ISSN: 8110 - 7304
Volume 8, Number 3, 2023
Global Journal of Applied and Physical Sciences

STRUCTURAL IMPACT ON AQUIFER HYDRAULIC PARAMETERS IN OKIGWE AND ENVIRONS, SOUTH EASTERN NIGERIA, USING INTEGRATED GEOPHYSICAL AND GIS PROCESSED REMOTE SENSING DATA

Ibim, D.F. & Piate, G.N
Department of Physics,
Ignatius Ajuru University of Education, Port Harcourt, Nigeria

Email: dagogo.ibim@iaue.edu.ng

ABSTRACT

An assessment of lineament impact on aquifer hydraulic parameters in Okigwe and Environs, South Eastern Nigeria, using integrated geophysical and GIS processed remote sensing data was carried out to ascertain the effects of lineament on the resistivity, hydraulic conductivity, transmissivity and storativity of the aquifers in the study area. Okigwe and Environs are in a complex geological setting of Imo State within the Imo River Basin and lies between latitude 5°35'N to 5°56'N and longitude 7°03'E to 7°38'E. The litho-stratigraphic units within the study area are Ajali Formation, Nsukka Formation, Imo Formation, Ameki Formation and Benin Formation. A total of 84 vertical electrical soundings (VES) using the ABEM terrameter (SAS) 4000 was acquired in the study area applying the Schlumberger electrode configuration and a maximum electrode spacing of 1000m. Out of the eighty-four sounding stations, seventeen soundings (parametric soundings) were made at the vicinity of existing boreholes for comparative analysis and for quality control of the data. The trend surface analysis in relation with the lineaments results within the study area show that the dominant structural trend is in the NE-SW direction corresponding to the major lineament trend of the Anambra basin. The lineament interpretation from LANDSAT data revealed that the Nsukka Formation is characterized by a high lineament density. The study revealed structural influence on the resistivity, hydraulic conductivity, transmissivity and storativity of the aquifers in the study area. The findings from the study also revealed that the Nsukka Formation could be a good target for groundwater exploration. The directional relationship between the drainage pattern and the lineaments could imply that the drainage of the study area is structurally controlled. The integration of geophysical and GIS processed remote sensing data can be highly effective to assessing the impact of lineaments on the aquifer hydraulic parameters. Drilling through the Nsukka Formation should be done with caution to avert or forestall loss of circulation due to suspected faults.

Key words: Lineaments, Geophysical, Hydraulic conductivity, Transmissivity and Stoativity.

INTRODUCTION

The difficulty encountered in the development of both rural and urban water projects and incessant borehole failures recorded in the area may have resulted from the fact that no detailed geophysical survey for mapping groundwater flow patterns has been sufficiently carried out in the study area. However, the hydraulic characteristics of these aquifers such as transmissivity, hydraulic conductivity and storage potentials and what influences them are not fully known and it has not been easy to design accurate management strategies for optimal exploitation of these aquifers, which could be further compounded by the inadequate knowledge of the aquifers (the geometry and nature of their hydraulic boundaries) being tapped. Although numerous boreholes have been drilled at various parts of the Imo river basin, there has not been any systematic and comprehensive study to establish the nature, distribution of and structural impacts on the aquifers beneath the basin (Ibim et al., 2021).

Lineaments are linear or curvilinear features that are directly visible on the earth's surface, or stand out on either topographical or geophysical maps, or on satellite or aerial photographs. Lineament can also be defined on the basis of one or more types of remote-sensing data, such as satellite or aerial photographs, gravimetric, magnetic and seismic measurements, etc. (Attoh and Brown, 2008). However, larger sustained yields require more extensive fracture networks, such as fault zones. Large faults or fractures extend for distances of a mile (1.6 km) or more and are visible on aerial photographs (Whitten and Brooks, 1982). These longer fracture features are known as lineaments. A lineament often consists of two or more parallel or sub-parallel, straight or gently curved linear segments. These segments may have different origins and extents, and may form parts of continuous or discontinuous lineaments (Attoh and Brown, 2008). Lineaments are assumed to reflect a geological in-homogeneity in the bedrock, such as a fracture, rock boundary, fold, linear rock body or ore body. Fracture zones, shear zones and igneous intrusions such as dykes can also give rise to lineaments (Whitten and Brooks, 1982).

