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PRINCIPAL COMPONENT ANALYSIS OF RURAL GROUNDWATER QUALITY OF BENUE STATE, NIGERIA

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Groundwater quality in rural communities of Benue State, Nigeria is assessed using principal component analytical techniques. Water samples were collected from 26 rural community boreholes of Benue State in the month of October being the rainy season. Physicochemical concentrations in boreholes as it affects the quality of groundwater is analyzed using both field and laboratory techniques as prescribed in the standard methods for water examination and reported based on the WHO drinking water guidelines. The result was subjected to correlation and principal component analysis(PCA). The PCA shows that groundwater quality in the study area is influenced by geology of the environment, mineralistion in soil and rocks, effect of agricultural landuses, effect of the materials used in borehole construction, and influence of seasons.It is recommended that rural groundwater developers should make exploitation of good quality a top priority as provision of polluted water will be counterproductive with all its attendant health hazards.

INTRODUCTION

Globally, groundwater provides about 50% of the current potable water supplies, 40% of the demand of self supplied industry, and 20% of water use in irrigated agriculture according to UNESCO (2003) estimate. Groundwater is the earth's largest accessible store of fresh water and excluding ice sheets and glaciers, has been estimated to account for 94% of all fresh water (Ward and Robbinson, 1990). This groundwater resource is however under pollution threats thus undermining its suitability for human consumption with all its concomitant health hazards. These threats may originate from both physical and anthropogenic sources such as geology and geochemistry of the environment, increasing water demand and withdrawal, mineral exploitation, industrialization and agricultural land use, indiscriminate drilling of boreholes and lack of pretesting of groundwater before drilling (Mackey, 1990; Edmund and Smedley, 1996; Adelana and MacDonald, 2005; Villholt, 2006; Ocheri, 2010).

Rural water supply programs especially in the developing countries of the world rely on groundwater exploitation. This is because of the advantages it has over surface water sources in terms of accessibility, development, natural quality or purity, pollution and seasonal fluctuations (Carter and Howsam, 1994; Habila, 2005; MacDonald et al., 2005; Adelana and MacDonald, 2008). These advantages notwithstanding, the challenges facing rural water developers is that of pollution. Because once polluted groundwater is difficult to remedy. According to MacDonald et al. (2005) many rural water supply projects rely on developing groundwater, but do so blindly, with little regard for quality. Boreholes are sited at random or by socioeconomic criteria alone, the supplies are assumed to be safe and sustainable with no water quality testing or understanding the nature or chemistry of the resource.

Knowledge of the chemistry of groundwater and factors that interact to influence its quality is therefore of paramount importance. Water quality is assessed by its physical, chemical and biological properties. These parameters or element interact to define the water resources quality of an area (Shibah, 1993; Caliandro et al. (1995). Some treat these parameters individually, while others combine them to describe the quality status of the water. The classification, modeling and interpretation of water quality data are important steps in assessment of the water quality (Bayacirglu, 2006).

Several researchers have used various multivariate statistical analyses to classify or describe the quality status of both surface and groundwater resources. Matthes and Rasmussen (2000) used multivariate statistics and GIS mapping to delineate zones of aquifer contamination potential in South Carolina, U.S.A. PCA was used to group variables that are most indicative of contaminant potential. Cluster analysis was used to group geographical and contaminant concentration into zones of homogenous behavior. In a related study, Rao et al. (2001) used multivariate statistical analysis to identify factors governing the groundwater quality in Guntur, Presdash, India. The R-mode factor analysis was employed to understand the process responsible for the decline of groundwater quality in the area.

Geostatistical techniques simplify and organize large geochemical data sets into meaningful information (Lambart et al., 2004; Amadi et al., 2012). Amadi (2012) used geostatistical techniques comprising Factor Analysis (FA) and Water Quality Index to assess groundwater quality in the coastal aquifer of Eastern Niger Delta, Nigeria. FA was used to evaluate the concentration of physical, chemical and bacteriological data from groundwater samples in the study area. Hydrochemical facies of groundwater in the Deltaic sand aquifer was delineated by Olobaniyi and

Owoyemi (2006). R-Mode factor analysis reveal the hydrochemical facies as signature of saline water interaction incursion from seepage into the aquifer of water from tide influence of River Warri; process of natural rainwater recharge and soil water and rock interaction; and dissolution of sulphide from stratified peat within the geological formation and vehicular activities and the petroleum refining process in the area. Amadi (2011) used water quality index and Factor analysis to assess the effect of Aladimna dumpsite soil and groundwater quality.

