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Geoelectrical Soundings for the Determination of Groundwater Potential Zones in Anambra State, Southeastern Nigeria

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ABSTRACT

Geoelectrical sounding technique has been used to determine the groundwater potential zones in Anambra state, Nigeria. The study area is underlain by four main geological formations. A total of four hundred and fifty-two (452) vertical electrical sounding (VES) was acquired over one hundred (100) locations, employing the Schlumberger array configurations. Static water level (SWL) and yield of the aquiferous layer at various observation points were determined by pumping test from fifty (50) borehole sites. The depth, thickness, lateral extent and resistivity of aquiferous horizon were determined by the electrical survey. Aquifer hydraulic properties were inferred using the empirical relationships. Interpreted VES data show predominance of A and K curve type, indicating dry overburden, underlain by wet/saturated horizon. Comparisons of geoelectric sections and borehole logs in a SW-NE direction show fairly good match, while correlation of geoelectric sections along SW-NE direction show variation in depth for the suspected aquiferous horizon. 2D maps of resistivity, depth, thickness, transverse resistance, longitudinal conductance, coefficient of anisotropy, aquifer transmissivity and hydraulic conductivity were constructed. High values of estimated aquifer transmissivity predominate, thus suggesting thick and prolific aquiferous zone. Groundwater flow direction is variable in the study area. Two potential groundwater zones were identified based on aquifer transmissivity potentials, interplay of apparent resistivity, thickness and coefficient of anisotropy. They are the moderate and high potential zones. The various contour maps and the groundwater potential zones map will serve as a useful guide for groundwater exploration and development in the study area. The developed physical transforms can be adapted to other areas with similar geologic setting.

Introduction

The need for groundwater has resulted in a geometrical rise in the drilling of private boreholes with case of abortive and extremely low discharge rate. Failure can occur as a result of poor design, construction and maintenance. In most cases, poor sitting of borehole or water well could be a major cause of failure. However, sitting of borehole in many geological environments are major concern to funding agencies, implementing institution and local communities (Anizoba, et al, 2015). Knowledge of groundwater potential zones in regions is key to a successful groundwater exploration. This is geared towards determining the water bearing formations; evaluate their hydrogeological properties and quality of water present in these formations. Many investigation techniques are commonly employed with the aim of understanding the lithologies and depth to water table. Geoelectrical sounding methods are useful tools (Utom, et al, 2012), especially the vertical electrical sounding (VES) techniques which is a non-invasive, relatively cheap and used for locating sites/depths for groundwater exploitation (Oborie and Udom, 2014) and high quality data in areas constrained with complex subsurface conditions (Urish, 1983 and Meju, 2000). In recent years, outstanding attempts have been made by several works to determine groundwater potential zones or water bearing formations from geoelectrical sounding method (Batte,et al, 2010; Nwosu, et al, 2013; Ayuk, et al, 2013; Okonkwo and Ujam, 2013; Anizoba, et al, 2015; Abiola, et al, 2009; Okoro, et al, 2010; Okonkwo, et al, 2016; Amadi, et al, 2011; Okereke, et al, 1998; Obiora, et al, 2016; Ishola, et al, 2013; Anudu, et al, 2011; Obiajulu and Okpoko, 2015). Batte, et al, 2010 correlated geoelectric data with aquifer parameters to delineate the groundwater potential of hard rock terrain in central Uganda. Nwosu, et al, 2013 measured the hydraulic properties of the aquiferous zones using geoelectrical method for the evaluation of groundwater potentials in the complex geological area of Imo State, Nigeria.Obiagulu and Okpoko, 2015 used resistivity information to characterize the groundwater potentials of Ihiala in Anambra State, Nigeria. Okereke, et al, 1998 integrated geological and geophysical techniques to determine potential groundwater sites in Cross River State, Nigeria. Amadi, et al, 2011 and Abiola, et al, 2009 used resistivity data and overburden thickness to evaluate the groundwater potential in a basement complex terrain. Okoro, et al, 2010 used hydrogeological properties of rocks and geomorphic characteristics to evaluate groundwater potentials in parts of the escarpment areas of Southeastern Nigeria. Okonkwo and Ujam, 2013 delineated groundwater potential

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zones at Oduma, Enugu State, Nigeria based on the classifications of aquifer transmissivity potentials. Anudu, et al, 2011 integrated maps of hydro-resistivity, geoelectric parameters and 1-grid vector basement relief map for groundwater potential zones in Awka municipality using 2D surface map of the anisotropic coefficient map layer, hydraulic conductivity map layer, isoresistivity map layer and isothickness map layer. In the above studies, it is evident that determination of groundwater potential zones using surface geoelectrical sounding is feasible. However, these studies are localized, area-specific and models, based developed. Therefore, the present study attempts to determine groundwater zones in a regional sense using comparisons of 2D maps of aquifer transmissivity potentials classification and overlay analysis of 2D resistivity map, overburden depth map, isopach map, aquifer transmissivity map and coefficient of anisotropy map.

Location and Physiography

The study area is located in Anambra State, Nigeria (Figure 1). The area lies between geographical co-ordinates, longitudes 06^{0} 38^{1}E – 007^{0} 15^{1}E and Latitudes 05^{0} 42^{1}N – 006^{0} 45^{1}N, with an area extent of about 4844sqkm (1870sqmi). The project domain is bordered to the north and northwest by Kogi State, to the West by Delta State and to the South, Southeast and Northeast-east by Imo, Abia and Enugu State respectively (Figure 1). The topography in the study area is characterized by geomorphic features, with typical cuesta of an escarpment region (Okoro, et al, 2010). It shows two major types of landforms which consist of a high relief zone and lowland areas with undulating residual hills and valleys (Figure 2).