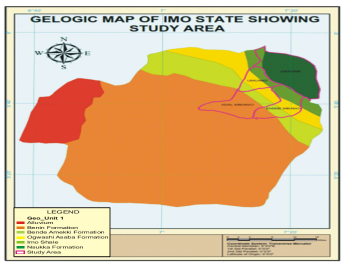
Minor drainages often develop in weaker fracture zones promoting recharge to granitic aquifers. Minor drainages that are controlled by these features tend to be abnormally straight, and thus can be recognized as potential target drilling areas (Whitten and Brooks, 1982). Another perspective of fracture zones being productive is that they are also the most vulnerable to surface contamination (Attoh and Brown, 2008). This is important for well-head or source-water protection issues.

It has become necessary and important to embark on a more articulated study of the aquifer systems in an area and also undertake a detailed geophysical and hydrogeological appraisal of the area in order to enhance an understanding of the aquifer hydraulic characteristics as well as its status to fractures, with the aim of reducing the risks associated with groundwater exploration and management in an area. This work is therefore aimed at determining the regional hydraulic properties and influence on the aquifer systems in Imo River Basin to fractures using integrated geophysical and GIS processed remote sensing methods in order to view the spatial distribution of lineaments in the study area and delineating the structural features of the study area and their influences on the regional groundwater flow.

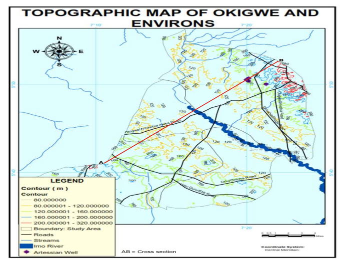
Climate, Physiography, Geomorphology, Geology and Hydrogeology of the Study Area

The project area lies within the Upper Imo River Basin, Nigeria and is located within latitudes $5^{0}35^{1}$N and $5^{0}56^{1}$N and Longitudes $7^{0}03^{1}$E and 7^{0} 38^{1}E. Geomorphologically, the study area has fairly gentle to undulating relief and punctuated by a few low hills, some of which are relics of sandstone and siltstone deposits that are more resistant to denudation than the surrounding shales (Uma, 1989). Figure 1b shows the digitized topography map of the study area. The study area lies in the rain forest and savannah vegetation zones typified by an almost continuous cover of thick forest and grasses with tall trees concentrated along stream valleys.

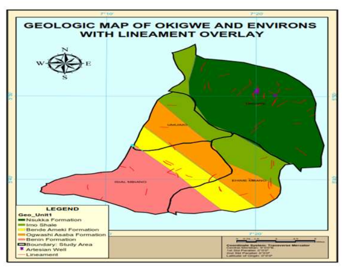
The climatic condition of the study area is characterized by uniformly high temperatures and a seasonal distribution of precipitation (Onyia, 2005). Two seasons are prominent in the area namely: dry and rainy seasons. Rainfall regime is rather simple and runs intermittently from May to October and sometimes to November. The mean annual rainfall ranges from 1500 mm to 2800 mm (Onyia, 2005). This is followed by dry months characterized by the harmmattan which lasts from November to February (Onyia, 2005). The cross section AB run across the Benin, Bende-Ameke, Ogwashi-Asaba, Imo shale and Nsukka formation from A – B.



a



b



c

Figure 1: (a) Geologic Map of Imo State Showing Study Area (b) Topographic Map of Okigwe and Environs (c) Geologic Map of Okigwe and Environs with Lineament Overlay.

The study area is situated in a complex geological setting in Imo State of Nigeria. The area lies between Latitude 5^0 35¹N to 5^0 56¹N and Longitude 7^0 03¹E to 7^0 38¹E, covering a land area of about 1,216 km^2 (Ekwe et al., 2006). The study area belongs to the coastal sedimentary lowlands of the southeastern Nigeria hydrological province. The geology and geomorphology of the study area have been described in details by various authors (e.g. Amajor, 2005).

Geological studies in Anambra Basin/Niger Delta in which the study area is situated have been reported widely in literature. The depositional histories of the Lower Benue Trough are dominated by repetitive transgressive/regressive sedimentary cycles interspersed with two main episodes of structural deformations in Cenomanian and Santonian times (Kogbe, 1976). The study area is underlain by thick sequence of sedimentary rocks ranging in age from Cretaceous to Recent. These include the Asu River group (Albian), Ezeaku Shale (Turonian), Agwu Shale (Campanian), Nkporo Shale (Campanian), Mamu Formation, Ajali Sandstones, Nsukka Formation (Maastrician), Imo Shale (Paleocene), Ameki Formation (Eocene), and the

Benin Formation (Miocene to Recent). Figure 1c shows the geological map of the study area with the various formations numbered in an order that reflects their decreasing age, (Nwajide and Reijers, 1995; Ibe and Uzokwu, 2004) with lineament overlay.