In this paper, attempt is made to identify underlying factors that influence the quality of groundwater in rural communities of Benue State. Benue State is predominantly a rural state with over 75% of the population living in rural areas. This segment of the population is faced with acute water shortage as traditional water sources such as streams, rivers, ponds are under stress from climatic variability and intensified agricultural land uses resulting into many of them drying up (Ocheri, 2010; Ocheri and Oche 2012; Ocheri and Atu, 2012). Efforts of government and non-government activities have been directed at groundwater development through borehole system in a bid to remedy the situation in rural communities of Benue State. This worthwhile gesture is however confronted with problems of pollution. According to Ocheri (2010) some of the boreholes produce water having colour, odour and taste which are indications of pollution. This has led to some communities abandoning using water from such borehole. This is described by MacDonald et al. (2005) as having raised the community expectation and it was dashed. Studies carried out by Ocheri (2010, 2012) have focused on the concentrations of physical, chemical and bacteriological constituents as they affect the quality of groundwater for drinking. This study sought to isolate factors that have a controlling influence on the quality of groundwater in rural communities of Benue State.

THE STUDY AREA

The study area is the rural communities of 13 Local Government Areas (LGAs) of Benue State (Figure 1) having a population of 2,195,041 (NPC, 2006). The area is underlain by a geological formation mainly of sedimentary rocks consisting of sandstones, mudstones and limestones, and pocket of basement complex which are of hydrogeological importance in terms of groundwater exploitation (Kogbe et al., 1978; Nwaqchukwu, 1978; Offodile, 2004; Abaa, 2004). The study area is drained by River Benue and its tributary River Katsina-Ala. Other rivers include Aya, Konshisha, Guma, Obi and Okpokwu. These rivers constitutes sources of drinking water to rural communities of Benue State. The soil is predominantly of tropical ferrugized type with hydromorphic soils along the flood plain of these rivers. The study area is controlled by tropical sub-humid climate with two distinct seasons wet and dry season. Annual rainfall ranges from 1200-2000 mm. The economy is predominantly agrarian been a rural communities. Crops produced in commercial quantities are yams, cassava, rice, maize and citrus such as oranges, mangoes etc. Because of the declining soil fertility use of chemical fertilizers is on the increase with its consequences of water sources.

MATERIALS AND METHODS

Data for this study were obtained from both primary and secondary sources. Water samples were collected from 26 rural community boreholes in the month of October when rainfall is heaviest in the area and vulnerability of water sources to pollution is highest. Both field based and laboratory determination of the physical and chemical concentrations in water samples were carried out as prescribed in the standard methods for water examination (APHA-AWWA-