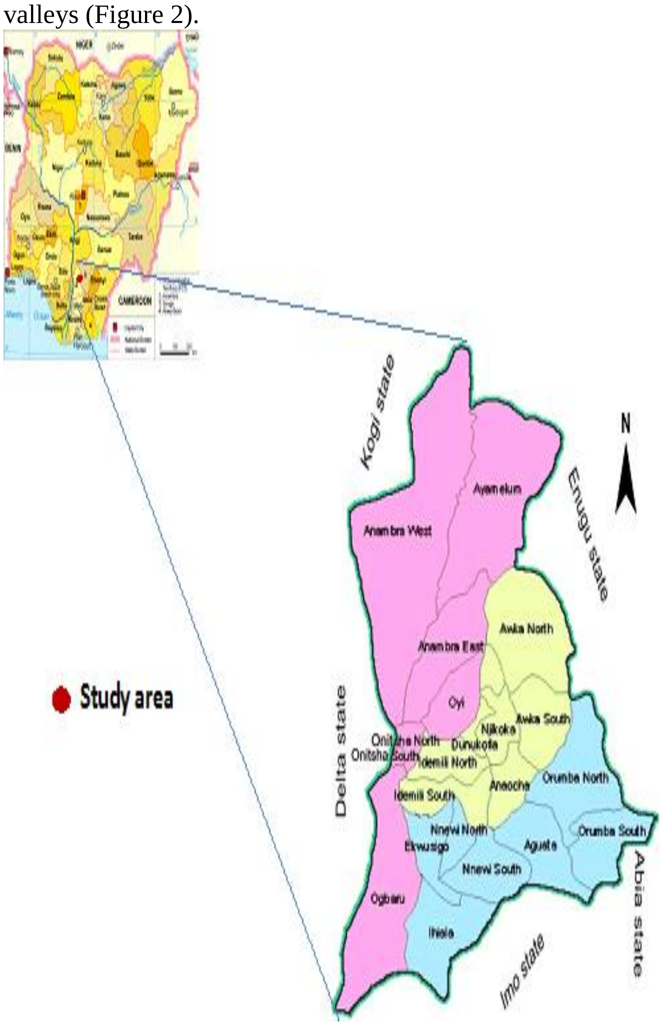

Figure 1. Map of Nigeria showing the study area (World Gazette, 2011).

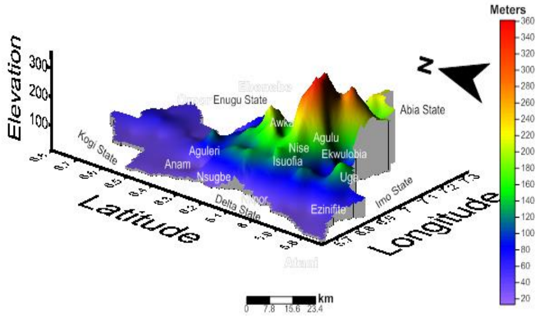

Figure 2. Relief map of the study area.

The high relief zones are found within the southeastern part, around Agulu-Nanka-Ekwulobia-Aguata axis with an elevation of about 380meters (1246.4feet) above sea level (ASL). While the lowland areas are most profound in the Northwest – Southwest, around Anam-Atani axis with an elevation of about 20meters (65.6 feet). The residual hills are remnants, resistant feature found mostly at the flank of high relief zone.

Geology and Hydrogeology

The study area falls within the Tertiary Niger Delta Basin (Nwajide, 2013). The age range is from Paleocene to Recent. Four main geological formations underlie the study area (Figure 3); the Imo Shale, Ameki Group (Ameki Formation, Nanka Formation and Nsugbe Formation), Ogwashi-Asaba Formation and Alluvial Sands. The lithostratigraphic units have a thickness of up to 2500meters (Reyment, 1965). Hydrogeologically, the study area falls within the Mamu River Basin (Offodile, 2002; Figure 4). It is a sub-basin of the Anambra River Basin. The River Mamu is a very important tributary of the Anambra River. The most important aquifers in the Mamu River Basin are the Ajali Formation, the Ebenebe, Amenyi and the Nanka Sands. The Ajali Formation exhibit confined condition towards the center of the center of the basin. It is estimated that in Awka area, this aquifer could be encountered at much deeper levels of about 360m to 800m depth. Nanka sands around Nanka, Idemili, Oko, Agulu, Nnobi and Ekwulobia, the water table is generally very low, ranging from 30 to 300m in depth. Apart from Ajali Formation, shallow aquifers exist within the Mamu River Basin. They are the Ugwuoba Sandstone, also described as Ebenebe Sandstone and Amenyi sands. These aquiferous sand bodies are members of Imo Shale. Higher water tables conditions are obtained in boreholes located in the lowland areas or valleys usually interspersing the predominantly hilly country.

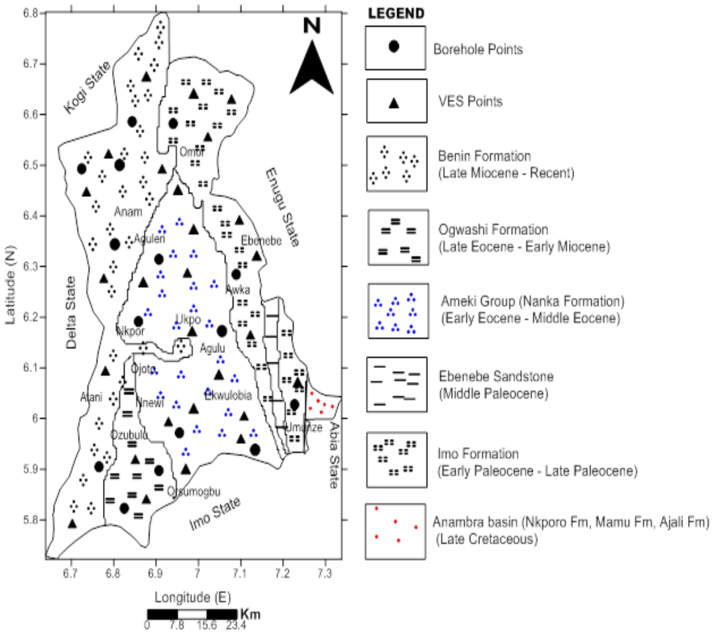

Figure 3. Geologic map of the study area showing VES and Borehole points.