A striking feature in the geologic map is the similarity in the pattern of surface outcrops of the formations. Almost all the formations occur along NW-SE bands that are megascopically parallel to the regional strike. The rock units also get younger southwestward, a direction that is parallel to the regional dip of the formations.

MATERIALS AND METHODS

Electrical methods primarily reflect variations in resistivity existing between lithological sequences (Dodds and Ivic, (1998). Resistivity contrasts in the subsurface are adequate to enable the delineation of geoelectric layers and identification of aquiferous or non aquiferous layers (Schwarz, 1988). Geoelectric resistivity sounding data have been used to delineate the boundaries and subsurface disposition of the water bearing units (Omosuyi, 2008).

Traditionally, one of the more effective ways of hydraulic conductivity calculation is the pumping tests that are carried out on certain boreholes sites. Nevertheless, a probable sparse spatial distribution of the available boreholes gives rise to significant problems in modeling the hydrogeological systems. In such cases, drilling new boreholes has proved to be rather expensive as well as time-consuming.

In the other hand, the integration of aquifer parameters calculated from the existed boreholes locations and surface resistivity parameters extracted from surface electrical measurements can be highly effective not only for aquifer hydraulic conductivity estimation but also for a group of hydraulic parameters.

Hydraulic Conductivity

It encompasses the ability of a material to conduct fluids under a unit hydraulic gradient considering the dynamic viscosity in units of length over time (LT^{-1}) (Fetter, 2007). Water contained within the interconnected voids of soils and rocks is capable of moving, and the ability of a rock to store and transmit water constitutes its hydraulic properties.

Hydraulic conductivity or, as it is occasionally referred to in older publications, the coefficient of permeability, has dimensions of $[LT^{-1}]$ and is a measure of the ease of movement of water through a porous material.

Mathematically the unit is given as

$$K = -\frac{Q}{A} \cdot \frac{\partial l}{\partial h} = \frac{\frac{m^3}{day}}{m^2} \cdot \frac{m}{m} = \frac{m}{day} \qquad (3)$$

Transmissivity

For a confined aquifer of thickness, b and hydraulic conductivity K, the transmissivity, T, is defined as:

$$T = Kb = K\frac{R}{\rho} = K\sigma R$$

$$= KS\rho = K\frac{S}{\sigma} \qquad (4)$$

where S is the longitudinal conductance and R the transverse resistance. Transmissivity represents the rate at which water of a given density and viscosity is transmitted through a unit width of aquifer or aquitard under a unit hydraulic gradient. Transmissivity has the units of L^2T^{-1}.

Based on the equation above, the quantities ($K\sigma$) and (K/σ) are assumed to be fairly constant within the watershed. Thus knowing the values of K from existing boreholes and the conductivity, the inverse of resistivity from the sounding interpretation around the borehole, one can estimate the transmissivity and its variation from place to place using the **Dar-zarrock** parameter determined for each aquifer. On the whole, σ or $1/\rho$ must be equivalent to any of the sets $K\sigma T$ or KS or KS/ρ to be used.

Storativity

The amount of water an aquifer can release or take into storage is known as the **storage coefficient**. The numerical value assigned to an aquifer is the **storativity**, a dimensionless value determined from pumping tests. In a pumping test the storativity represents the storativity from the saturated thickness contributing to the well bore. The standard value of storativity is $S \leq 0.005$ (Fetter, 2007).The storativity S, of. the confined aquifer system and the deep and thick unconfined aquifer which may be hydraulically similar to it may be estimated from the rule of the thumb equation given by lohman (1972) and Todd (1980)

$$S = 1.3 \times 10^4 \qquad (5)$$

A trip on site survey of artesian wells in the study area with the aim of acquiring their Global Positions was carried out. A total of 84 vertical electrical soundings (VES) were acquired in the study area (Figure 2) using the Schlumberger electrode configuration and a maximum electrode spacing of 1000m. Out of the eighty-four sounding stations, seventeen parametric soundings were carried out at the vicinity of existing boreholes for comparative analysis and for quality control of the data. Three (3) parametric soundings on the average were carried out in each of the five geological formations encountered in the study. The ABEM SAS (Signal Averaging System) 4000 model consisting of a basic unit called the Terameter SAS 4000 was used to acquire the data. Four stainless non polarizable electrodes were used, two current electrodes and two potential electrodes. A freshly charged 12V dc supply was used to supply current. The current electrode spacing was increased symmetrically about the station point, keeping the potential electrode constant until it became necessary to increase the potential electrode as the recorded signal diminished.

