

Controlling Factors of Groundwater Chemistry in the Benin Formation of Southern Nigeria

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ABSTRACT:- Groundwater is valuable natural resources for various human activities. Factor Analysis (FA) were applied to the hydrochemical data from the Benin Formation aquifers of Owerri in order to extract the principal factors responsible for the different hydrochemical facies. By using Kaiser Normalization, the principal factors were extracted from the data. The analysis reveals six sources of solutes. The processes responsible for their enrichment includes: Mineral leaching/chemical weathering from the overlying rock, seawater intrusion, agricultural practices, and dissolution of carbonate mineral and industrial effluent. Such processes are dominated by the significant role of anthropogenic interference with the groundwater in the area. The identified factors contributed to the changes in the groundwater chemistry. The effectiveness of this method in characterizing the groundwater chemistry/facies is commendable.

KEYWORDS:- Factor analysis, Principal Component Analysis, Groundwater Chemistry, Benin Formation, Owerri and Southeastern Nigeria.

I. INTRODUCTION

Understanding the quality of groundwater with its temporal and seasonal variation is important because it is the factor that determines the suitability for drinking, domestic, agricultural and industrial purposes (Amadi and Olasehinde, 2008). Hydrochemical facies used to describe the bodies of groundwater in an aquifer that differ in their chemical condition, topography and resident time, solution kinetics and flow pattern of the aquifer (Abdullahi, et al., 2004). Hydrochemical facies can be classified on the basis of the dominant ions in the facies by means of diagrams and graphs (Schoeller, 1962; Stiff, 1951 and Piper, 1944). These methods combine chemically similar elements together and large data are usually cumbersome to handle. The demerit of the traditional Piper, Stiff and Schoeller methods has been overcome in this study by the factor analysis. Factor analysis has been used with remarkable success as a tool in the study of groundwater chemistry (Raghunath, et. al., 2002; Soyak, et. al., 2002; Olobaniyi and Owoyemi, 2006; Aris, et. al., 2007). In factor analysis, observed variables are products of linear combinations of some few underlying source variables known as factors. It attempts to find out which of these factors can explain a large amount of variance of the analytical data. The effectiveness of factor analysis in Hydrochemical studies has been successfully demonstrated in the delineation of zones of natural recharge to groundwater in the Florida aquifer (Lawrence and Upchurch, 1983), the delineation of areas prone to salinity hazard in Chitravati watershed of India (Briz-Kishore and Murali, 1992) the delineation of effluent contaminated groundwater at two industrial sites at Visakhapatnam in India (Sabbarao, et. al., 1995) and characterization by factor analysis of the chemical facies of groundwater in the deltaic plainsands of Warri, western Niger Delta, Nigeria (Olobaniyi and Owoyemi, 2006).

The factor analysis techniques has the potentials to reveal hidden inter-variable relationships and allows the use of virtually limitless numbers of variable, thus trace elements, physical parameters and microbial parameters can be part of the classification parameters. By the use of raw data as variable inputs, errors arising from close number systems are avoided. Also because elements are treated as independent variables, the masking (shielding) effects of chemically similar elements that are combined together are avoided (Dalton and Upchurch, 1978; Liu, et. al., 2003; Lambarkis, et. al., 2004 and Aris, 2005). The aim of this study is to determine with the aid of factor analysis, the Hydrochemical facies and quality status of groundwater in the Benin Formation aquifer of southern Nigeria. The tendency of contaminant migrating through the porous and permeable overlying formation into the shallow water table necessitated the study and a groundwater

vulnerability map was generated for the area. It will serve as a guide to stakeholders in water management and utilization. The study area is parts of the Niger Delta region as shown in figure 1.