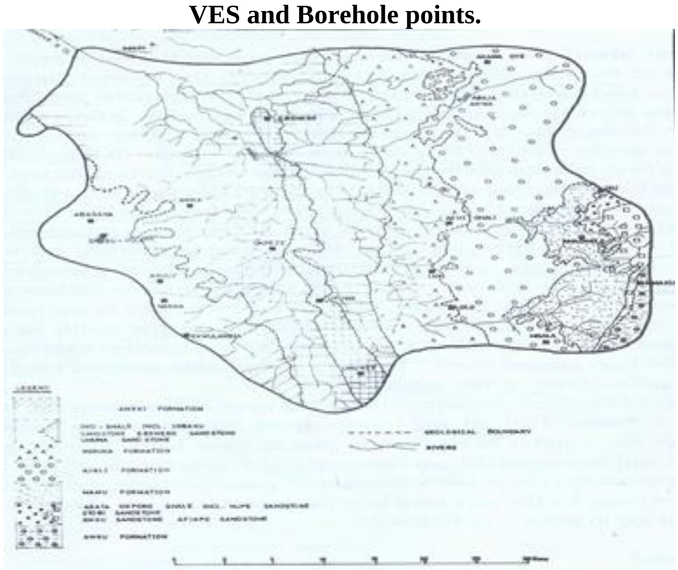

Figure 4. Geological map of the Mamu sub-basin (Offodile, 2002).

Methodology

Theoretical Basis

Evaluation of groundwater potential was done using information from Electrical Resistivity (ER) method. The ER method is utilized in diverse ways for groundwater water exploration (Zohdy, 1976; Choudhury, et al, 2001; Frohlich and Urish, 2002). Electrical surveys are usually designed to measure the ER of subsurface materials by making measurements at the earth surface. Currents are introduced into the ground by a pair of electrodes, while measuring the subsurface expression of the resulting potential fields with an additional pair of electrodes at appropriate spacing.

Data acquisition and Interpretation

A total of four hundred and fifty-two (452) vertical electrical sounding (VES) were carried out in over one hundred and seven towns (107) within the study area (Figure 3). Some VES stations were very close to existing boreholes for correlation purposes. The Schlumberger electrode configuration (Figure 5) was used, with a maximum current and potential electrodes separation of AB=800meters and MN=40meters respectively. The equipment used for the fieldwork was the versatile ABEM terrameter SAS 1000 resistivity meter. After acquiring the data, measured field resistance (R) in Ohms was converted to apparent resistivity (ρ_a) in Ohm-meter by multiplying resistance (R) by the geometric factor (k). A log-log graph plot of apparent resistivity (ρ_a) against current electrode distance (AB/2) was plotted for each VES station to generate a sounding curve. Using the conventional partial curve matching technique, in conjunction with auxillary point diagrams (Orellana and Mooney, 1966; Koefoed, 1979; Kellar and Frischknecht, 1966), layer resistivities and thickness were obtained, which served as a starting point for computer-assisted interpretation. The computer program INTERPEX was used to interprete all the datasets obtained. From the interpretation of the resistivity data, it has been possible to compute for every VES station, the Transverse resistance (T)

$$T = h \times \rho_a \quad (1)$$

And longitudinal conductance (S)

$$S = h/\rho_a \quad (2)$$

Where h and ρ_a are thickness and apparent resistivity of the aquiferous layer. These parameters T and S are known as the Dar-Zarrouk variable and Dar-Zarrouk function respectively (Maillet, 1947). Both parameters T and S and the derived concept of Dar-Zarrouk curves (Maillet, 1947) are of prime significance in the development of interpretation theory for VES data. Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity and transverse resistance on the one hand and between aquifer transmissivity and aquifer longitudinal conductance on the other. Taking into account a prism of aquifer material having unit cross-sectional area and thickness (h), they combined equations 1 and 2 to obtain the following relationship between Transmissivity (Tr) and the so called Dar-zarrouk parameters.

$$Tr = K\sigma R \quad (3)$$

$$Tr = K/\sigma \times S \quad (4)$$

Where σ is the aquifer conductivity or electrical conductivity and K, the hydraulic conductivity of aquifer. In equation 3 & 4, the quantities Kσ and K/σ are assumed to remain fairly constant in areas of similar geologic setting and water quality (Niwas and Singhal, 1981).

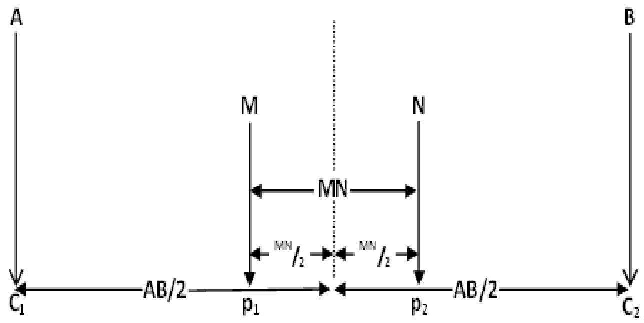

Figure 5. Schlumberger electrode configuration (Okonkwo, et al, 2017).

Results and Discussion

Analysis of Well logs

Available borehole lithologs in the study area show variations in the drilled depth (Figure 6), from 80meters to approximately 300m. Drilled depth generally increases from the East and gets deeper towards deeper towards the central part and shallows towards the west and southwest. The textural characteristics are mainly lateritic sand, fine-grained sand, clay sand, clay/shale and medium to coarse-grained sand. Based on the foregoing, two hydrostratigraphic units can be deciphered. The first is a composite aquifer unit. This unit consists of an interbed of fine sand-clayey sand-clay/shale. This unit is typical of transition zone. It is the dominant unit within and around the country Mbosi. Thickness of the sequence range from 10meters to 50meters. The second is the main aquifer consisting of medium to coarse-grained sands. This is a good groundwater potential zone. This zone is thick (30meters to 80meters) within and around Nanka, Agulu, Ekwulobia etc, and thins gradually towards Achalla, Ukwulu, Nawagu etc.

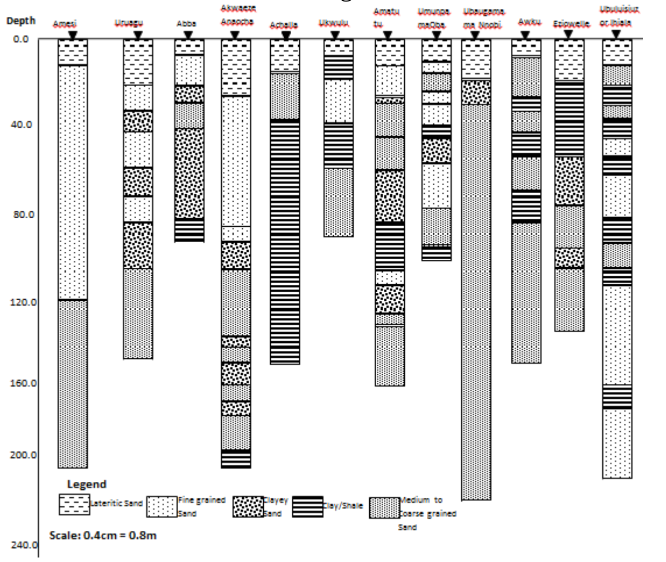

Figure 6. Sequential records of drill cuttings of some wells in the study area.