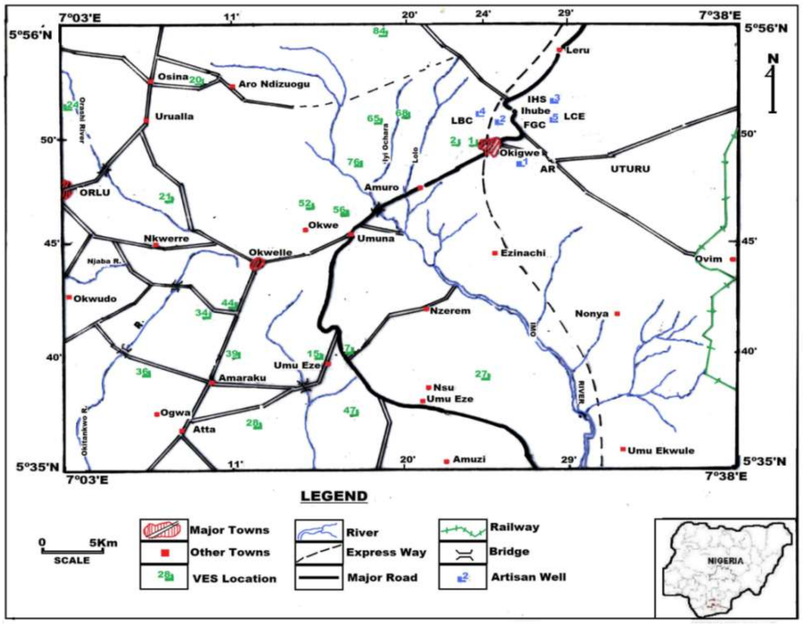


Figure 2: Location Map of the Study Area Showing VES Points

Garmin GPS 72 was used in determining the coordinates in longitude and latitude and elevation height above mean sea level of the locations of sounding points. The injected current developed a ground potential difference whose voltage was determined using the potential electrodes which were kept in line with the pair of current electrodes.

The observed field data which is the ratio of the resulting voltage to the imposed current is only a measure of resistance of the subsurface (ground resistance). This is read off directly from the terrameter and is used to compute the corresponding apparent resistivity in Ωm by multiplying with the geometric factor 'values as functions of electrode spacing', which then gives the required apparent resistivity results as functions of depths of individual layers:

$$\rho_a = \pi R\left[\frac{a^2}{b} - \frac{b}{4}\right] \qquad (4)$$

where ρ_a= apparent resistivity, R = resistance in ohm, $a = AB/2$ = half current electrode spacing (m), $b = MN$ = potential electrode spacing (m) $\pi\left[\frac{a^2}{b} - \frac{b}{4}\right]$ = geometric factor (K).

The apparent resistivity values computed were plotted against half of the current electrode spacing (AB /2) on a log-log graph scale. The sounding curves obtained were subjected to conventional partial curve matching using the Rijks Waterstaat (1988) master curves to obtain the initial model parameters (resistivities and thickness) of the various geoelectric layers.

A useful approximation is that the depth of the interface is equal to two thirds (2/3) of the electrode spacing at which the point of inflection occurs (Vingoe, 1972). This approximation has found useful applications in computer iterative modeling. Parameters such as apparent resistivity and thickness obtained from both partial curve matching were used as input data for computer iterative modeling (Zohdy, 1989; Igbokwe and Okereke, 2006). Detailed quantitative interpretation was done using the OFFIX 3.1 software.

Pumping test data and VES data relevant to this work were collected from Imo Water Development Authority (IWADA), Anambra-Imo River Basin Authority (AIRBDA) and UNICEF, Owerri which are then processed and interpreted. Also, GIS processed remote sensing data on Drainage System, Spatial Distribution of Lineaments and Lineament Density of the study area were acquired.

RESULTS AND DISCUSSION

Outcome of the curve matching were analyzed. The configuration of the curve for each sounding gave an understanding on the character of the beds or layers between the surface and the maximum depth of penetration. This is because the configuration of a VES curve is a function of the number of layers in the subsurface, the thickness of each layer, and the ratio of the resistivity of the layers. Figure 3 displays some the resulting model curves with 5-7 interpretable geo-electric layers.