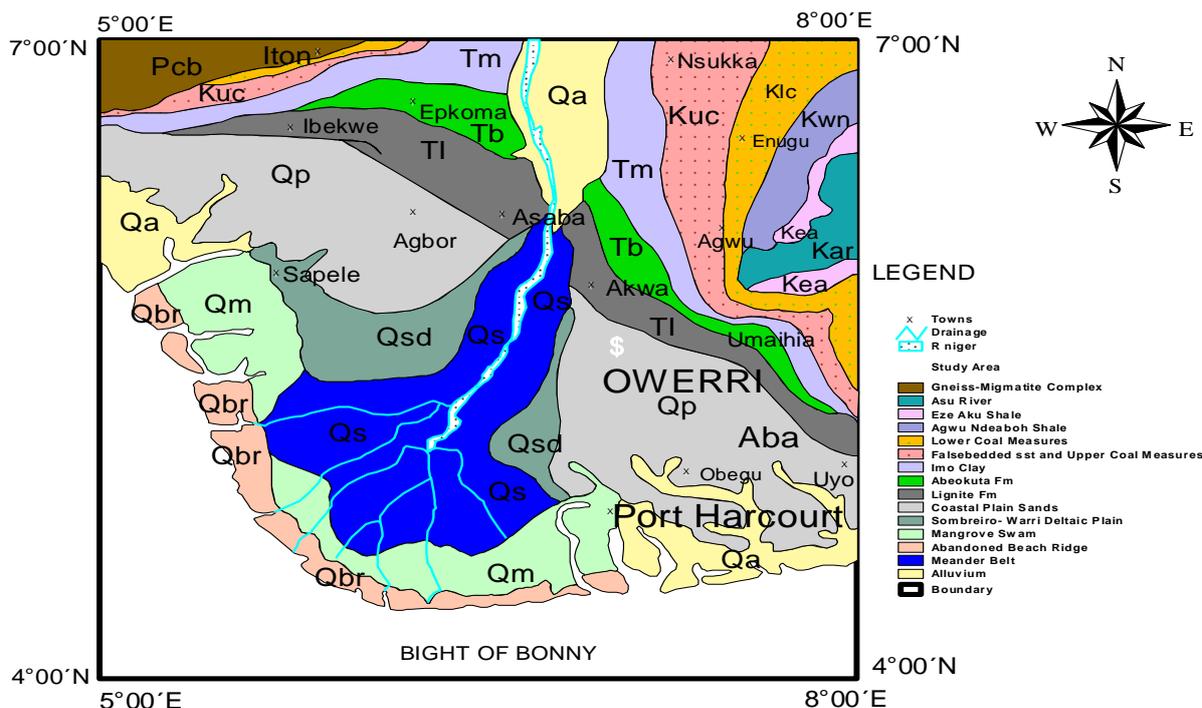


Figure 1: Geology Map of Southern Nigeria

II. METHODOLOGY

A pair of 50 groundwater samples was collected from boreholes tapping the Benin Formation of southern Nigeria in both plastic and glass bottles. The 50 samples in the plastic bottles were added 2 drops of concentrated trioxonitrate (v) acid for homogenization and prevention of absorption/adsorption of trace metals to the walls of the container (Schroll, 1976). These samples were used for the determination of cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) as well as trace metals (Fe, Cu and Pb). The remaining 50 samples were collected in glass bottles and were used for the determination of anions (NO_3^- , NO_2^- , SO_4^{2-} and HCO_3^-). To these latter samples, no acid was added. Prior to the collection of the water samples, the physical parameters were determined in the field using standard equipment. The reason for collecting two sets of samples is to allow for the addition of 2 drops of concentrated trioxonitrate (v) acid in the set for cations and trace elements analysis in order to prevent their interference with the walls of the container while the remaining pair in which no acid was added is used for anion analysis. After the collection, the water was stored in a cool box and later taken to the regional water quality laboratory of Federal Ministry of agriculture and Water Resources, Minna for the determination of ions and trace metals. The Atomic Absorption Spectrophotometer (AAS) was used for the determination of the concentrations of Ca^{2+} and Mg^{2+} as well as the trace metal; Pb, Cu and Fe while Flame analysis was used for the determination of the concentration of Na^+ and K^+ . The calorimetric method was used to determine SO_4^{2-} while the concentration of HCO_3^- was determined using titrimetric method. The Ultra-Violet Spectrophotometer (UVS) was utilized in the determination of NO_3^- and NO_2^- . The data obtained from the laboratory analyses were used as variable inputs for factor analyses.

A factor analysis was performed using the SPSS package described by Nie, et al., (1975). Before the analysis, the data were standardized to produce a normal distribution of all variables (Davis, 1973). This was followed by a preparation of a correlation matrix of the data from which initial factor solutions were extracted using the principal component analysis method. Factor extraction was done with a minimum acceptable eigen value of 1 (Kaiser, 1958; Harman, 1960)). Orthogonal rotation of these initial factors to terminal factor solutions (Table 1) was done with Kaiser's varimax scheme (Kaiser, 1958). This method maximizes the variance of the loadings on the factors and hence adjusts them to be either +1 or -1 or zero (Davis, 1973). Factor score coefficients are derived from factor loading. Factor scores are computed for each sample by a matrix multiplication of the factor score coefficient with the standardized data. The value of each factor score represents the importance of a given factor at the sample site. It should be noted that a factor score $> +1$