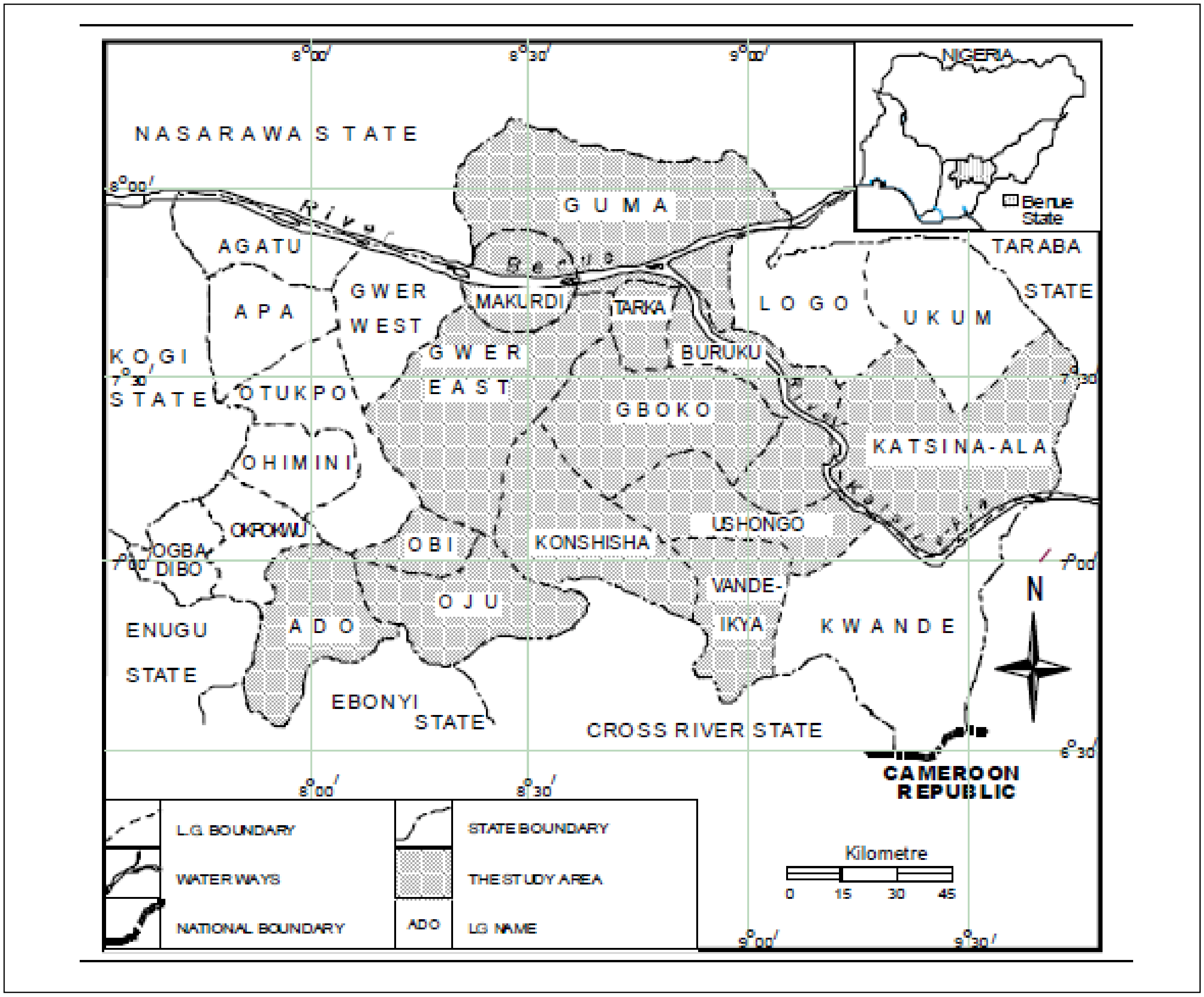

Figure 1. Benue State showing study area (source: Benue State Ministry of Lands and Survey).

WPCF,1995) and interpreted based on the WHO guidelines for drinking water. The result of analyses of physical and chemical concentrations in groundwater samples were then subjected to pearson product moment correlation and principal component analysis (PCA). PCA was used to identify those factors influencing the quality of groundwater in the study area.

RESULTS AND DISCUSSION

The physicochemical parameters whose concentrations in groundwater in borehole considered to have influenced the quality of water in the study area are: temperature, pH, total harness, electrical conductivity, chloride, total dissolved solids, alkalinity, turbidity, iron, manganese, zinc, lead and copper. The descriptive characteristics of these parameters is shown in Table 1.

From Table 1, temperature ranged between 27 to 31^{0}C with a mean and CV of 29.15 and 4.19%. Temperature of the water samples are within the WHO prescribed limit for drinking water.

The pH of the water samples analyzed ranged between 6.73-8.50, with a mean and coefficient of variation of 7.55 and 6.21% respectively. The groundwater is predominantly of alkaline type. The low coefficient of variation suggests that the water is of the same type.

The total hardness in groundwater as analyzed ranges from 20 to 230 mg/l, having a mean and

Manganese in groundwater analysed ranged between 01-1.47 mg/l, with a mean and coefficient of variation of 0.73 and 52.38% respectively. A good number of boreholes analysed exhibited elevated manganese concentrations above the WHO prescribed limit for drinking water. Manganese is found coexisting with iron and are responsible for colour in water. Excessive concentrations in water may come from soil and sediments (Todd, 1980; Ezeigbo, 1988).

Zinc concentrations in water samples analysed ranged between 0.00 to 0.76 mg/l, with a mean and coefficient of variation of 0.10 and 140% respectively.

The result of analyses show lead concentrations in the boreholes ranged from 0.08 -2.39 mg/l, with a mean and coefficient of variation of 0.74 and 75.68% respectively. The analyses also revealed that 95% of the boreholes examined had elevated lead concentrations above the WHO guide limit for drinking water. This can pose serious health implications if such water is consumed for long period of time.

Copper concentrations as analysed ranged between 0.08 to 2.29 mg/l, with a mean and coefficient of variation of 0.88 mg/l and 64.77% respectively.