Comparison of Borehole logs and Geoelectric sections

Geoelectric sections are lithologically inferred from VES interpreted layer models. They reflect the underground lithology up to which it reaches (Sattar, et al, 2014). This comparison is between the VES interpreted models and available nearby well logs to observe their vertical distribution. From the comparison (Figure 7), it shows a fairly good match.

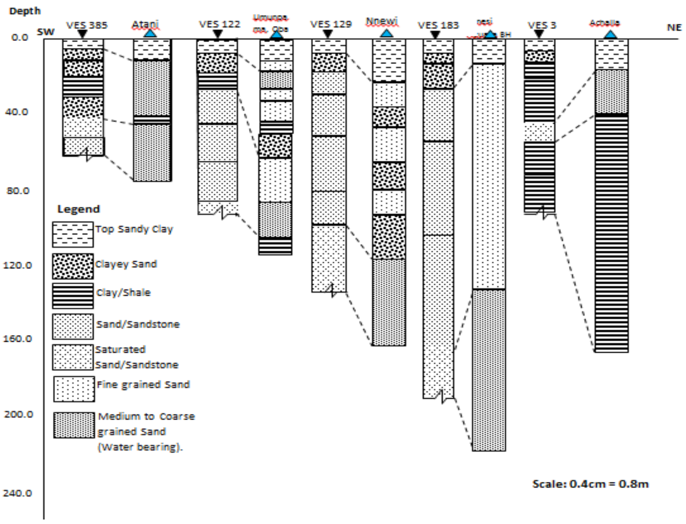

Figure 7. Correlation of geoelectrical section with borehole logs in the study area.

Geoelectrical Soundings

Two dimensional (2D) maps of apparent resistivity, isopach, depth, transverse resistance, longitudinal conductance and the electrical anisotropy of the aquiferous horizon have been constructed using the results of the surface geoelectrical sounding interpretation. Apparent resistivity (Figure 8) variation is generally high, with variable aquifer thickness (Figure 9). The aquifer depth map (Figure 10) also show similar trend with aquifer thickness. The spatial distribution of the aquifer transverse resistance and longitudinal conductance computed from geoelectrical sounding interpretation is shown in figures 11 and 12 respectively. Maximum values of transverse resistance resistance are observed around Ogbunka-Ekwulobia-Agulu-Nkpor axis, indicating thick resistive horizon. The longitudinal conductance shows thick resistive basement topography trending N-NW-SE direction along Awka-Anam-Omor axis in the range of $6\Omega^{-1}$ to $18\Omega^{-1}$.Coefficient of electrical anisotropy (Figure 13) range from 0.2 to 4.6 in the study area. Variation in electrical anisotropy (λ) shows changes in water tables (Shailaja, et al, 2016).

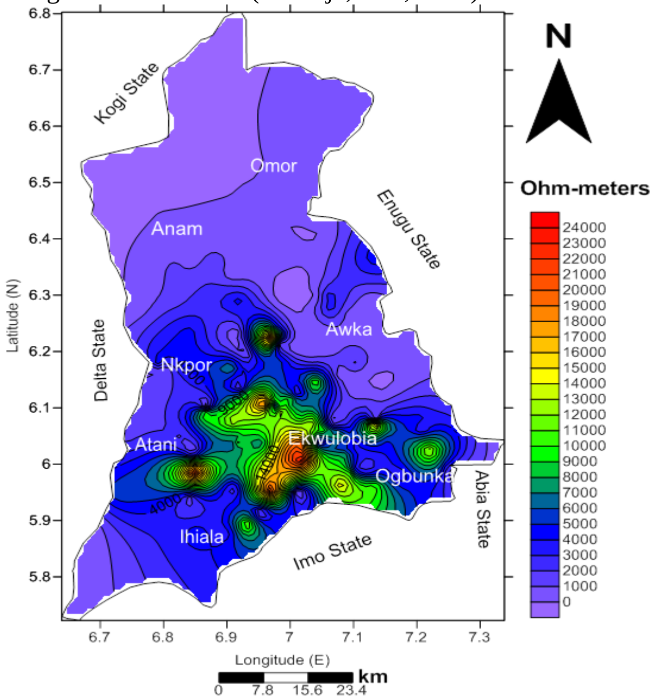

Figure 8. Apparent resistivity map of the study area.

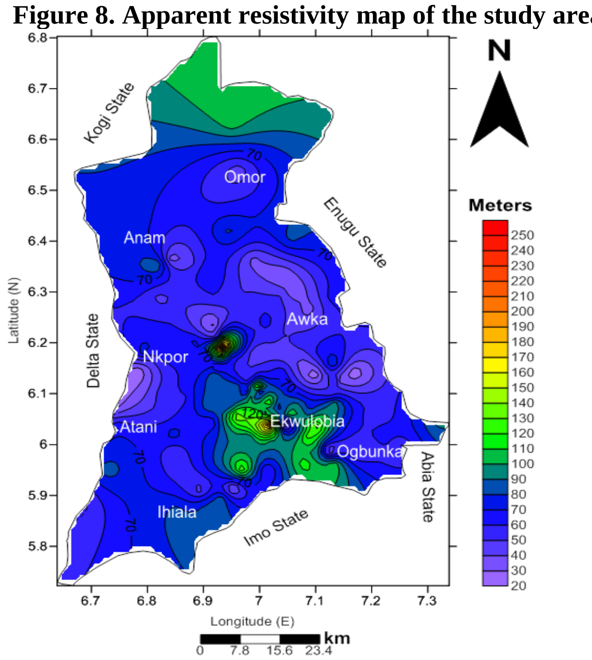

Figure 9. Aquifer thickness map of the study area.

