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Integration of Hydrogeophysics and Principal Component Analysis in Hydrogeochemical Evaluation of Some Aquifers of Anambra Basin, Nigeria

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Abstract
The hydrochemical characteristics of groundwater in parts of Anambra Basin has been evaluated using Principal Component Analysis (PCA). Water samples were collected and analysed for physicochemical parameters which were interpreted using principal component analysis that consolidated large number of observed variables into smaller number of factors. The PCA produce 4 significant components that explain more than 93% of the total variance of the original data set of the basin. While PC1 has a high load of TH, TDS, SO_4, Cl, Mg, Ca, and explains 39.51% of the total variance, PC2 with high loading of NO_3 explains 22.23% of the total variance in the analysis. PC3 and PC4 characterized by high loading of Fe and pH accounted for 19.34% and 12.26% of the total variance respectively.
The extracted principal components PC1, PC2, PC3, and PC4 are associated with the effects of agriculture, geology and poor waste disposal in the area. The strong correlation of Ca with TH, TDS and Cl also indicate a common source of the parameters influencing water quality in the area.

Keywords*: Groundwater quality, Principal component analysis, Vertical Electrical Sounding, Anambra Basin*

1. Introduction

The Anambra Basin in southeastern Nigeria is one of the most densely populated regions in the country. Water of good quality and quantity plays an important role in the sustenance of both life and socio-economic activities in the area.Irrigation agriculture using groundwater to contain the challenges of climate change especially during the dry season has been encouraged by both government and non-governmental organization (Rapti-Caputo, 2010; Faruta et al., 2012). Groundwater quality and suitability for agricultural purposes have been the interest of many researchers going by its implications on human existence (Sankhari, et al., 2015, Nageswara et al., 2015,Mohammed et al., 2017, Okolo et al., 2017). On a pilot basis, groundwater is been exploited for irrigating vegetable farms under the National Fadama Development Project (Faruta et al., 2012; Olalu et al., 2011). However, saline water contamination is a well-established problem in some parts of Anambra Basin and consequently, the suitability of the groundwater in the area for agricultural and other purposes needs to be ascertained (Egboka and Uma, 1986; Tijani, 2004, Edet et al., 2011, Ene and Okogbue, 2012).

The overall quality of groundwater at any point below the surface is reflective of the totality of the effects of many processes and intersections made by the water along its flow path (Jeevanandam et al. 2007; Young, 2007; Bahar and Rezar, 2010, Jacintha et al., 2016). Factor analysis technique is a useful tool in the analysis of groundwater data (Panda et al., 2006). The factor analytical approach assumes that the observed variables are products of linear combinations of some few variables originating from some sources technically called factors. It therefore attempts to isolate these factors that are responsible for the observed variance in the data. Several authors have successfully applied the factor analysis tool in assessing groundwater quality and apportioning the sources of the contamination in (i) iron ore mining site and (ii) a municipal sewage disposal works in two southern Africa cities. Olobaniyi and Owoyemi (2006) applied the factor analysis approach in mapping the areal distribution of groundwater facies and in explaining the controlling processes responsible for the various facies in the Deltaic Plain Sands of Warri and its environs in Nigeria. Lu et al. (2011) applied the factor and other multivariate statistical tool in evaluating and interpreting the quality of groundwater in blackfoot disease endemic areas of Taiwan. Bakari et al. (2012) adopted the factor analysis as isotopic approaches in assessing groundwater provenance and quality in the coastal aquifers of southeastern Tanzania. Lu et al. (2012) employed the multivariate statistical approach that includes factor analysis in assessing the hydrochemical characteristics of water in the arsenic-contaminated aquifers of Choushui River alluvial fan and Chianan Plain, Taiwan and several other instances.

Inspired by the numerous successes associated with the application of factor analysis in assessing groundwater quality, we adopted the factor analysis approach in assessing the hydrochemical properties of groundwater present in the shallow Nanka aquifer of Anambra Basin in southeastern Nigeria.