To determine whether the interrelationships among these parameters were significant pearson correlation moment was performed. This is shown in Table 2. Correlation is significant at 0.01 and 0.05

Levels are indicated in asterisk. From the correlation some variables appeared to have significant contributions to the observed variation in groundwater quality while others have very low or no contributions. This suggests that some of the variables are interrelated. To ease difficulty of explanation, principal component analysis (PCA) was used to transform our data. The 13 parameters analysed were used as variable inputs for principal component analysis. The PCA was performed by using the SPSS computer program. Since water quality parameters had different magnitude and scales of measurement the data were standardized to produce a normal distribution of all the variables (Davis, 1973; Mazin et al., 2008). PCA was further strengthened by the application of orthogonal varimax rotation (Table 3) of the original variables without changing the position of the original variables. This is to enable further determination of distinctive loading of the variables so that each variable has the highest load on and only one component. Explanations are given with reference to structure of the variable loading on the component together with their separate and joint contributions to the variance of loading pattern. Significant loadings are considered from the threshold of -/+0.6 which is statistically significant at 95% confidence level. This cut off value is based on the size of the component loading. According to Johnson (1991) is chosen to ease interpretation. Each squared component loading indicates the degree to which the new variables replaces the original variables. The sum of these squared loadings known as eigenvalue therefore show the total variance explained by the component. Hence, the eigenvalue is employed in accounting for the total variance in the data matrix. As to the number of components to be extracted according to King (1991) the rule is that only those components whose eigenvalues account for over 5% of the total variance should be extracted.

From Table 3, component I has eigenvalue of 3.39 and explains 24.2% of the total variance. This component has significant loadings on alkalinity, total dissolved solids, hydrogen ion electrical conductivity, chloride and zinc. This component is described as influence of chemical weathering on groundwater.

Component II has significant loadings on turbidity, iron and calcium with an eigenvalue of 1.83

Table 1. Descriptive characteristics of the physicochemical parameters of rural groundwater of Benue State.

Parameters	Min	Max	Mean	STD	CV
Temperature	27	31	29.19	01.22	4.19
pH	6.73	8.50	7.55	0.47	6.21
TH	20	230	73.31	57.43	6.21
EC	30	2230	414.27	569.9	137.58
CL	10	450	72.88	100	137.42
TDS	10	1109	167.73	233.58	139.29
AK	25	475	117.15	91.68	78.26
TBD	1.0	230	27.09	55.82	206.05
Fe	0.03	2.38	0.82	0.67	81.71
Ca	2.33	33.61	8.66	8.54	98.61
Mn	0.01	1.47	0.73	0.38	52.38
Zn	0.00	0.76	0.10	0.10	140
Pb	0.08	2.39	0.74	0.56	75.68
Cu	0.08	2.29	0.88	0.57	64.77

STD-standard deviation, CV-Coefficient of variation, TH-total hardness, EC-electrical conductivity, CL-chloride, TDS-total dissolved solids, AK-alklinity, TBD-Turbidity, Fe-iron, Mn-manganese, Zn-zinc, Pb-lead, Cu-copper

coefficient of variation of 73.31 and 5.74%. The concentrations of total hardness in groundwater in the study area are all within the WHO allowable limit for drinking water.

The electrical conductivity is a valuable indicator of the amount of materials dissolved in water. The electrical conductivity of water samples analysed ranged between 30-2230 unhos/cm, with a mean and coefficient of variation of 414.27 and 137.58%.

Chloride concentrations in groundwater ranged from 10 to 450 mg/l, mean of 72.88, and coefficient of 137.42%. The high coefficient of variation in the chloride concentrations in groundwater is a reflection of the nature of environmental characteristics.

The results of analyses show total dissolved solids has a range of 10 to 1109 mg/l, with a mean and coefficient of variation of 167.73 and 139.26%. The wide disparity of the coefficient of variation is a reflection of the heterogeneity of the environment.

The alkalinity of the water samples analysed ranges from 25-475 mg/l. The mean and coefficient of variation is as follows: 117.15 mg/l and 78.26%.

Groundwater from the boreholes analysed for turbidity ranges from 1.0 to 230 mg/l with a mean and coefficient of variation of 27.09 and 206.05%. The results of analyses show some of the boreholes have turbidity concentrations above the WHO guide limit for drinking water.

Iron concentrations in the water sample analysed ranged between 0.03 to 2.38 mg/l. The mean and coefficient of variation of the iron concentrations are 0.82 mg/l and 81.71% respectively. A good number of the boreholes analysed exhibited iron concentrations above the WHO permissible limit for drinking water. Iron is abundant in tropical ferrugized soils and sandstone environment as reflected in the boreholes located within the environment.

The mean and coefficient of variation of calcium concentrations in water samples are 8.66 and 98.61% ranged from 2.33 to 37.61 mg/l. Calcium is responsible for hardness of water.

Table 2. Correlation matrix of results of physicochemical analysis of groundwater quality in the study area.