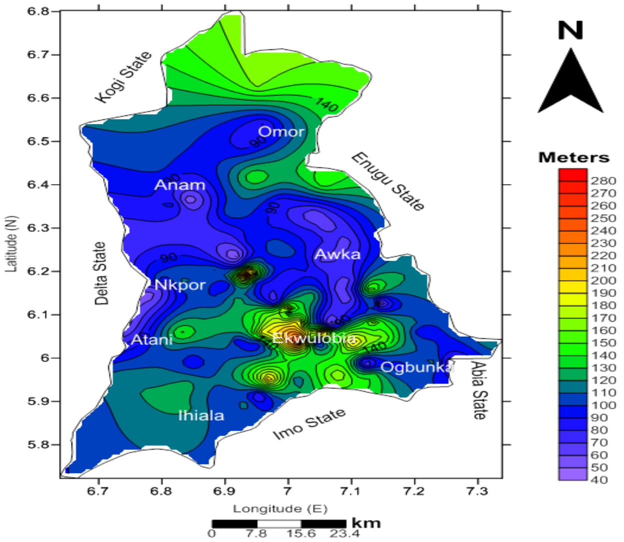

Figure 10. Aquifer depth map of the study area.

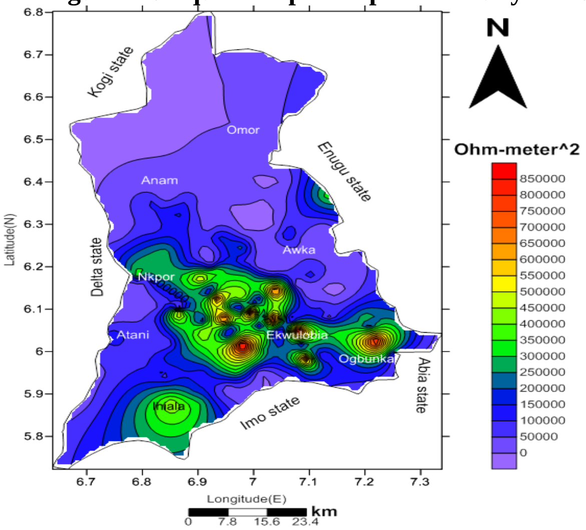

Figure 11. Aquifer transverse resistance map of the study area.

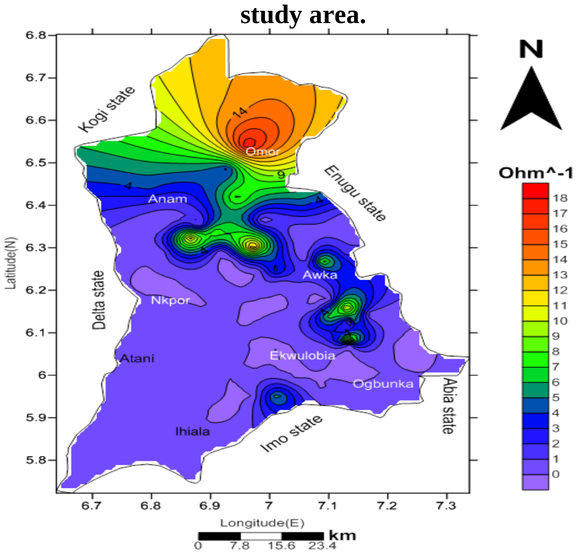

Figure 12. Aquifer longitudinal conductance map of the study area.

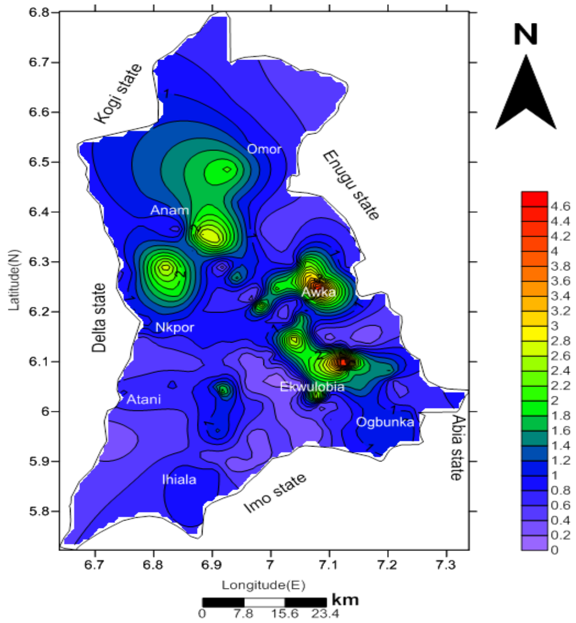

Figure 13. Coefficient of electrical anisotropy map of the study area.

Correlation of Geoelectric layer sections

Correlation of geoelectric layer sections in a SW – NE direction were constructed (Figure 14). This section cut across the geology in the study area. The correlation shows thinning (pinch-out) of the suspected saturated sand/sandstone to the NE. The sand pinch-out occurs around the country Mgbakwu, Amansea and Achalla. The sand is well developed around Ekwulobia, Agulu, Nanka, Nnobi, etc in the central part (VES 222, VES 129). From the correlation, a basin structure is depicted based on the thickness of saturated sand variation. The sand seems progradational to the SW.

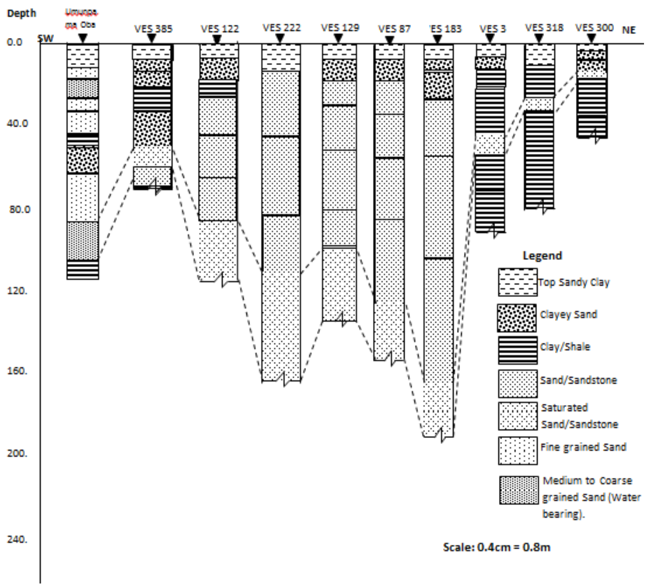

Figure 14. Correlation of geoelectric layer sections in a SW-NE direction in the study area.