indicates intense influence by the process while zero score shows areas with only moderate effect of the process. The combining of two chemically similar elements such as Na^+ and K^+ , HCO_3^- and CO_3^- in the process of classification as obtained in Piper, Durov, Schoeller and Stiff diagram has been overcome by factor analysis. The impact of each element to the overall pollution is better understood using factor analysis techniques. Also physical parameters such as pH, temperature and colour as well as heavy metals are now used in categorizing the water quality. Furthermore, factor analysis has the capacity of handling, reducing and grouping of large chemical data that appear cumbersome to handle (Amadi et al., 2010).

III. RESULT AND DISCUSSION

Table 1 contains the univariate overview of the hydrochemical data of the study area. Results of the factor analysis of the groundwater chemistry data (n=50) shows five trends (factors) that can be related to the various controlling processes presumed to have produced the different water species. These factors are summarized in Table 2. The loading of the variables on each factor and the percentage (%) of the data variance are explained in each factor. These five factors accounts for 86.43% of the total variance in the data set.

Factor 1 has a high loading for conductivity, magnesium and total dissolved solid (TDS) and accounts for 32.53 % of the total variance (Table 2). TDS comprises of inorganic salt majorly calcium, magnesium, sodium, bicarbonate, and sulphate and small amount of organic matter dissolved in the water. The TDS and the conductivity are as a result of the dissolution of these ions in the water through natural means in the course of groundwater movement or anthropogenic means via leachate migration from soakaway, pit-latrines, dumpsites and industrial wastes.

Factor 2 explains 19.418 % of the total variance and it includes pH, salinity and total hardness (TH). These suggest an intrusion of seawater into the aquiferous system which increases its salt content and hardness. The saltwater incursion into the coastal plain-sand aquifer can be attributed to the aquifer recharge from the tide-influenced Imo River in the area which induces saltwater infiltration into the area (Amadi and Olasehinde, 2008).

Factor 3 is a moderate loading from temperature, turbidity and iron and constitutes 17.676 % of the total variance. The proximity of the Niger Delta to the sea favours high precipitation and relative humidity (Olobaniyi and Owoyemi, 2006). This coupled with temperature in the area encourages rapid chemical weathering, which leads to the formation of lateritic soils in the area. They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the reddish-brown or yellow colour to the soil. Furthermore, at the Owerri end of the study area, where the Benin Formation is underlie by the Ogwashi-Asaba Formation which is composed of shale, clay and lignite. Around Imo Concorde Hotel, Owerri, high iron content in the groundwater was traceable to the presence of marcasite in the shale and lignite horizons of the Ogwashi-Asaba Formation. The mineral marcasite is iron sulfide (FeS_2) with orthorhombic crystal structure. It is physically and crystallographically distinct from pyrite, which is iron sulfide with cubic crystal structure. Marcasite is soluble and more brittle than pyrite and easily breaks up due to the unstable crystal structure and this explains its availability in the groundwater system in the area. Studies revealed that marcasite occurs in sedimentary rocks (shales and low grade coals horizons) as well as in highly acidic conditions. The marcasite is likely from the shale and coal seams of the Ogwashi-Asaba Formation and low pH in the area enhances its enrichment in the groundwater system through high rate of infiltration due to heavy rainfall in the area.

The iron in groundwater is leached from the minerals contained in the Ogwashi-Asaba Formation overlain the Benin Formation in the area through the porous and permeable formation into the shallow water table below it. Leachate of metallic object from dumpsite also migrates through the unconfined highly permeable sandy formation to the water table. Iron may also be present in drinking water as a result of iron coagulants or the corrosion of steel and cast iron pipes during water distribution as well as weathering process of minerals. Iron is one of the most abundant metals in the earth's crust and an essential element in human nutrition. Estimates of minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability. Excessive iron in the body does not present any health hazard, only the turbidity, taste and appearance of the drinking water will usually be affected.

Factor 4 explains 9.898 % and comprises of sulphate, nitrate and nitrite. Both nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle (Egboka, 1985). However, the concentration of sulphate, nitrate and nitrite increases in water due to fertilizer application in farming. Soils in the area are still fertile and fertilizer application in the area is very low. This is why sulphate and nitrate concentration in the water is very

low. High nitrate, nitrite and sulphate in water are majorly induced by fertilizer application (Amadi and Olasehinde, 2008).

