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Full Length Research Paper

Characterization of groundwater chemistry in the coastal plain-sand aquifer of Owerri using factor analysis

A. N. Amadi[1], P. I. Olasehinde[1] and J. Yisa[2]

[1]Department of Geology, Federal University of Technology, P. M. B. 65, Minna, Nigeria.
[2]Department of Chemistry, Federal University of Technology, P. M. B. 65, Minna, Nigeria.

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Groundwater is a valuable natural resource for various human activities. Factor analysis was applied to the Hydrochemical data from the coastal plain-sand (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 five sources of solutes. The processes responsible for their enrichment includes: leaching of the overlying rock, seawater intrusion, chemical weathering, agricultural practices, dissolution of carbonate mineral and industrial effluent. Such processes are dominated by the significant role of anthropogenic interference with the groundwater from the aquifer in the area. The identified factors have contributed to the changes of the groundwater chemistry. The effectiveness of the method in characterizing groundwater hydrochemical facies is very high.

Key words: Factor analysis, groundwater chemistry, Benin formation, Owerri, Nigeria.

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 is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of the lithology, prevailing climatic condition, topography and resident time, solution kinetics and flow pattern of the aquifer (Abdullah 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, 1965; Stiff, 1951; 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 (Reghunath et al., 2002; Soylak 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 the 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., 1996) and characterization by factor analysis of the chemical facies of groundwater in the deltaic plainsands aquifers of Warri, western Niger Delta, Nigeria (Olobaniyi and Owoyemi, 2006).

The factor analysis technique 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

*Corresponding author. E-mail: akoamadi@yahoo.com. Tel: 08037729977.