1.1. Description of the Study Area

The study area is located between latitudes 6º 9' and 6º 14.5'N and longitudes 6º 53.5' and 6º 59'E in Anambra Basin, southeastern Nigeria Fig. 1. The topography of the area is characterized by a major north-south trending Awka-Umuchu-Orlu Cuesta (Egboka, et al., 1990). This cuesta creates a high lying areathat is surrounded by lowlands. Two major climatic conditions are prevalent in the area. The dry season that starts in October and ends in March and the wet (rainy) season that begins in April and ends in September.

There have been significant shifts in both the upper and lower boundaries of these climatic conditions occasioned by the global climatic changes (Martinez et al. 2008; Rapti-Caputo 2010; Riddell et al. 2010; Wagner and Zeckhauser 2011; Farauta, et. Al., 2012, Okoyeh, et al., 2013).

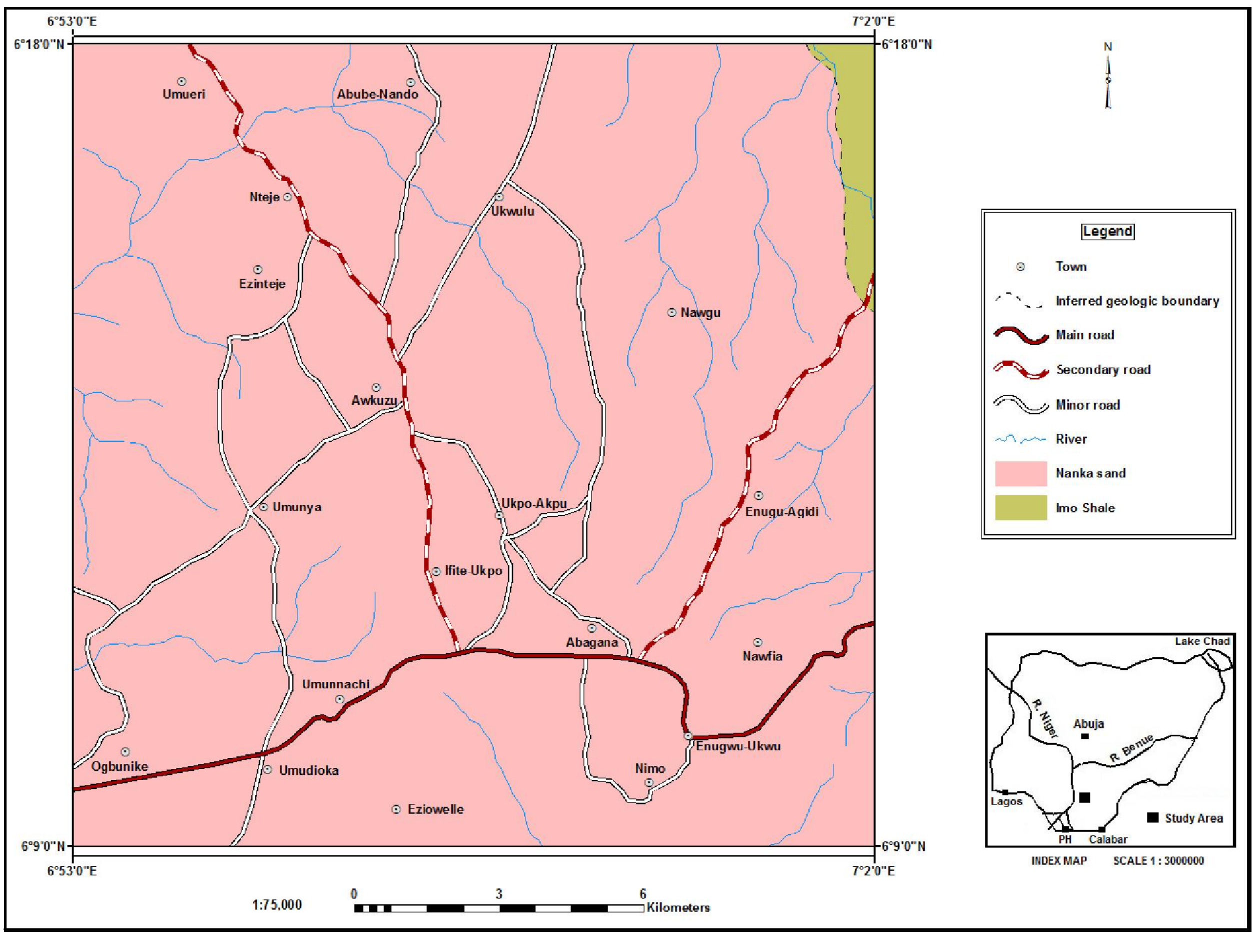

Figure 1: Geological map of part of Anambra Basin

1.2. Geological History and Lithostratigraphy of the Anambra Basin

The development of Anambra Basin set the background for the geomorphic and geologic history of the study area. Southeastern Nigeria lies within the wide fault bounded depression of Benue Trough that consists of deformed Cretaceous sedimentary and volcanic rocks (Murat, 1972). The major tectonic event (Santonian uplift) results in the folding and upliftment of Albian sediments, which led to the formation of Abakaliki Anticlinorum that is surrounded by the Anambra and Afikpo depositional basins on either flank of the anticlinorum. The study area comprises several geologic formations of regional extent. The Oligocene Ogwashi-Asaba Formation characterized by lignite, clay and sands is underlain by the Nanka Sands (Eocene), the lateral equivalent of Ameki formation (Reyment, 1965). The Nanka Sands consist of poorly sorted, cross bedded, medium to coarse grained sands with shale-siltstone and finely laminated shale exhibiting a systematic pattern of alternating cross bedded sands and thick dark grey shales (Nwajide, 1977; Nwajide; 2013). The fine grained sands are over 60m thick in some places and highly