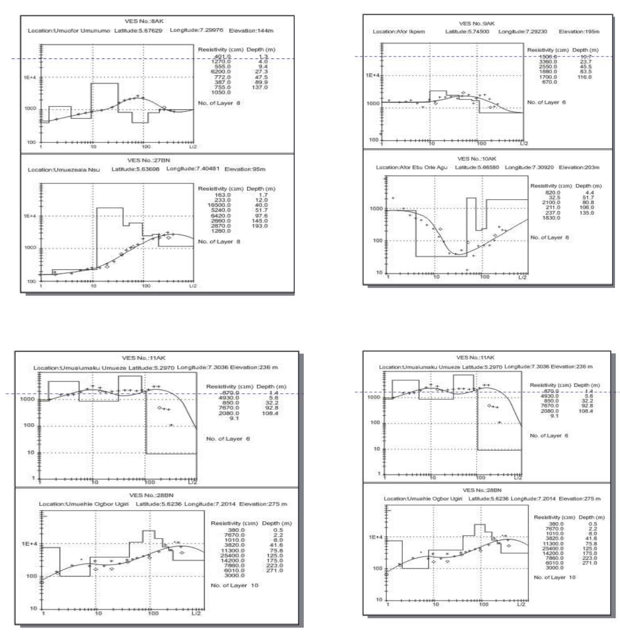


Figure 3: Vertical Electrical Sounding (VES) Curves of the Study Area.

Figure 4 illustrates a polar plot of fracture strikes (rose diagram) obtained from field geological mapping (LANDSAT) of Okigwe and its environs (study area). The fractures generally strike northeast-southwest (NE-SW), with minor variations in the north-south (N-S) and northwest-southeast (NW-SE) directions.

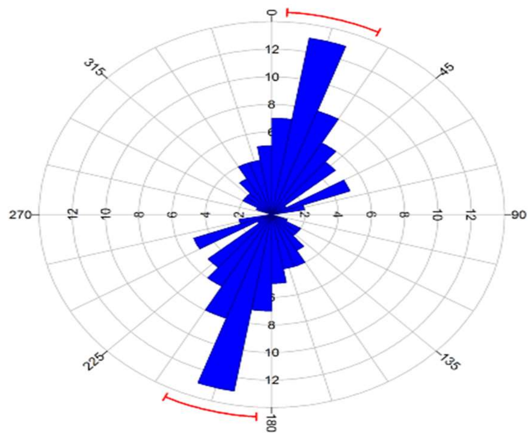


Figure 4: Polar Plot (Rose Diagram) of the Fracture Orientations Obtained from Geological Mapping (LANDSAT) of the Study Area: Class Interval = 10^0, Minimum-Azimuth = 0^0, Maximum-Azimuth = 360^0, Confidence Interval = 11.1^0, Total Length of all Lineaments = 136, Mean Bin Population = 3.33%, Standard Deviation of Bin Population = 2.28%.

Drainage System of the Study Area

Figure 5 displays the drainage system of Okigwe and environs overlain with lineaments. The study area is largely drained by the Imo Rivers. The composite images reveal the drainage pattern of the study area to be dendritic. The dendritic drainage pattern of the area generally trends in the NE-SW direction as shown in the figure. Mendosa et al. (2003), established that when drainages are parallel to each other, the drainages are structurally or tectonically controlled. The drainage pattern in the study area is almost parallel to each other and some of the lineaments imposed on the map are parallel to the direction of the drainage hence it could be said that the drainage is structurally or tectonically controlled.

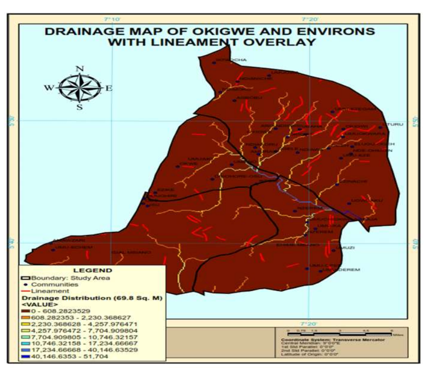


Figure 5: Drainage Map of Okigwe and Environs (Study Area) with Lineaments Overlain

Lineament Density

Lineament density is the ratio of the number of lineaments to the area of the space within which the lineaments lie. The lineament density is therefore determined by counting the number of lineaments in a constant rectangular or circle shaped figure placed over the formations respectively. Figure 6 shows a spatiotemporal distribution of lineament density across the study area. The lineaments generally trend in the NE-SW, N-S, NW-SE directions and few in the W-E directions. From the map, it was indicated that the location of the artesian aquifers in the Nsukka Formation is highlighted as a zone of high lineament densities. This corresponds to the dark brown colored regions.

High lineament density could imply more opportunities for the circulation of groundwater; hence the lineaments over the artesian aquifers in the Nsukka Formation could be the cause of flow of the groundwater to the surface.