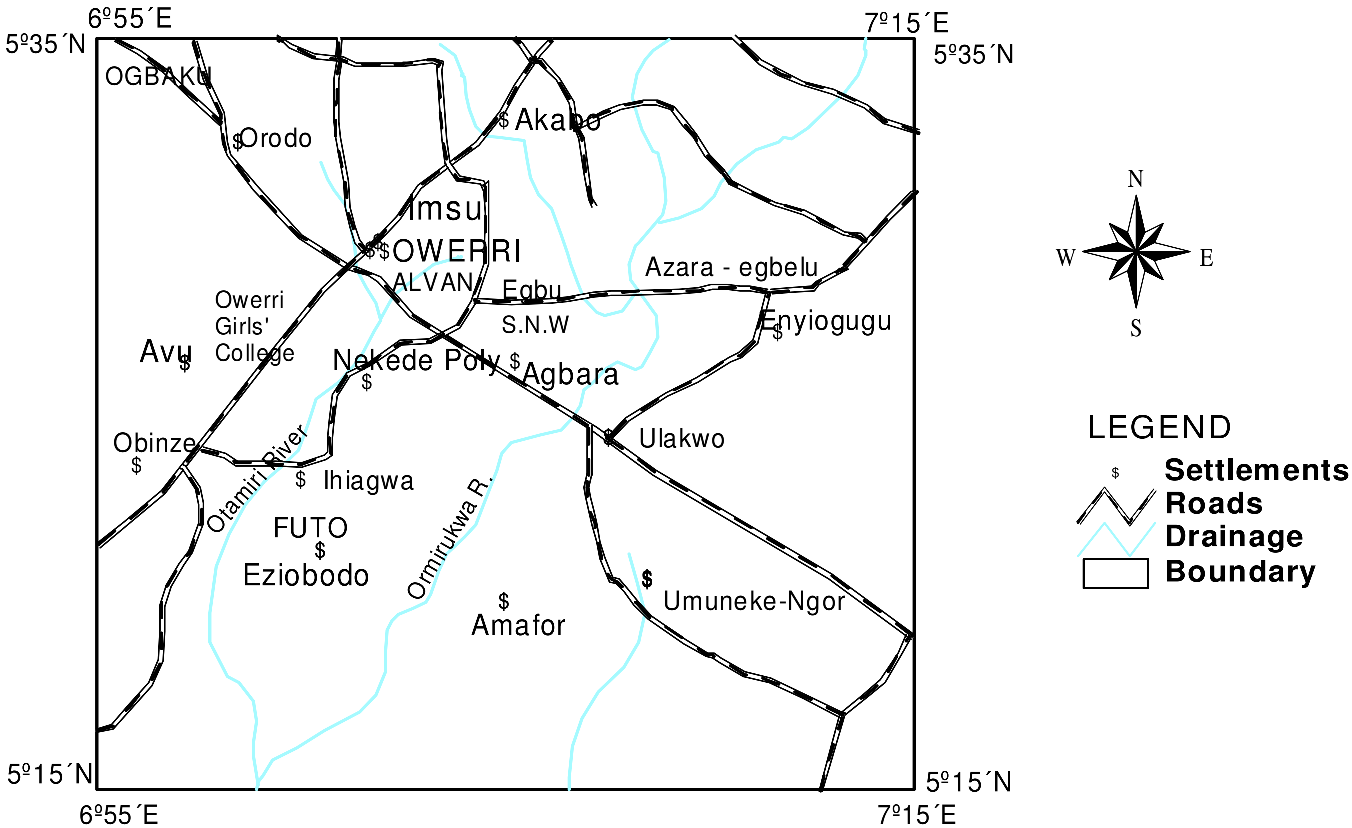

Figure 1. Map of the study area showing road network and drainage system.

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; Abdullah and Aris, 2005).

The aim of this study is to determine with the aid of factor analysis, the Hydrochemical facies of groundwater in the Benin Formation aquifer of Owerri and environ. 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.

LOCATION AND ACCESSIBILITY OF THE AREA

Owerri the 'Eastern Heart-land' lies between longitudes 6°55 'E to 7°15'E and latitudes 5°15'N to 5°35'N (Figure 1), covering an area of about 1340 km^2 and with population of 300,000 people. The area is generally flat with a good road network (Figure 1).

Climate and physiography of the area

The prevalent climatic condition is marked by two main regimes: the rainy and the dry seasons. The rainy season is from (April to October) during which the temperature varies from 23 to 26°C and this season is associated with the prevalent moisture-laden south-west trade wind from the Atlantic Ocean. This wet season is also characterized by double maximum rainfall during which the first peak occur in July and the second occurs in September with a mean annual rainfall of 2152 mm (Short and Stauble, 1967). Due to vagaries of weather, the August break sometimes occurs in July or early September. The dry season starts in November when the dry continental North-eastern wind blows from the Mediterranean Sea across the Sahara Desert and down to the southern part of Nigeria. Humidity is usually low and clouds are absent, during the dry season. The effect of the harsh North easterly wind, also called Harmattan, is felt within the period. The average monthly temperatures are high throughout the year. A mean annual temperature of 32°C is typical of the area (Ezeigbo, 1989). The area lies within the tropical rain forest belt of Nigeria. The natural vegetation in greater part of the area had been replaced by derived savannah grassland interspersed with oil palm trees.