aquiferous. The north-south trending Awka-Orlu escarpments with its structural features are predominantly associated with Nanka Sands (Akudinobi and Egboka, 1996). The palaeocene Imo Shale which consists of a thick sequence of blue and dark grey shales with occasional bands of clay-ironstone and thin Sandstone unconformably overlies the Nsukka Formation and underlie the Nanka Sands and mainly occupies the lowland areas of the study area (Egboke and Uma, 1986). The Ebenebe Sandstone member of Imo Shale also forms high yielding aquifer.

2. Materials and Methods

Ten water samples were collected in 1 litre plastic bottles and taken to the laboratory for analysis. The sample sources were allowed to flow for some time and bottles rinsed 3 times before collection to avoid the use of stagnated water and contamination from external influence. The physical parameters of pH, EC and TDS were measured in-situ using digital hand held meter (Hanna pHep pocket-sized pH meter). The chemical parameters of HCO_3, SO_4, Cl, NO_3, Mg and Ca were determined using analytical methods of titrimery, EDTA as well as AAS equipment. A summary of the data set is presented in Table 1. The Principal Component Analysis (PCA) for the study was processed using XLSTAT, 2011.

Variable	Observations	Minimum	Maximum	Mean	Standard deviation
pH	10	3.860	7.400	6.141	0.948
TH	10	7.000	65.000	23.450	18.358
TDS	10	16.000	151.000	56.470	46.910
HCO_3	10	0.000	38.000	11.997	12.406
SO_4	10	1.000	21.600	10.012	9.178
Cl	10	1.000	16.000	6.322	4.128
No_3	10	0.000	23.900	5.776	7.366
Mg	10	0.660	38.900	10.153	11.826
Ca	10	0.830	66.800	15.005	21.215
Fe	10	0.010	7.360	0.909	2.279

Table 1: Summary of physicochemical analysis

About thirteen vertical electrical soundings (VES) were carried out using Schlumberger electrode configuration with Abem Terrameter SAS 1000 model. The acquired apparent resistivity data were inverted and interpreted using RESIST automated inversion software. The modeled VES curves was used to generate the geoelectric layer of parts of the basin and hence establish the depth and thickness of aquifer in the area Fig. 2.

