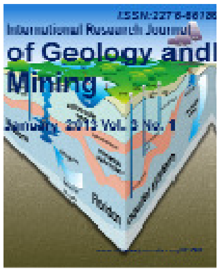

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Full Length Research Paper

Using the relationships between geoelectrical and hydrogeological parameters to assess aquifer productivity in Udi LGA, Enugu State, Nigeria

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This paper presents the results of 58 vertical electrical soundings conducted within the vicinity of 24 boreholes in Udi Local Government area, Enugu State, Nigeria. The study area falls between longitudes 7^0 9^1E and 7^0 28^1E and latitudes 6^0 12^1N and 6^0 41^1N, in the Southeastern part of Nigeria, encompassing an area of about 897km^2, with elevation ranging from 231m to 456m above mean sea level. The objective was to correlate surface resistivity with hydrogeological parameters in order to reveal the groundwater potential of the area. Results show a strong correlation between borehole yield and aquifer resistivity (r^2 = 0.8), and the later may be used as a reliable indicator of aquifer productivity where no borehole data are available. An average Transmissivity value of 509.68m^2/day for the study area was obtained from Dar – Zarrouk parameters while the average estimated value from specific capacity was 412.35m^2/day. Thus, it can be inferred from the study that the geoelectrical sounding method can be successively used not only for exploration of groundwater in the study area but also for estimating the hydraulic properties the groundwater aquifers.

Keywords: Resistivity, Yield, Specific Capacity, Transmissivity.

INTRODUCTION

A useful approach to the study of the groundwater in regions is the use of relationships and comparisons between aquifer properties and between hydrogeological and geophysical parameters. Relationships between aquifer characteristics and geoelectrical parameters have been studied and reviewed by many authors (Kelly, 1977; Heigold et al.; 1979; Niwas and Singhal, 1981; Kosinki and Kelly, 1981; Schimscal, 1981; Urish, 1981; Mazac et al; 1985; Frohlich and Kelly, 1988, Huntley, 1986; Onuoha and Mbazi, 1988; Kalinski et al; 1993; Frohlich and Urish, 2002; Lashkaripour, 2003; Louis et al; 2005; Singh, 2005). Some researchers assume that the geology and ground water quality remain fairly constant within the area of interest and the relationships between aquifer and geophysical parameters deduced are based on this assumption (Niwas and Singhal, 1981. Mazac et al. (1985) analyzed the correlation between aquifer and geoelectrical parameters on both the saturated and unsaturated zones of the aquifers. Louis et al. (2005) estimated aquifer transmissivity on the basis of monitoring the variations of the ground water resistivity. In porous media and alluvial aquifers, transmissivities, formation factors and permeability have been estimated from empirical/semi-empirical correlations, often using simple linear relations (Kelly 1977; Heigold et al; 1979; Schimschal, 1981; Urish, 1981; Chen et al. 2001).

In the present study, Schlumberger resistivity soundings have been assessed for possible relationship with hydraulic parameters in the study area (figure 1). An attempt has also been made to present and discuss the correlations between transmissivity estimates derived from geoelectrical soundings and specific capacity, following the ideas explored by Niwas and Singhal (1981), Mazac et al (1985) and Mace (200).