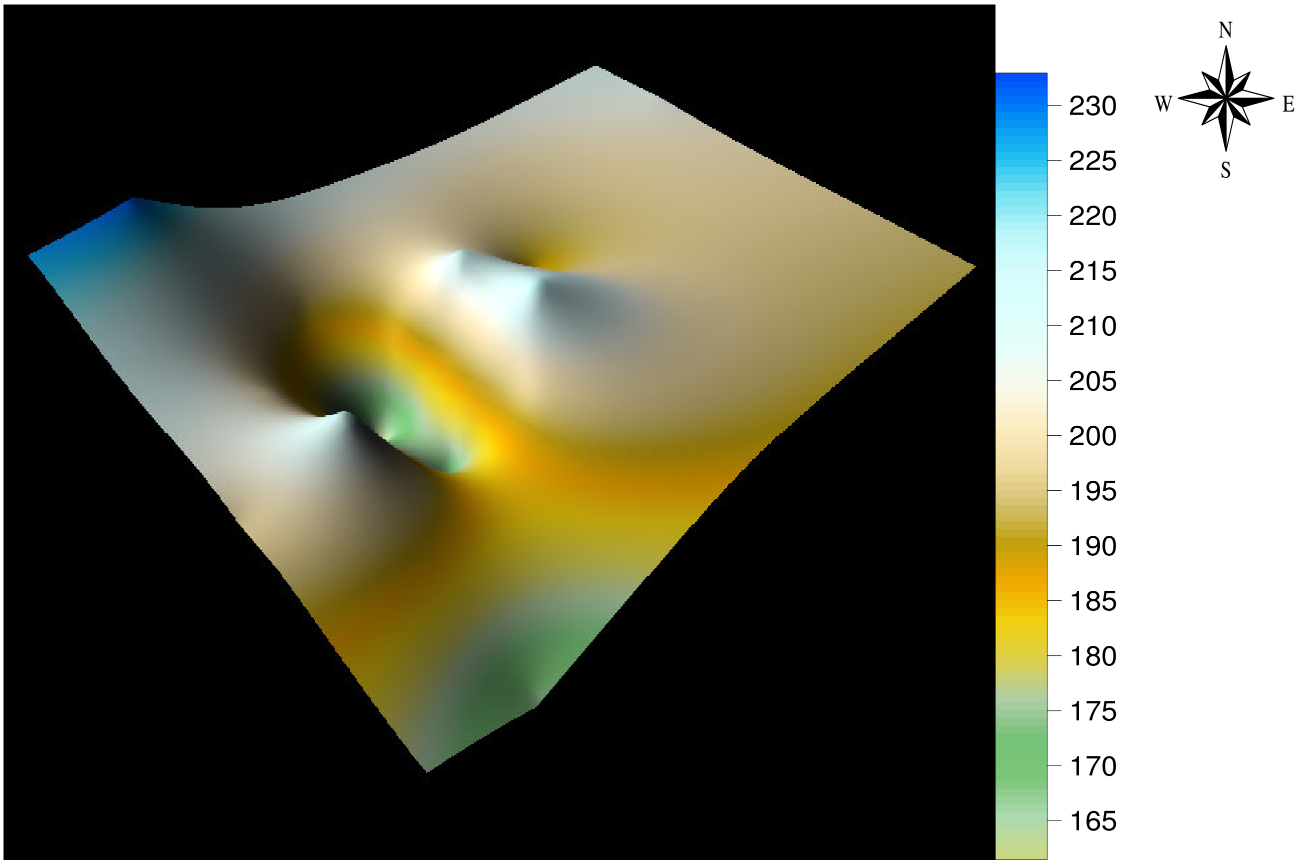

Figure 2. Digital terrain model (DTM) of the study area using surfer 8.0 software (Source: Amadi and Olasehinde, 2008).

A topographical mapping of the area was done using the GPS. Digital Terrain Model (DTM) of the area was made using Surfer 8.0 software as shown in Figure 2. The highland is at the Northwestern part of the area and slopes Southward. Since groundwater flow is topographically controlled (Amadi and Olasehinde, 2008), it implies that the groundwater flow direction is NW-SW.

Regional geological setting

Owerri falls within the Southeastern part of the Niger Delta, Nigeria. The Niger Delta basin of Nigeria is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 4°00 to 7°00'N and longitude 5°00'E to 8°00'E covering an area of about 108,900 km^2 (Figure 3). Apart from petroleum, the Niger Delta is very unique geologically among the deltas of the world as it typifies the most classic delta in geologic literature (Weber, 1971). The Niger Delta is a pro-grading depositional complex within the Cenozoic Formation of Southern Nigeria. It extends from the Calabar Flank and the Abakaliki Trough in Eastern Nigeria to the Benin Flank in the West and it opens to the Atlantic Ocean in the South (Ofoegbu, 1998).