Factor 5 has the lowest loading with copper contributing about 6.904 %. Its presence in the groundwater may be attributed to the huge industrial and human activities in the area. Contributors to Factor 1, 2 and 3 are attributed to natural sources while Factors 4 and 5 comes from anthropogenic sources arising from the various human activities in the area.

Table 1: Univariate statistical over view of groundwater chemistry from Southern Nigeria

Parameters	Minimum	Maximum	Mean	Std. Deviation
Temperature	20.60	26.00	23.59	2.01
Turbidity	0.00	13.00	4.23	4.62
Conductivity	2.00	141.40	49.95	45.62
pH	6.00	7.70	6.81	0.48
Calcium	0.06	30.00	9.75	9.18
Magnesium	0.87	10.90	3.98	3.36
Sulphate	ND	4.00	1.57	1.63
Bicarbonate	ND	60.00	8.77	16.09
Nitrate	0.02	44.00	28.08	17.33
Nitrite	ND	0.13	0.06	0.05
Lead	ND	0.07	0.01	0.02
Iron	ND	1.17	0.21	0.35
Copper	0.07	1.00	0.59	0.24
TDS	6.00	75.00	23.92	21.96
Salinity	0.70	9.90	3.57	2.77
TH	2.00	98.70	33.96	29.88

Table 2: Varimax rotated factor loading matrix for groundwater chemistry data from Southern Nigeria

Parameters	F 1	F 2	F 3	F 4	F 5
Temperature	-0.005	0.215	0.785	-0.407	-0.095
Turbidity	0.010	-0.109	0.858	0.200	0.239
Conductivity	0.703	0.375	-0.074	0.082	0.400
pH	0.182	0.931	0.151	0.130	0.058
Calcium	0.940	0.064	-0.148	0.111	0.058
Magnesium	0.963	-0.033	-0.117	-0.020	-0.165
Sulphate	0.613	0.190	0.380	0.535	0.146
Bicarbonate	0.482	0.261	0.163	0.530	0.128
Nitrate	-0.131	-0.498	-0.193	0.745	-0.271
Nitrite	0.215	-0.013	0.072	0.857	0.286
Lead	0.121	-0.193	-0.088	-0.195	0.817
Iron	-0.220	-0.145	0.865	0.136	0.202
Copper	0.131	-0.013	0.217	-0.005	0.845
TDS	0.912	0.250	-0.009	0.119	-0.026
Salinity	0.015	0.923	-0.039	-0.117	0.234
TH	0.293	0.863	-0.276	-0.102	-0.103
Eigen Value	5.206	3.107	2.828	1.584	1.105
% Variance	32.534	19.418	17.676	9.898	6.904
Cumulative %	32.534	51.952	69.628	79.526	86.43

TDS – Total Dissolved Solid, TH – Total Hardness

Scree-plot and Factor Score Diagram

The screen-plot (Figure 2) is a graph of eigenvalues versus magnitude. It shows a distinct break between the steepness of the high eigenvalues and the gradual trailing off of the rest of the factors (Figure 2). In the present study, the 5 factors extracted (eigenvalues > 1) represent adequately the overall dimensionality of the data set and accounted for 86.43 % of the total variance, while the remaining factors (eigenvalues < 1) accounted for only 13.57 % of the total variance. Factor whose eigenvalues are <1 suggest that their contribution is minimal and can be ignored. Their contamination impact on the soil and water system are negligible (Amadi et al., 2012).

Similarly, the high communalities indicate that most of the variance of each variable is explained by the extracted factors. Loadings (< 0.500) have negligible impact or effect in respect to groundwater contamination in the area and were therefore omitted from Table 4.8. Similarly, the factor scores accounted for the six extracted factors with (eigenvalues > 1) and factor loading (> 0.500), contributing about 86.43 % of the total pollution in the area. This procedure reduces overall dimensionality of the linearly correlated data by using a smaller number of new independent variables called varifactor, each of which is a linear combination of originally correlated variables (Figure 3). The FA/PCA reduces the dataset into six major components representing the different sources of the contaminant. The usefulness of FA/PCA in interpreting the hydrogeochemical data as well as identifying and categorizing pollutants has been demonstrated in this study.