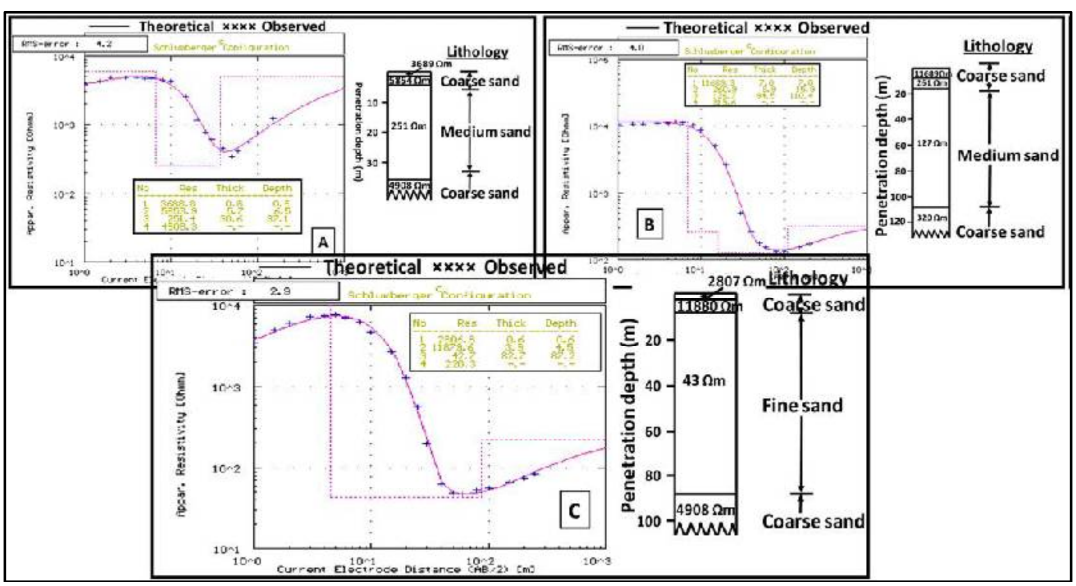

Figure 2: Modeled VES curves of part of Anambra Basin Southeast, Nigeria

3. Results and Discussion

Principal Component Analysis was carried out on correlation matrix of water samples described by physical and chemical parameters. The process is to transform the observed variables to a new set of variable (PC) which are uncorrelated and arranged in decreasing order of importance so as to simplify the problem. The obtained eigen values, % variability and % cumulative of the initial PCs are shown in Table 2 with the scree plot of the eigen values for each component presented in Fig. 3. It is observed both from the eigen values and from the scree plot that the first four PCs representing more than 93% of the variance of water quality of the study area are the most significant components. While PC1 contributed 39.51%, PC2 contributed 22.23%. 19.33% and 12.26% were contributed by PC3 and PC4 respectively. The above conclusion is confirmed by their respective eigenvalues that are greater than one.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
Eigenvalue	3.951	2.223	1.934	1.226	0.338	0.189	0.102	0.035	0.002
Variability (%)	39.511	22.232	19.336	12.262	3.378	1.891	1.023	0.347	0.019
% Cumulative	39.511	61.744	81.079	93.342	96.720	98.612	99.634	99.981	100.000