The present general morphology of the Niger Delta (Figure 3) is that of a wave and tide dominated delta, though more wave dominated. At present, it appears to be constructive in the center and destructive in the flanks. The sediments in the Niger Delta are mostly sandy as a result of the fact that nearly all the environments in the sub-aerial part are of upper coastal or delta plain origin (Weber, 1971). The sediment source area in the shield consists mainly of crystalline rocks of the Guinea highlands basement complex together with the cretaceous and tertiary sediments derived from the Cameroun volcanic zone. The quality and abundance of reservoir throughout the tertiary sequence of the delta indicates

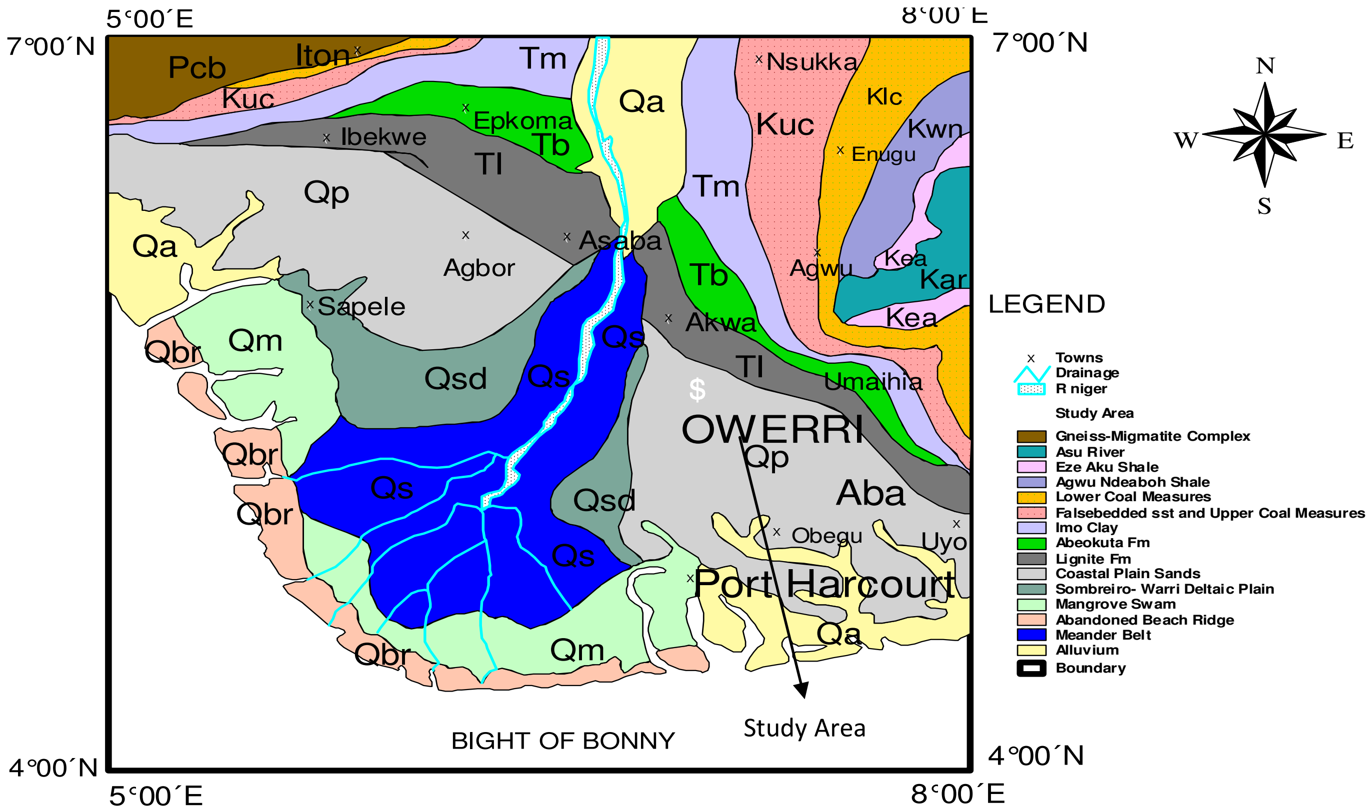

Figure 3. Geological map of Niger Delta showing study area.

that there has always been a major sand contribution from the shield area. Long-shore currents carry sediments discharged at the apex of the delta both Northwest and Eastward along the coast to form sand beaches, beach ridges and offshore bars (Short and Stauble, 1967). The marginal portions of the delta are relatively starved of sand and in some places, suffer encroachment from the sea. The strength of these currents diverts the sediments brought into the sea by the rivers, distributing them along the coast and preventing the formation of a bird-foot-type delta. This gives the delta its present accurate marginal shape (Figure 3).