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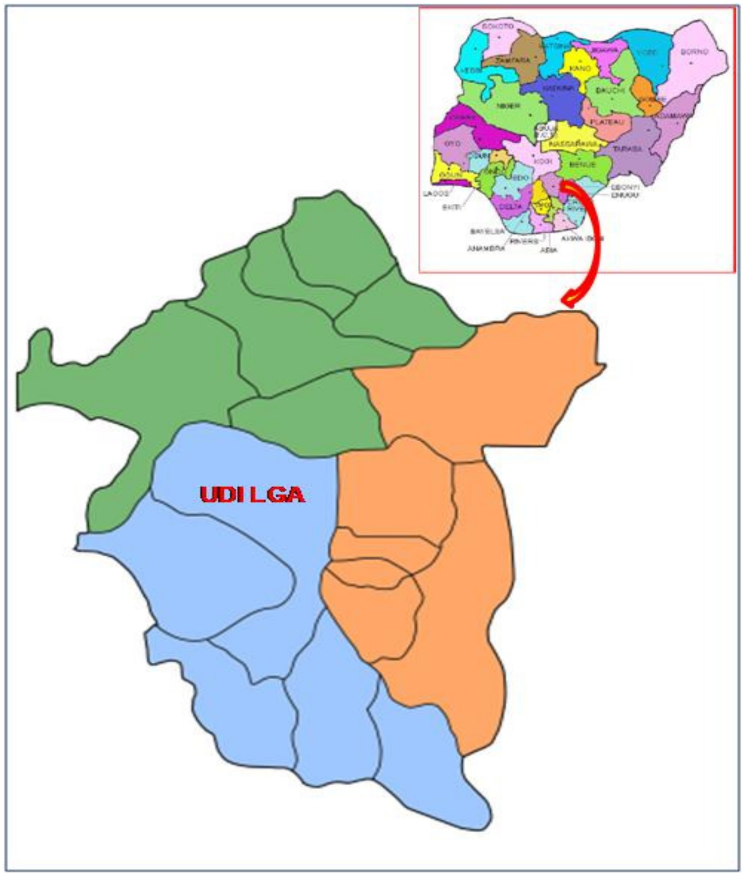

Figure 1. Map of Enugu State showing the location of the study area (Modified from world gazette 2000 and Google Maps 2012)

Physiography

The dominant physiographic feature in the study area is the undulating hills and ridges that trend N-S, as well as numerous dome-shaped outliers. These features are related to geology. The ridges and outliers are geologically associated with the outcrops of the Nsukka Formation while the valleys are underlain by the Ajali Sandstone (figure 2)

Geology

The study area is underlain by three major geologic formations; the Mamu, Ajali and Nsukka Formatiions respectively. (Figure 3)

The Mamu Formation, previously known as lower coal measures (Reyment, 1965), underlies the eastern part of the study area. It consists of fine-medium grained, white to grey sandstones, shaly sandstones, sandy shales, grey mudstones, shales and coal seams.

The Ajali Formation, also known as False Bedded Sandstone, covers about 80% of the study area. The Sandstone consists of thick friable, poorly sorted arkosic sandstones, typically white in colour but sometimes iron-stained. The thickness averages 300m and is often overlain by considerable thickness of red earth, which consists of red, earthy sands, formed by the weathering and ferruginisation of the formation. In areas of exposed outcrops, it exhibits distinctive cross-bedding with the fore-set laminae making an angle of about 20^{o} with the major bedding planes. Westwards, the Ajali Sandstone follows a gentle dip-slope.

The Nsukka Formation, previously known as the upper coal measures (Reyment, 1965), lies conformably on the Ajali sandstone. They exist as reddish ironstone covers of Ajali Sandstone and as outliers marked undulating hills (figure 2). The lithology is very similar to that of Mamu Formation and consists of an alternating succession of sandstone, dark shale and sandy shale, with thin coal seams at various horizons.

Hydrogeology

The target aquifer in the study area is the Ajali Sandstone. The Ajali Sandstone aquifer is a regional aquifer and ranks as the second most prolific aquifer in