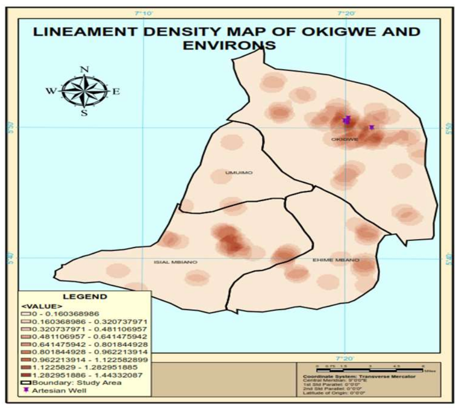


Figure 6: Map of Lineament Density Overlying Artesian Aquifer in the Study Area

Resistivity, unconfined and Artesian Aquifer Context

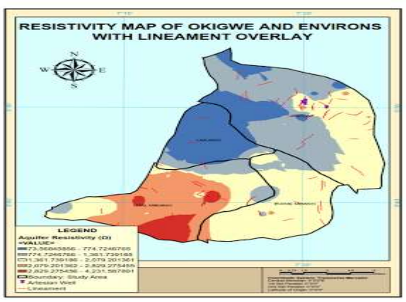
The figure 7a shows the resistivity map of Okigwe and environs overlain with lineaments. The estimated average resistivity values of the unconfined aquifers in Ajali, Ameki, Benin and Nsukka Formations are 1555 Ωm, 2664 Ωm, 2881 Ωm and 1855.3 Ωm respectively. These values are within the acceptable range for unconfined aquifers in the study area. The artesian aquifers within the zone highlighted as high lineament density located in the Nsukka Formation appeared to have resistivity values ranging from 1341 to 2079 Ωm corresponding to the cream colored region. The lineaments run across the artesian aquifers, an indication that can imply structural influence on the resistivity of the artesian aquifers.

Hydraulic Conductivity, unconfined and Artesian Aquifer Context

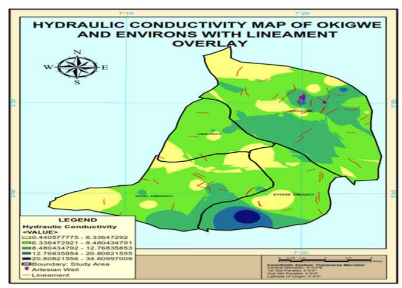
The figure 7b below is a display of lineaments imposed on hydraulic conductivity of Okigwe and environs indicating locations of artesian aquifers in the Nsukka Formation. As shown in the figure, the lineaments transverse the artesian aquifers. The average values of the hydraulic conductivity calculated from established relationship gave 5.55 m/day for Ajali Formation, 5.26 m/day for Ameki Formation, 5.26 m/day for Benin Formation and 11.93 m/day for Nsukka Formation. These values are consistent and well defined within the range of observed hydraulic conductivity values in the study area. The hydraulic conductivity values within this zone of high lineament density as exhibited by the map ranged from 8-13 m/day corresponding to the grey color. This range is within the values of potential aquifers. By the above analysis, it could be inferred that the hydraulic conductivity of the artesian aquifers and the high value of hydraulic conductivity of the unconfined aquifers in the Nsukka Formation are controlled structurally.

Transmissivity, unconfined and Artesian Aquifer Context

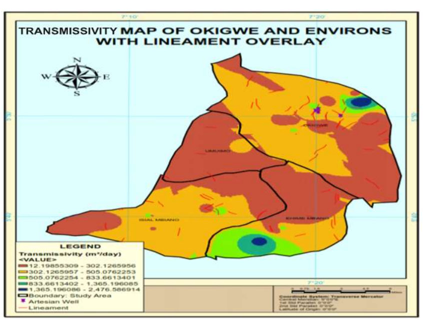
The transmissivity map of Okigwe and environs overlain by lineaments and indicating locations of artesian aquifers is displayed in the figure 7c below. The estimated average transmissivity values as calculated for Ajali, Amaki, Benin and Nsukka Formations are 314.7 m^2/day, 405.09 m^2/day, 338.68 m^2/day and 723.65 m^2/day respectively. These values are within the range for productive aquifers. The lineaments are shown cutting across the artesian aquifers. The transmissivity values within the zone of high lineament density and



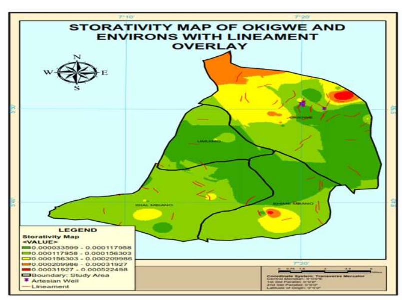
a



b



c



d

Figure 7: (a) Resistivity Map of Okigwe and Environs (Study Area) with Lineament Overlay on Artesian Aquifers. (b) Aquifer Hydraulic Conductivity Map of Okigwe and Environs (Study Area) with Lineament Overlay on Artesian Aquifers. (c) Aquifer Transmissivity Map of Okigwe and Environs (Study Area) with Lineament Overlay on Artesian Aquifers. (d) Aquifer Storativity Map of Okigwe and Environs (Study Area) with Lineament Overlay on Artesian Aquifers

aquifers in the Nsukka Formation ranged from 302-833 m^2/day and correspond to the lemon green and dark orange colors. This range is within the values of potential aquifers. The high transmissivity values of the artesian aquifers within these lineaments and those of the unconfined aquifers in the Nsukka Formation could be attributed to fractures, subject to structural influence.

