600	0.26	0.095
Salinity (mg/l)	10.00	672.75	142.41	0.17
NO_3^-(mg/l)	0.010	34.000	3.24	0.43
HCO_3^-(mg/l)	3.003	58.040	16.68	0.45
Sr^{2+} (mg/l)	0.91	4.370	6.53	0.69
Ca^{2+}(mg/l)	2.300	18.300	3.02	0.07
Na^+(mg/l)	0.213	3.445	1.58	0.17
Mg^{2+}(mg/l)	0.233	8.721	3.16	0.22
K^+(mg/l)	0.044	0.891	0.47	0.54
PO_4^{3-}(mg/l)	0.001	0.788	0.28	0.02
Mn^+ (mg/l)	0.002	0.782	0.19	0.04
F^-(mg/l)	0.010	2.310	0.85	0.05
SiO_2(mg/l)	0.38	60.02	8.38	0.86
Zn^{2+}(mg/l)	0.03	10.09	0.70	0.77
Cu^{2+}(mg/l)	0.00	0.75	0.08	0.05
Pb^+ (mg/l)	0.00	0.28	0.08	0.01
Br^-(mg/l)	7.90	93.01	43.07	0.31

Table 2: Rotation Sums of Squared Loadings of Initial Eigenvalues

Components	Rotation sums		Cumulative %
	Total	% Variance	
1.	2.943	11.319	11.319
2	2.386	9.178	20.497
3	2.154	8.285	28.782
4	2.142	8.239	37.022
5	2.130	8.191	45.212
6	2.125	8.731	53.385
7	1.867	7.179	60.564
8	1.789	6.880	67.444
9	1.452	5.586	73.030
10	1.413	5.434	78.464

Table 3: Rotated component matrix of extracted variables

Parameters	1	2	3	4	5	6	7	8	9	10
EC	0.838									
Eh		0.746								
Cu			0.934							
SO_4^{2-}				0.814						
Hardness					0.809					
HCO_3^-						0.803				
pH							0.810			
C_a^{2+}								0.701		
K^+									0.858	
TSS										0.839

Regression analysis using SPSS 17.0 (PEC, 2008) was conducted to investigate the relationship between TDS and water properties. The [Na], [K], [Mg], [SO_4], [HCO_3], [Cl], [Ca] were considered as independent variables and TDS as a dependent variable.

According to R square statistic, 99% for the total variance for the estimation of TDS is explained by the MLR model. The model was checked to see if it was prone to any multi-colinearity effect. The Variance Inflation Factor (VIF) value obtained was close to 1 and thus, there was no evidence of multicolinearity (Hair and Anderson, 1998).

CONCLUSION

Principal Component Analysis (PCA), which is multivariate data analytical technique was used to extract related variables and infer the processes that control water chemistry. The application of PCA reveals that the classification of groundwater sampled was achieved according to their chemical and physical properties. The study provided the basic tool for sustainable groundwater management in the context of quality assessment. The methodology illustrated in the study allows the incorporation of hydrochemical information (variables) into a statistical model that takes into consideration all possible interactions between the variables and has provided a method to characterize groundwater quality using statistical analyses of hydrochemical data to explain the groundwater chemistry origin in the area. More importantly, the study provided the basic tool for sustainable groundwater management in the context of quality assessment.

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