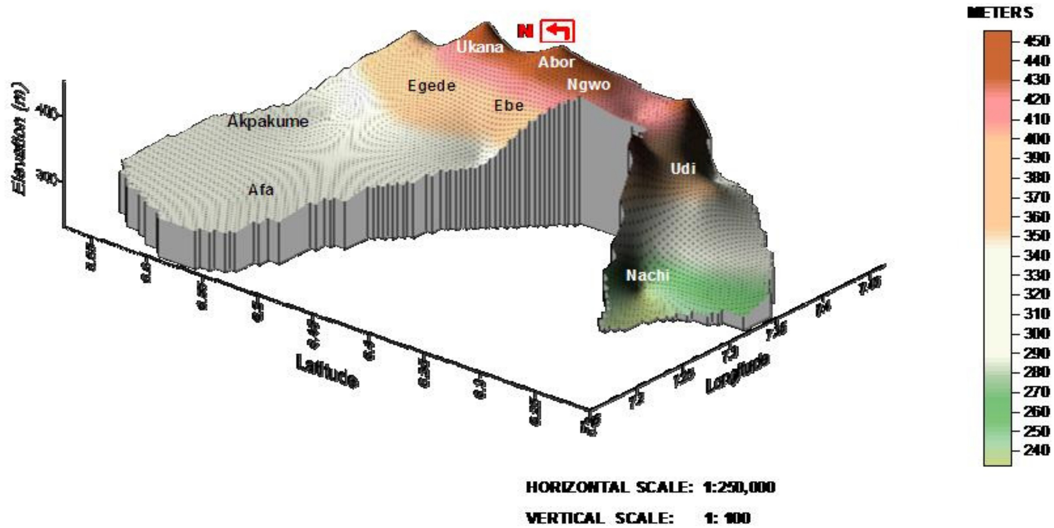

Figure 2. Surface map of the study area

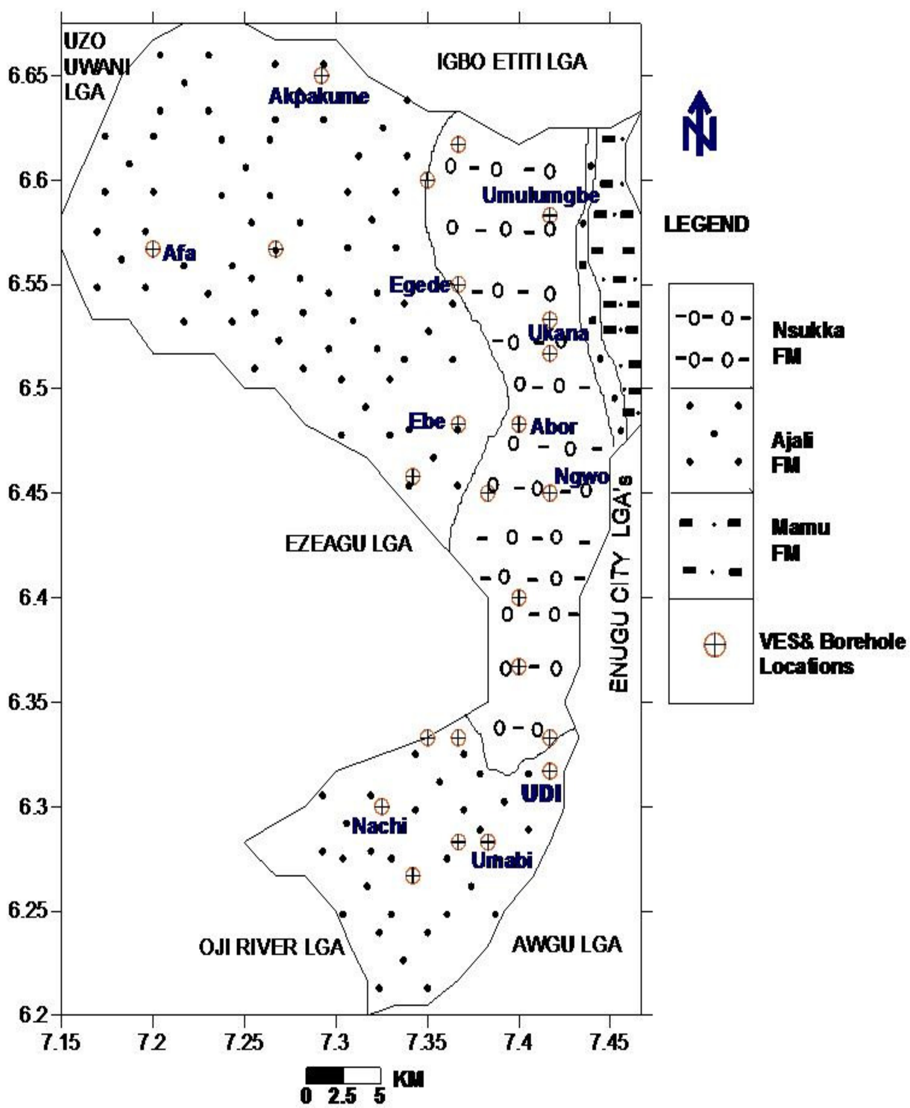

Figure 3. Geologic map of the study area showing ves and borehole locations

Nigeria after the coastal plain sands. Its permeability and high storage capacity enables it to absorb all the run off resulting from rainfall. Also due to high surface porosity the run-off coefficient is almost zero. The Ajali Sandstone is confined by the Nsukka Formation in the eastern part of the study area.