Storativity and Artesian Aquifer Context

The figure 7d is the map of Okigwe and environs showing the spatiotemporal distribution of the storativity of the study area overlain by lineaments and indicating artesian aquifers locations appearing in the Nsukka Formation. The calculated average storativity values are 2.38×10^{-4}, 2.22×10^{-4}, 1.22×10^{-4}, and 1.7×10^{-4} respectively for Ajali, Ameki, Benin and Nsukka Formations. These values are satisfactory for aquifer storativities. The artesian aquifers as shown in the map are under the transverses of lineaments. The storativity values as highlighted within the zones of the artesian aquifers range from 1.03×10^{-4} to 1.58×10^{-4} corresponding to regions of yellow, lemon green and green colors. These values must have been enhanced by expected fractures within the artesian aquifers and one can conclusively say that the storativity may have been structurally controlled.

CONCLUSION

Okigwe and Environs (Study Area) is in the complex geological environment of Imo State in the Imo River Basin and lies between latitude 5°35'N to 5°56'N and longitude 7°03'E to 7°38'E, covering a land area of about 1,216 km^2. Potable water is relatively scarce in the study area owing to increasing demand and deteriorating quality due to pollution. This is compounded by the gradual increase in the rate of industrial and commercial activities and boreholes failure in some parts of the study area. Artesian wells (or sprigs) under the influence of geological and geophysical factors exist in some parts of Okigwe within the study area. This study therefore aimed at delineating sites for productive boreholes and revealing the origin and possible factors influencing artesian wells (or springs). To achieve this aim, 84 Vertical Electrical Soundings (VES) were sited within the study area. The ABEM terrameter SAS 4000 was used to acquire data using the Schlumberger electrode array and a maximum current electrode spread of 1000 m. The Schlumberger electrode array was chosen because it is time effective in terms of field work. Seventeen of the VES stations were sited near existing boreholes to enhance interpretation.

The hydrogeophysical properties of the study area which is in the Imo River Basin were determined. The results of the interpretation of the VES data are in near agreement with the lithological information from boreholes. The resistivity of the aquiferous zones within the study area varied from 59.5- 4860 Ωm with an average resistivity value of 1675.9 Ωm. Adopting an average transmissivity of 368.19 m^2/day, determined from pumping test, a mean hydraulic conductivity value of 7.73 m/day was obtained for the area. Hydraulic conductivity (K) varied from 0.38-34.6 m/day while transmissivity (T_r) ranged from 9.99-2483.87 m^2/day. These results and the distribution of storativity values, gave an indication of a fairly homogenous geological environment with high water yielding capacity. Groundwater occurs in unconfined condition mostly in the Benin Formation, but becomes semi-confined to confine in Ajali, Ameki and Nsukka Formations.

The study area is largely drained by the Imo Rivers. The drainage pattern of the study area is dendritic and generally trend in the NE-SW direction (Figure 39). The drainage pattern in the study area is almost parallel to each other and some of the lineaments imposed on the map are parallel to the direction of the drainage.

The spatial distribution of lineament density across the study area revealed lineaments generally trending in the NE-SW, N-S, NW-SE and W-E directions. The lineament density map indicated that the location of the artesian aquifers in the Nsukka Formation is highlighted as a zone of high lineament densities. High lineament density could imply more opportunities for the circulation of groundwater.

Conclusively, the calculated aquifer parameters are consistent and well defined within the range of observed aquifer parameters as obtained from the works of Uma, 1989 and other related works carried out within the study area and they also compared favourably well with those obtained from pumping test analysis. The occurrence of aquifer in the study area is presumed to be linked to the presence of fractures in the shale members. The trend surface analysis in relation with the lineaments results within the study area showed that the dominant structural trend is in the NE-SW direction corresponding to the major lineament trend of the Anambra basin. Hence the NE-SW direction could be regarded as the principal flow direction of groundwater in the study area. The Nsukka Formation is characterized by high lineament density, which suggest good groundwater recharge potential for the formation and more opportunity for the circulation of groundwater in the formation, hence the lineaments over the Nsukka Formation, all other factors remain constant could be responsible for the flow of groundwater to the surface. The study showed that the Nsukka Formation could have been affected by tectonic activities and the effect of these tectonic activities on the geologic formation, all other factors remain constant is likely to be responsible for the artesian springs and contributive to the artesian wells in the study area. By the above findings, the Nsukka Formation could be a good target for groundwater exploration. The directional relationship between the drainage pattern and the lineaments could imply that the drainage of the study area is structurally controlled.