Resistivity Curve type

Resistivity curves generated for the 452 VES data in the study area were multilayer curve systems. The model starts from 4 layers to 8 layers case. Analysis was based on the 3 layer model (Figure 15) in order to generate their curve types from the frequency distribution chart; the 7 layer case dominates having the AAAAK and HAAAK curve types dominating (Figure 16). Based on the individual curve type, A and K curve types are dominant in the study area (Figure

17). This indicates dry overburden, underlain by wet/saturated horizon.

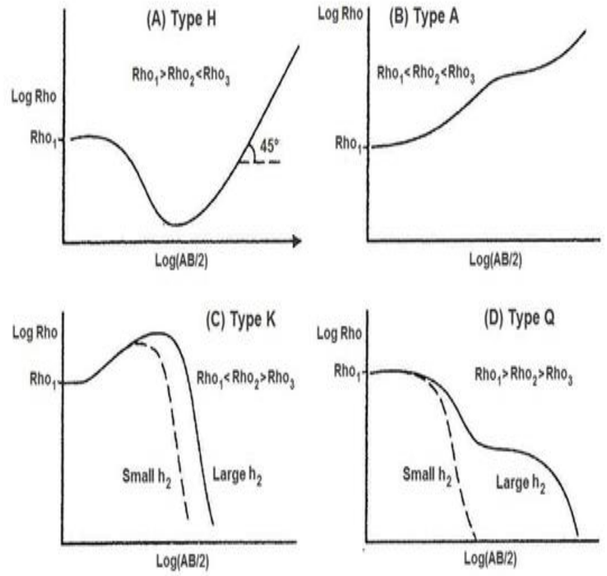

Figure 15. Three layer based auxillary resistivity curve types (Reynold, 1997).

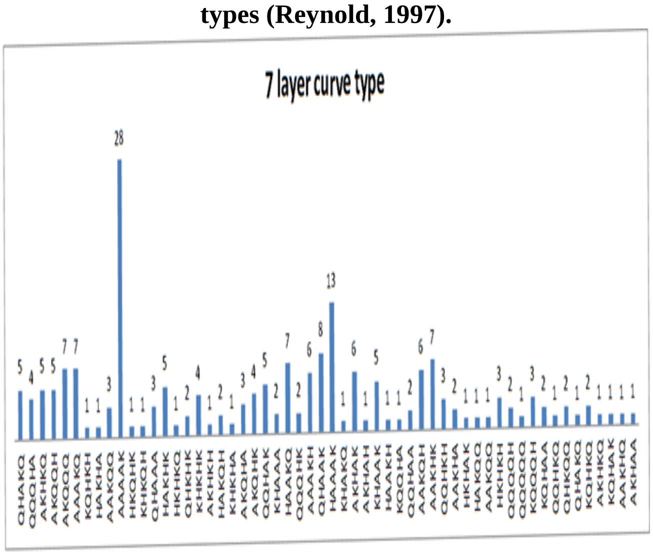

Figure 16. Resistivity curve types frequency distribution bar charts for a 7 layer case in the study area.

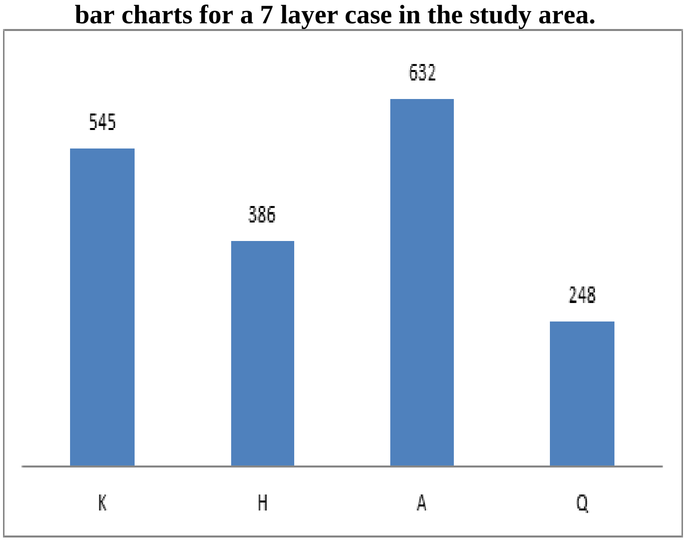

Figure 17. Summary of the dominant curve type in the study area.

Estimating aquifer transmissivity

Representative averages of transverse resistance (R) and the corresponding available transmissivity (T) from pumping test data were plotted (Figure 18). The scatter plot reveals fairly linear relationship between T and R with coefficient of regression, R = 0.86.

$T\ (m^2/day) = 0.0003 \times R + 21.711$ (5)

Hence, with the relation (equation 5), it was possible to estimate transmissivity in the study area (Figure 19) even to areas where no borehole records exists.

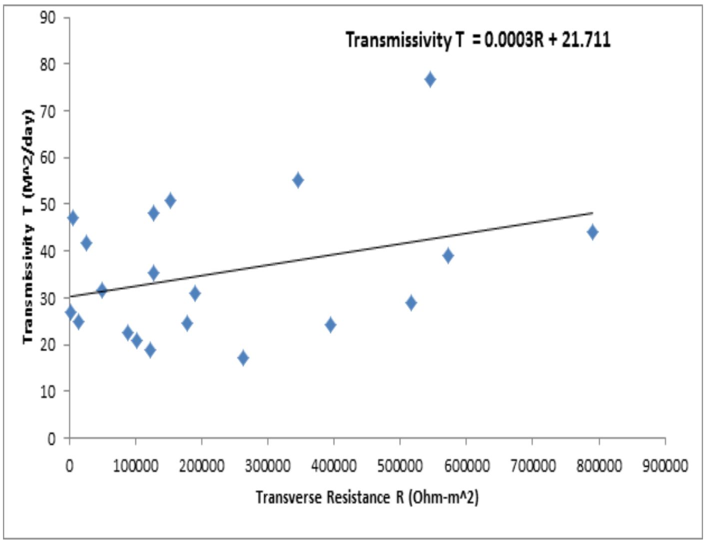

Figure 18. Relationship between Transmissivity and Transverse resistance in the study area.