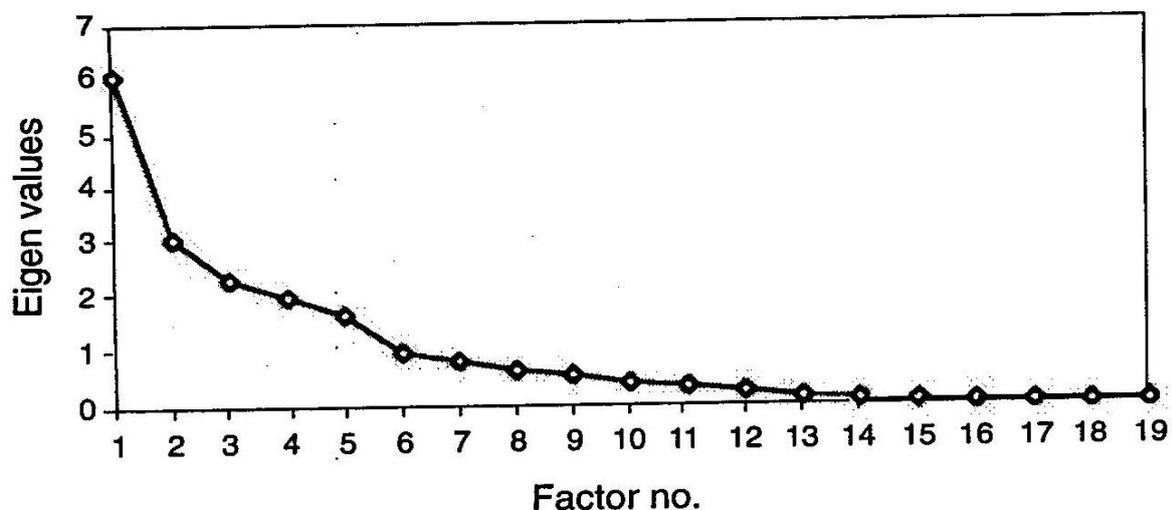


Figure 2: Scree-plot of the Factor Analysis

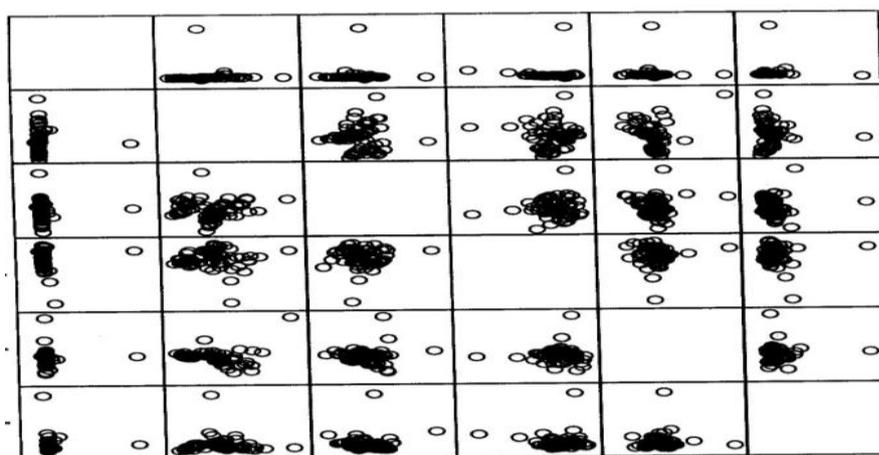


Figure 3: Factor Score diagram generated from the Factor Analysis

IV. CONCLUSION

The result of the factor analysis, as applied to the chemical data set of groundwater in the Benin Formation provides an insight into the hydrochemical processes prevalent in the area. Five factors including Factor-1 (Conductivity, Magnesium and TDS), Factor-2 (pH, Salinity and TH), Factor-3 (Temperature, Turbidity and Iron), Factor-4 (Sulphate, Nitrate and Nitrite) and Factor-5 (Flouride and Copper) extracted from the data-set represents the signature from dissolution of bedrock through which the groundwater passes, salt-water intrusion, leaching from the lateritic overburden, agricultural activities (fertilizer application) and effluent from industries in the area respectively. The major contributors to factors 1 and 3 are natural phenomenon while loading in factors 4 and 5 are anthropogenic, due to human interference. Out of 86.43 % of the total variance in the data-set, pollution coming from natural means account for 69.63 %. The porosity and permeability of the aquifer system in the area allows for easy movement of contaminant from one point to another. The remaining 16.80 % is attributed to man-made factors like farming activities, poor land-use system and industrial activities prominent in the area. Factor analysis techniques have been effectively demonstrated in the characterization of the Hydrochemical facies of the groundwater in the coastal plain-sand of Owerri area as well elucidating the various contamination sources and their spatial distribution.

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