The integration of geophysical and GIS processed remote sensing data can be highly effective to assessing the impact of lineaments on the aquifer hydraulic parameters. In this research work, the researchers have used geophysical and geographic information to present spatial distribution of lineaments over the aquifer resistivity, hydraulic conductivity, transmissivity and storativity of the study area. Drilling through the Nsukka Formation should be done with caution to avert or forestall loss of circulation due to suspected faults.

REFERENCES

Amajor, L.C. (2005). Aquifers in the Benin Formation (Miocene-Recent), Eastern Niger Delta; lithostatigraphy, hydraulics and water quality. Environmental Geology, 1, 85 – 101.

Attoh, K. & Brown, L.D. (2008). The Neoproterozoic Trans-Saharan/Trans-Brasiliano shear zones: Suggested Tibetan Analogs. American Geophysical Union. Retrieved 2011-01-30.

Dodds, A.R. & Ivic, D. (1988). Integrated Geophysical Methods Used for Groundwater Studies in the Murray Basin, South Australia. In: Geotechnical and Environmental Studies, SEG Tulsa, OK. 11, 303 – 310.

Ekwe, A.C., Onu, N.N., & Onuoha, K.M. (2006). Estimation of Aquifer Hydraulic Characteristics for Electrical Sounding Data: The Case of Middle Imo River Basin Aquifer, South Eastern Nigeria, Journal of Spatial Hydrology, 2(6), 121 – 132.

Fetter, C.W. (2007). Applied Hydrogeology, 2nd Ed. C.B.S. Publishers and Distributors, New Delhi India, 161-201:550.

Ibe, K.M. & Uzokwu, S.C. (2004). An Appraisal of subsurface geology and groundwater resources of Owerri and environs based on electrical resistivity survey and borehole data evaluation. Journal of Environmental Monitoring and Assessment, 303 – 321.

Ibim, D.F., Opara, A.I., & Womuru, E.N. (2021). Estimation of aquifer hydraulic parameters from surficial geophysical methods: a case study of Imo River Basin in Imo State, Southeastern Nigeria. Innovative Journal of Scientific and advanced Studies, 9(3), 74 – 91.

Igbokwe, M.U., Okwueze, E.E., & Okereke, C.S. (2006). Delineation of Potential Aquifer Zones from Geoelectric Soundings in KWA Ibo River Watershed, Southeastern, Nigeria. Journal of Engineering and Applied Sciences, 4(1), 410 – 421.

Kogbe, C.A. (1976). Paleogeographic History of Nigeria from Albian times. In Kogbe C.A (Ed), Geology of Nigeria. Elizabeth Publisher, Lagos, 237 – 282.

Lohman, S.W. (1972). Well hydraulics. US Geological Survey Professional Paper 708

Mendosa, F.G., Steenhuis, S.T., Todd Water, M. and Parlenge, J.Y. (2003). Estimating Basin Wide Parameters of a Semi-arid Mountainous Watershed by Recession-flow analysis. Journal of Hydrology, 50, 393 – 399.

Omosuyi, G.O., Ojo, J.S. & Olorunfemi, M.O. (2008). Geoelectric sounding to delineate shallow aquifers in the coastal plain sands of Okitipupa Area, Onyia, V.A. (2005). Study of road failure along Umuahia-Bende highway, Southern Nigeria. Unpublished M.Sc. Thesis, Federal University of Technology, Owerri.

Schwarz, S.D. (1988). Application of geophysical methods to groundwater exploration in the Tolt River Basin, Washington State: In Geotechnical, Environmental and Engineering. Geophysical Society and European Section, E.E.G.S., 9 – 12.

Todd, D.K. (1980). Groundwater Hydrology: John Wiley and Sons Inc., New York.

Uma, K.O. (1989). An appraisal of the groundwater resources of the Imo River Basin. Nigerian Journal of Mining Geology, 19(25), 305 – 315.

Vingoe, P. (1972). Electrical resistivity surveying. ABEM Geophysical Memorandum, 5(72), 1 – 13.

Whitten, L.N. & Brooks, D.K. (1982). The penguin dictionary of geology.

Zohdy, A.A.R. (1989). A New Method for the Automatic Interpretation of Schlumberger and Wenner sounding curves, Geophysics, 54, 245 – 253.