	TP	P^H	TH	EC	CL	TDS	AL	TBD	Fe	Ca	Mg	Zn	Pb	Cu
TP	1.00													
P^H	0.05	1.00												
TH	0.26	0.38	1.00											
EC	0.37	0.42*	0.06	1.00										
CL	0.28	0.34	0.13	0.39	1.00									
TDS	0.23	0.67**	0.20	0.78**	0.58**	1.00								
AL	0.07	0.71**	0.07	0.67**	0.48**	0.88**	1.00							
AC	0.23	0.10	0.20	0.13	0.11	0.22	0.20							
TBD	0.12	0.00	0.19	0.20	0.22	0.17	0.14	1.00						
Fe	0.19	0.08	0.11	0.39*	0.15	0.23	0.12	0.48*	1.00					
Ca	0.16	0.23	0.17	0.20	0.03	0.13	0.01	0.06	-0.06	1.00				
Mg	0.31	0.05	0.32	0.38	0.17	0.30	0.28	0.09	0.20	-0.02	1.00			
Zn	0.13	0.02	0.07	0.10	0.13	0.05	0.06	0.08	0.26	-0.17	-0.15	1.00		
Pb	0.05	0.20	0.48*	0.03	0.07	0.07	0.01	0.23	0.17	0.26	0.01	0.01	1.00	
Cu	0.26	0.13	0.24	0.13	0.16	0.16	0.21	0.09	0.04	0.12	0.03	-0.21	0.00	1.00

Correlations significant at 0.01(*) and 0.05(**)levels

Table 3. Varimax rotated components matrix of physicochemical analysis of rural groundwater.

Variable	COMPONENTS					
	I	II	III	IV	V	VI
TP	0.146	-0.162	0.523	0.526	-0.104	-0.314
PH	0.836*	0.154	-0.196	-0.215	0.191	0.103
TH	0.186	0.262	0.409	0.191	0.758*	0.162
EC	0.691*	0.310	0.437	0.076	0.086	0.179
CL	0.610*	-0.164	0.502	0.413	0.161	-0.283
TDS	0.913*	-0.169	0.222	-0.185	0.106	-0.582
ALK	0.937*	-0.290	-0.031	-0.111	-0.114	-0.766
TBD	-0.121	0.810*	0.172	-0.149	-0.623	0.189
Fe	-0.302	0.845*	-0.265	-0.521	-0.607	-0.164
Ca	0.100	-0.914	-0.186	-0.390	0.181	0.867*
Mn	-0.153	-0.037	-0.876*	-0.441	-0.401	-0.734
Zn	-0.611	0.313	0.226	-0.558	-0.488	-0.393
Pb	-0.130	0.261	-0.402	0.191	0.885*	0.156
Cu	-0.148	0.157	0.289	0.827*	-0.389	0.380
Eigenvalue	3.392	1.835	1.661	1.509	1.498	1.226
% Variance	24.2	13.1	11.9	10.8	10.7	8.8
Cum %	24.2	37.3	49.2	60.1	70.6	79.4

and explain 13.1% of the total variance. This component may be ascribed to influence of dissolved minerals from soils and rock on the quality of groundwater.

Component III has an eigenvalue of 1.66 and explains 11.87% of the total variance. This component has a negative significant loading on manganese. Manganese is found to coexist with iron and they are responsible for colour in water. This component is described as chemical reaction influencing the quality of groundwater.

Component IV has significant loadings on copper with an eigenvalue of 1.51 and explains 10.78% of the total variance. This relates to the effect of galvanized materials used in borehole construction.

Component V has an eigenvalue of 1.50 and explains 10.70% of the total variance. The component has significant loadings on lead and total hardness. This component may be described as the effect of agricultural activity on groundwater quality.

Component VI has significant loading on calcium ,alkalinity and iron with an eigenvalue of 1.22 and explains 8.8% of the total variance. This may be described as effect of rainfall on calcium rich rock influencing the quality of groundwater.

The quality of groundwater in the study area is influenced by geology of the environment, mineralization in soil and rocks, effect of material used in borehole construction, influence of agricultural land use and effect of seasons.

CONCLUSION

Our study has shown the groundwater quality in rural communities of Benue State is controlled by both physical processes and anthropogenic activities. These include geology, chemical weathering facilitating mineralization and dissolution of minerals from rocks and soil, season and materials used in borehole construction. It is recommended that appropriate measures be taken by rural groundwater developers to ensure that water provided for rural communities is safe, clean and of a good quality as provision of polluted water will be counterproductive.

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