Local geology of the area

The study area is outcropped by the Benin Formation which is known as the coastal plain-sands (Figure 4). It consists mainly of sands, sandstone and gravel with clays occurring in lenses. The sands and sandstones are coarse to fine partly unconsolidated with thickness ranging from 0 - 2100 m (Avbovbo, 1978). The sediments represent upper deltaic plain deposits. The shales are few and they may represent upper deltaic plain deposit. However, the formation lacks faunal content and this makes it difficult to date, though an Oligocene-Recent age is generally accepted. The Benin Formation is composed mainly of high resistant fresh water-bearing continental sands and gravels with clay and shale intercalations (Onyeagocha, 1980).The environment of deposition is partly lagoonal and fluvio-lacustrine/deltaic (Rayment, 1965). The formation which dips South westward starts as a thin edge layer at its contact with the Ogwashi-Asaba Formation in the Northern part of the area and thickens Southwards to about 100 m in Owerri area (Rayment, 1965). The sandy unit which constitutes about 95% of the rock in the area is composed of over 96% of quartz (Onyeagocha, 1980). A marked banding of coarse and fine layers with a large scale cross bedding constitute the major sedimentary structures in the area.

Stratigraphy

The stratigraphy of the Southeastern Nigeria (Table 1) has been studied in details by Uma and Egboka (1985). The stratigraphic succession of rocks in the study area consists of Nsukka Formation, being the oldest formation and followed by Imo-Shale, Ameki Formation, Ogwashi-Asaba Formation while the youngest is the Benin Formation (Uma and Egboka, 1985) as contained in Table 1. The coastal plain sand belonging to the Benin Formation extends to a considerable depth in the area and with good hydraulic properties for groundwater development.