Table 2: Eigenvalues, variability and cumulative

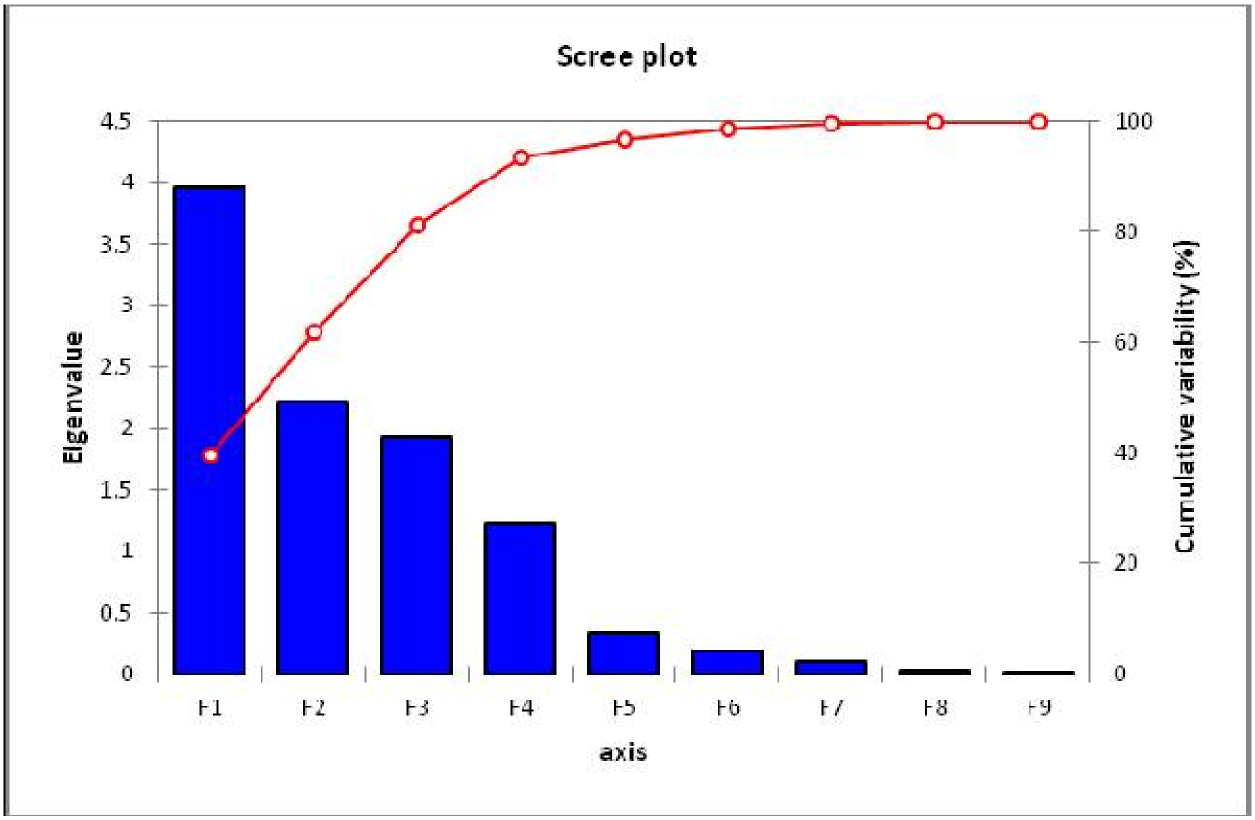

Figure 3: Scree plot of the eigenvalues and % cumulative

The degree of closeness between the variables and the PCs are measured by the component loading Table3. The loading factors of large positive and negative values have implications on the meaning of the dimensions. While positive loading signifies increase in variable contribution as a result of increase loading in dimension, negative loading indicated a reverse effect. For this analysis, component loading values greater than 6.0 was given special attention during interpretation.