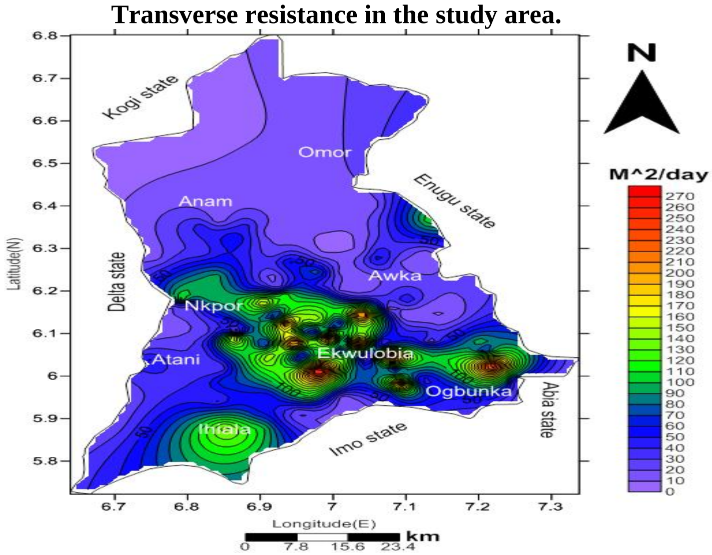

Figure 19. Aquifer transmissivity map of the study area.

Estimating aquifer hydraulic conductivity

Average hydraulic conductivity (K) computed from pumping test data was plotted against the aquifer resistivity (ρ_a) obtained from geoelectrical sounding in the study area. An empirical transform between K and ρ_a (Figure 20) was generate, with a correlation coefficient, R = 0.77.

$K\ (m/day) = 0.0002 \times \rho_a + 1.6831$ (6)

Hence, with the transform (equation 6), it was possible to estimate hydraulic conductivity in the study (Figure 21) area even to locations where no borehole records exists.

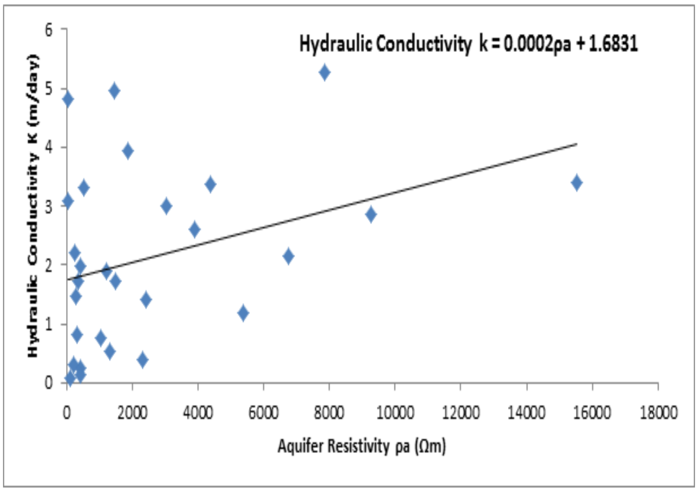

Figure 20. Relationship between Hydraulic conductivity and Aquifer resistivity in the study area.

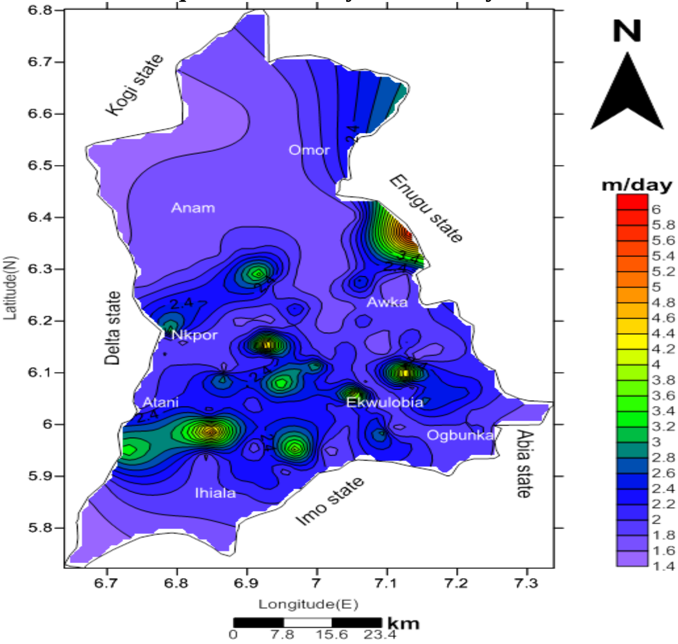

Figure 21. Aquifer hydraulic conductivity map of the study area.

Groundwater flow direction

The groundwater flow direction of the study area was evaluated using the 1-grid vector map; it was possible to determine the groundwater flow direction and groundwater divide from the hydraulic head (Figure 22). The groundwater flow direction (Figure 23) is roughly divergent to the west and east, with possible groundwater divide arising from the south, NW of Imo State, through Ekwulobia-Awka-Achalla axis and vias east, west of Enugu State. The groundwater divide is possibly the Awka-Umuchu-Orlu escarpment which separates the Odo River Basin to the east the divide and Idemili River Basin to the west of the divide respectively (Okoro, et al, 2010).

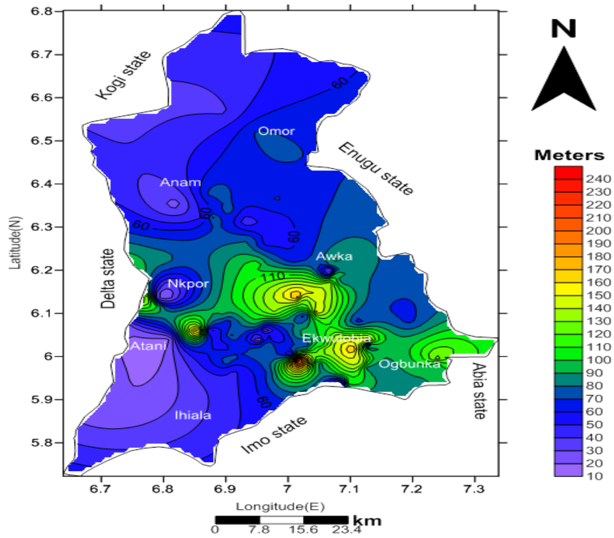

Figure 22. Hydraulic head map of the study area.