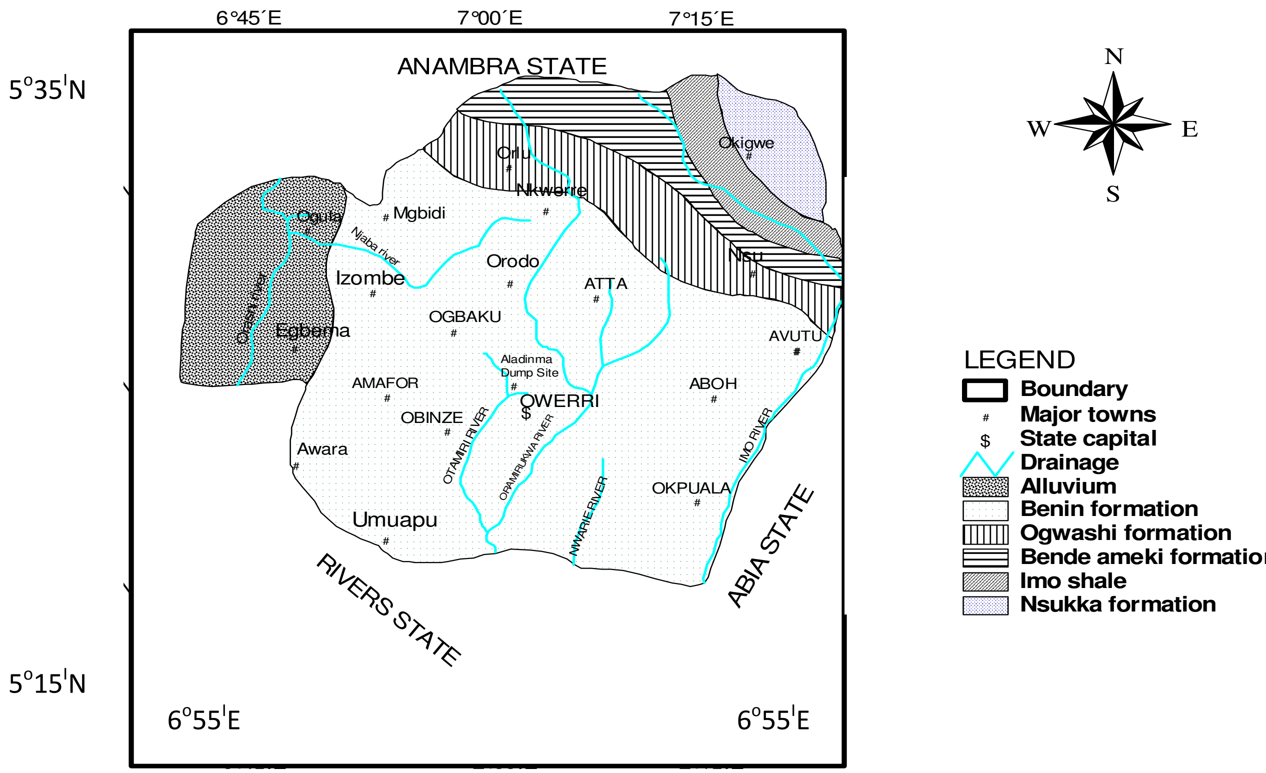

Figure 4. Geology map of the study area.

Table 1. Stratigraphy succession of rocks in Owerri area (Uma and Egboka, 1985).

	Age	Formation	Lithology
	Micoene-Recent	Benin Formation	Medium to coarse grained, poorly consolidated with clay lenses and stringers.
Tertiary	Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsolidated sand with lignite seams at various layers.
	Eocene	Ameki Formation Nanaka sand	Grey clayey-sandstone and sandy clay stone.
	Paleocene	Imo Shale	Laminated clayey-shale
Upper Cretaceous	Maastrichian	Nsukka Formation	Sand stone intercalated with shale and coal beds.

The formation consists predominantly of very thick coastal sand, sandstone, clays and sandy clays occur in lenses. The Benin Formation is in part cross-stratified with the forset beds alternating between coarse and fine-grained sands (Table 1). Petrographic study on several thin sections (Onyeagocha, 1980) shows that quartz makes up more than 95% of all grains. Groundwater occurs abundantly in the coastal plain sands (Benin Formation) and the static water level (SWL) ranges from 8 - 65 m depending on the location and the time of the year. The Benin Formation is a good aquifer with an average annual replenishment of about 2.5 billion m^3 per year (Onyegocha, 1980). In most areas, the sandy components forms more than 90% of the sequence of the layers therefore permeability, transmissivity and storage coefficient are very high.

METHOD OF STUDY

A pair of 50 groundwater samples was collected from boreholes tapping the Coastal Plain-sand (Benin Formation) aquifer of Owerri and environs 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

Table 2. Univariate statistical overview of groundwater chemistry data from Owerri and environs.

	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	0.60	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

absorption/adsorption of trace metals to the walls of the container (Schroll, 1975). 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 the 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 equipments.

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 colorimetric 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 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 eigenvalue 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, -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. Highly Negative values (< -1) reflects areas virtually unaffected by the process while zero score shows areas with only moderate effect of the process. The three factor scores represent the three types of vulnerability in the area.

RESULTS AND DISCUSSION

Table 2 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 3. 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 dataset.

ND-Not detected, TDS-Total dissolved solid and TH-Total hardness

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 soak away, pit-latrine, 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

Table 3. Varimax rotated factor loading matrix for groundwater chemistry data in Owerri and environs.

	Factor-1	Factor-2	Factor-3	Factor-4	Factor-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	0.440
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
Eigenvalue	5.206	3.107	2.828	1.584	1.105
Percentage of variance (%)	32.534	19.418	17.676	9.898	6.904
Cumulative(%)	32.534	51.952	69.628	79.526	86.43

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. The iron in groundwater is leached from thick lateritic over-burden in the area through the porous and permeable formation into the shallow water table below it. Leachate of metallic object from dumpsites 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 the use 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 sulfate, 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.

Groundwater vulnerability

The results of the chemical data and the factor analysis were used to develop a groundwater vulnerability map (Figure 5).

The study area was categorized into three: areas of high vulnerability, moderate vulnerability and low vulnerability. Areas close to the four tertiary institutions in the area: Federal University of Technology, Owerri (FUTO), Imo State University, Owerri (IMSU), Federal Polytechnic Nekede (FEDPONEK), Alvan Ikoku College of Education, Owerri (ALVAN) and Aladimma dumpsites have high vulnerability to groundwater pollution. The upsurge in students' population and the poor sanitary system (unlined soakaway and pit-latrine) common in the area might be responsible for the observed anomaly.