	F1	F2	F3	F4	F5	F6	F7	F8	F9
pH	0.069	0.217	-0.215	0.931	-0.165	0.022	-0.092	0.000	-0.012
TH	0.746	-0.504	0.356	-0.026	0.171	0.164	-0.048	-0.063	-0.011
TDS	0.940	0.155	-0.135	-0.077	-0.163	-0.072	0.187	-0.043	-0.021
HCO_3	0.019	0.198	0.882	0.337	0.086	-0.239	0.058	-0.041	0.011
SO_4	0.588	0.545	0.289	-0.438	-0.187	-0.117	-0.182	0.032	-0.007
Cl	0.827	-0.503	-0.019	0.167	0.081	-0.076	0.047	0.144	0.003
NO_3	0.263	0.716	-0.467	0.039	0.439	-0.070	-0.027	-0.002	-0.008
Mg	0.718	0.608	-0.288	0.036	-0.096	0.129	0.061	-0.012	0.027
Ca	0.939	-0.272	0.121	0.119	0.039	0.033	-0.103	-0.037	0.013
Fe	-0.104	0.594	0.753	0.060	0.045	0.240	0.055	0.062	-0.008

Table 3: Factor loading

3.1. Principal Components Interpretation

PC1 has high loading of TH, TDS, SO_4, Cl, Mg, and Ca and explains 39.51% of the total variance. This factor can be attributed to geological process such as gully erosion and landslide prevalent in the area that release Ca into the environment increasing the TH and Mg in the water. Poor waste disposal and agricultural practices can also increase the concentration of TDS and SO_4 in the groundwater of the area. PC2 with high load of NO_3 explains 22.23% of the total variance in the analysis. The variance reflects the impact of poor agricultural practices. PC3 accounts for 19.34% of the total variance. It is characterized by high load of Fe which is a reflection of the impact of thick lateritic overburden of the area. PC4 has a high load of pH representing 12.26% of the total variance attributed to the influence of anthropogenic practices.

The extracted principal components PC1, PC2, PC3, and PC4 are associated with the effect of agriculture, geology and poor waste disposal in the area.

3.2. Correlation of Physio-Chemical Parameters

High correlation coefficient value (1 or -1) predicts a good relationship between two variables and correlation coefficient value around zero means no relationship between them at a significant level of P >0.05. TH showed strong correlation with Cl, Ca and TDS indicating influence from the same source table 4. Strong correlation of Mg with TDS, SO_4 and NO_3 indicates the impact of agricultural activities in the area. The correlation of Mg with SO_4 and TH with Cl also indicate possible ion exchange process in the aquifer system. Cl correlated strongly with Ca and TDS reflecting contribution from similar source. The moderate correlation of Fe with HCO_3 and SO_4 is also an indication of geogenic influence.

Variables	pH	TH	TDS	HCO_3	SO4	Cl	NO_3	Mg	Ca	Fe
pH	**1**	-0.179	0.064	0.143	-0.266	0.088	0.238	0.289	0.094	0.009
TH		**1**	**0.531**	0.194	0.234	0.849	-0.267	0.128	**0.897**	-0.070
TDS			**1**	-0.082	**0.635**	**0.683**	0.346	**0.823**	**0.789**	-0.129
HCO_3				**1**	0.226	-0.023	-0.198	-0.143	0.101	**0.747**
SO_4					**1**	0.123	0.324	**0.646**	0.393	0.409
Cl						**1**	-0.088	0.283	**0.922**	-0.392
No_3							**1**	**0.707**	0.018	0.051
Mg								**1**	0.474	0.101
Ca									**1**	-0.160
Fe										**1**

Table 4: Pearson correlation matrix

4. Conclusion

The result of the analysis shows that the first four components are sufficient to explain the hydrochemistry of the water of the study area. These components explain more than 93% of the total variance of the original data set from the basin with over 10% contribution from each of the four PCs respectively. The principal component analysis of the basin indicates that significant variation in water quality of the area is cause by geologic effects, agriculture and poor waste disposal practices. Strong positive correlation observed between parameters indicates significant contribution from the source. The study will enhance success of future water quality project in the area.

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