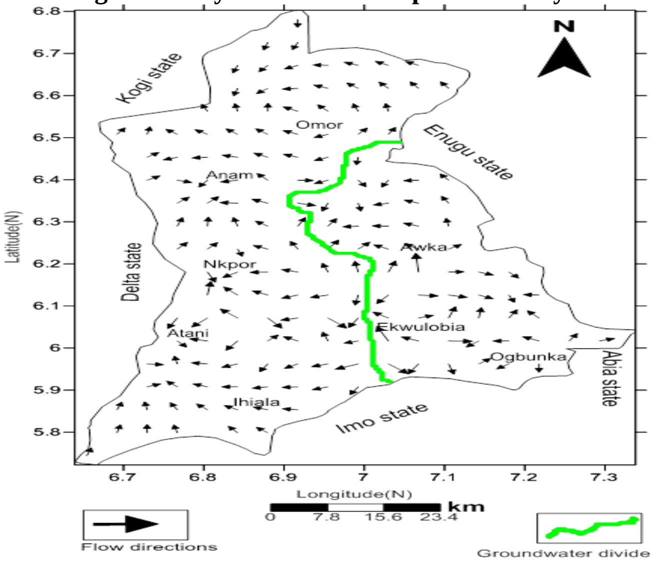

Figure 23. Groundwater flow direction map of the study area.

Groundwater Potential Zones

The groundwater potentials zones were determined using three approaches – aquifer transmissivity potentials (Gheorghe, 1978), the interplay between aquifer resistivity, thickness and overburden depth and coefficient of electrical anisotropy (Figures 24, 25 and 26) respectively. Two groundwater potential zones where delineated; moderate and high potentials.

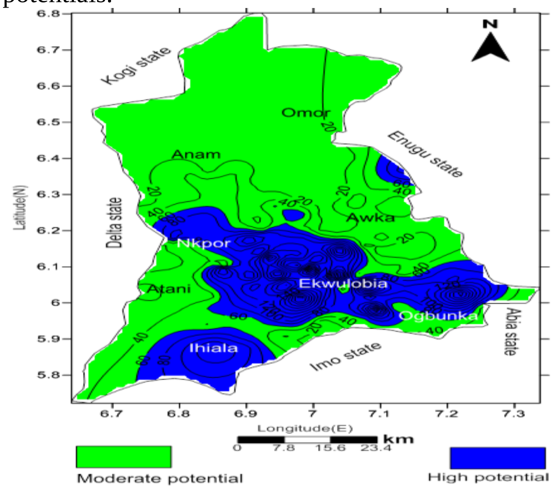

Figure 24. Groundwater potential zones map (based on aquifer transmissivity potentials) in the study area.

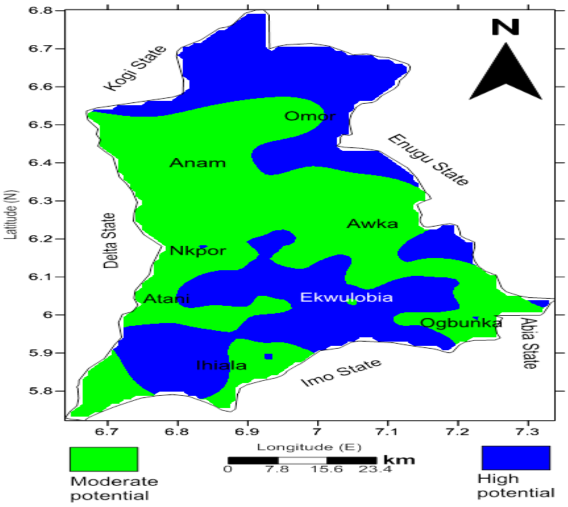

Figure 25. Groundwater potential zones map from the interplay between aquifer resistivity, thickness and overburden depth in the study area.

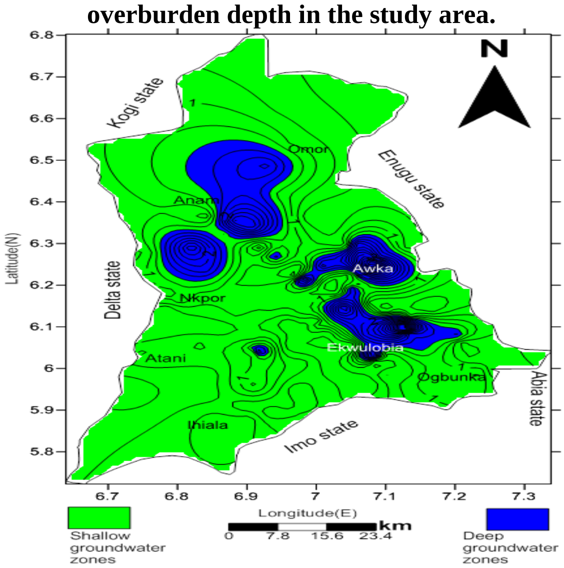

Figure 26. Groundwater potential zones map from the coefficient of electrical anisotropy in the study area.

Conclusion

Knowledge of groundwater potential zones is key to successful groundwater exploration and production. The use of surface geoelectrical sounding method has proved useful in determining the groundwater potential zones in Anambra State, Nigeria, using 452 VES data. The geoelectric curve types are multi-layer system, having A and K dominating. The interpreted geoelectrical layer models show varied subsurface lithologies. The geoelectrical parameters elated with borehole data from pumping test were used to estimate aquifer hydraulic properties and produce groundwater potential maps. The estimated aquifer hydraulic properties show fairly good match with the borehole data from pumping test. Moderate and high groundwater potential zones were delineated. About 70% of the study area falls within the moderate potential zone, while the remaining 30% zone. Hence, the groundwater potential rating in the study area is generally considered moderate.

Acknowledgements

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