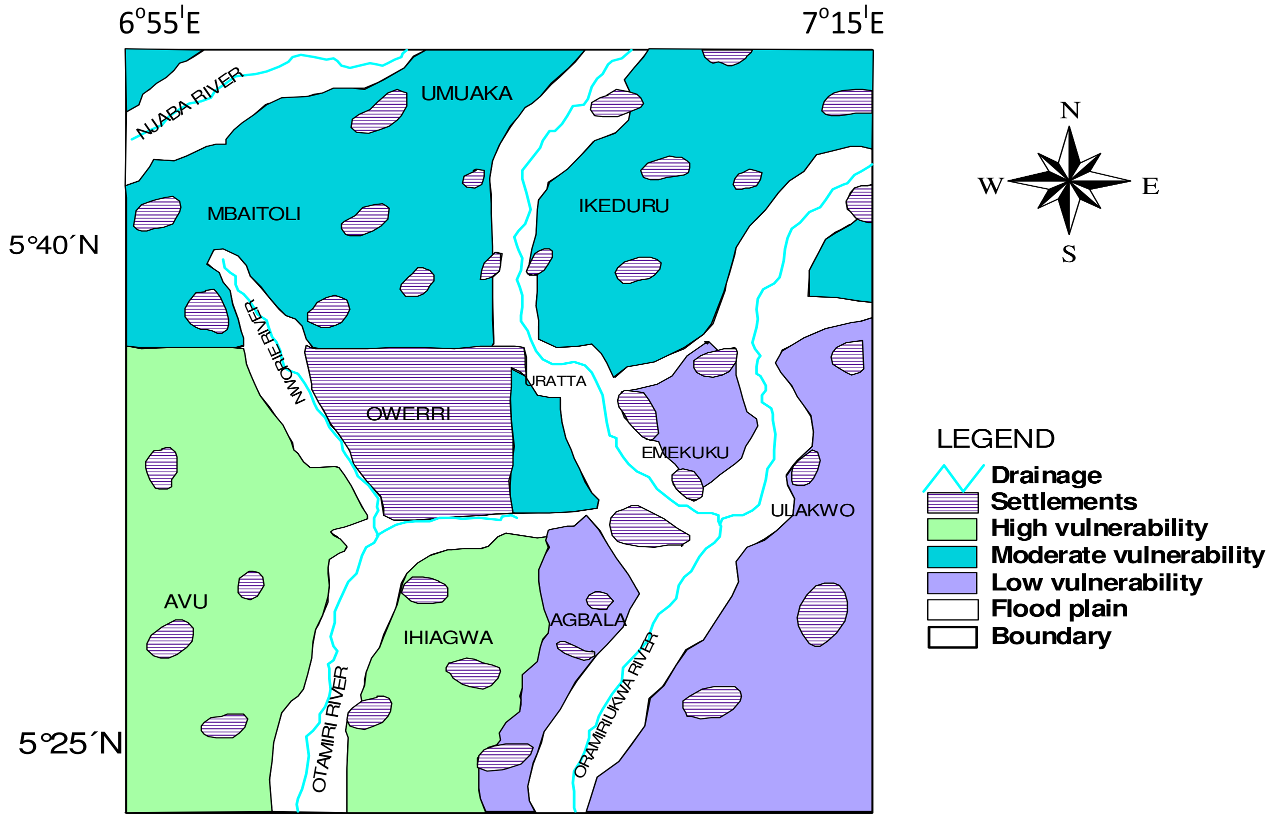

Figure 5. Vulnerability map of the study area.

Conclusion

The result of the multivariate statistical analysis, as applied to the chemical data set of groundwater in the coastal plain-sands of Owerri area provides an insight into the underlying controlling Hydrochemical processes 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 signatures 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 to 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 dataset, pollution coming from natural means accounts 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 aquifer of Owerri area as well elucidating the various contamination sources and their spatial distributions.

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