Theoretical background

Estimating aquifer transmissivity from specific capacity

Thomason et al (1960) developed one of the first techniques to relate transmissivity to specific capacity. Theis (1963) developed a more definitive approach using the Theis non-equilibrium equation. Empirical relationships were first used by Eagon and Johe (1972) and improved upon by Razack and Huntley (1991). Geostatistical techniques were first used by Delhome (1978,) and Aboufirassi and Marino (1984). The appropriate technique for relating specific capacity to transmissivity depends on well construction, aquifer setting, pumping tests, number of available tests and ultimately the accuracy of the applied technique.

Mace et al (2000) have developed a statistically derived linear relationship between transmissivity and specific capacity. The empirical approach involves (1) compiling all available aquifer test information for an aquifer, (2) determining the transmissivity and specific capacity for each of the tests, using regression to fit a line to the plotted pairs of log transmissivity and log specific capacity and (4) calculating the uncertainty in the linear relationship. Once the transmissivity and specific capacity pairs are compiled, least-squares regression can be used to fit a line to the log-transformed values. According to Mace (2000), this is done by defining

$Yi = b_0 + b_1 Xi$ --5.1

where

$Yi = \log (Ti)$ and --5.2

$Xi = \log \{(Sc)i\}$ ---------------------------------------5.3

By solving for b_0 and b_1 equation can be rearranged into:

$Tr = (10^{b0})\, Sc^{bi}$. --5.4

Once the best-fit line is found, how well the line fits the data can be estimated. The coefficient of determination (also called the goodness of fit), R^2, is used to describe how much of the observed variability of a parameter can be explained by the regression model.

Mace et al (2000) plotted 214 pairs of transmissivity and specific-capacity values and calculated a best-fit line at 91 percent prediction intervals for the Carrizo-Wilcox sandstone aquifer. The best-fit line to these data in the form of equation 5. 4 is:

$Tr = 1.03(Sc)^{1.08}$---5.5

This relationship by Mace et al (2000) has been used in this study to estimate the transmissivities from specific capacity data obtained from wells drilled mostly in the sandstone aquifers within the study area.

Estimating aquifer transmissivity from Dar Zarrouk parameters

The concept of Dar Zarrouk parameters was introduced by Maillet (1947). For a sequence of n horizontal, homogeneous, and isotropic layers of resistivity ℓi and thickness hi, the longitudinal unit conductance S and transverse unit resistance TR were defined by Maillet (1947) as:

$S = \sum hi/\ell i$ ---5.6

And

$TR = \sum_{i=1}^{n} hi.\ell i$ ---5.7

Both variables and the derived concept of Dar-Zarrouk curves (Maillet, 1947) are of prime significance in the development of interpretation theory for vertical electrical soundings. 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 5.6 and 5.7 to obtain the following relationship between transmissivity T_r and the so-called Dar – Zarrouk parameters:

$Tr = k\sigma\, TR = kS/\sigma$ --5.8

where σ is the aquifer conductivity and k the hydraulic conductivity of aquifer. In equation 5.8 the quantities (kσ) or k/σ are assumed to remain fairly constant in areas of similar geologic setting and water quality (Niwas and Singhal, 1981). Therefore with known values of k for the existing boreholes and with σ values extracted from the sounding interpretation at the borehole locations, it is possible to determine transmissivity and its variation within a geologic formation, including places where no boreholes are available.

Data acquisition and interpretation

Fifty eight vertical electrical soundings (VES) were carried out within the vicinity of twenty four boreholes in the study area (figure 3). The Schlumberger electrode spreading was used with maximum current electrode separation ranging from 800m to 1.2km.

The initial interpretation of the VES data was accomplished using the conventional partial curve matching technique, with two-layer master curves in conjunction with auxiliary point diagrams (Orellana and Mooney, 1966; Koefoed, 1979; Keller and Frischknecht, 1966). From this, estimates of layer resistivities and thicknesses were obtained which served as starting

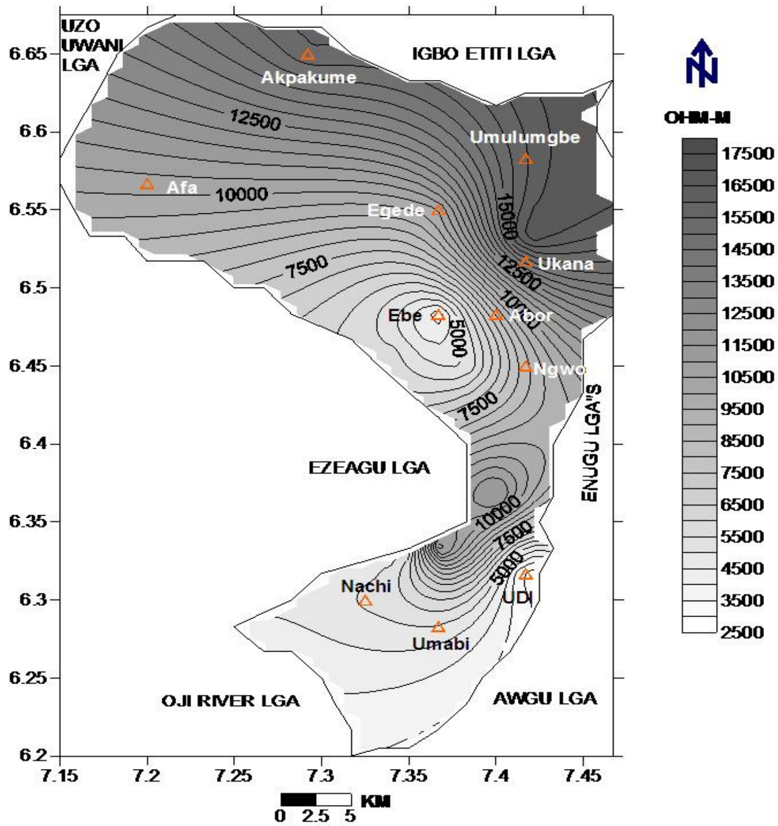

Figure 4. Aquifer resistivity map of the study area

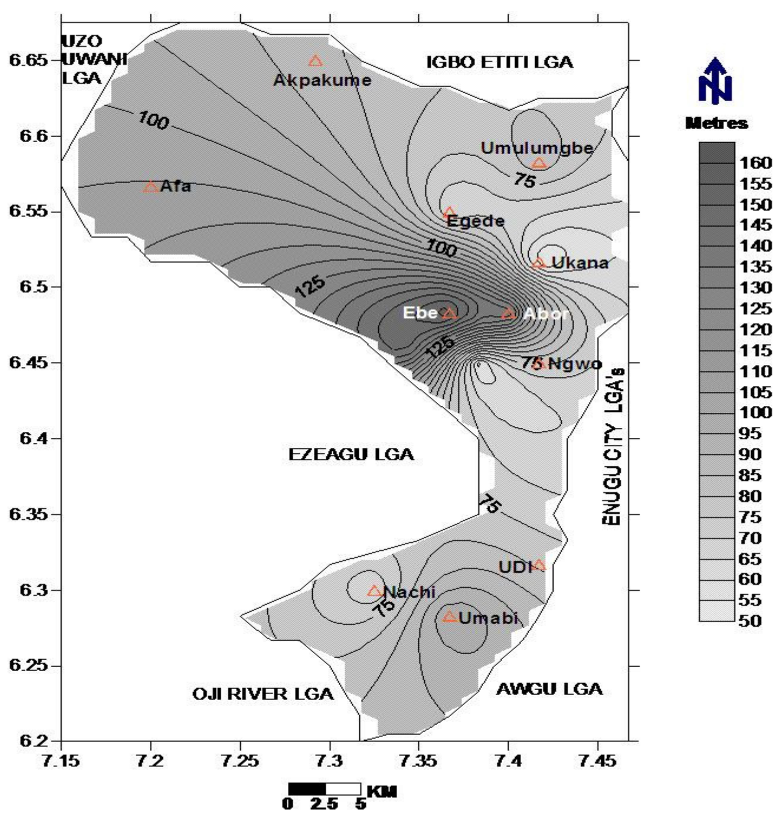

Figure 5. Isopach map of the aquiferous layer

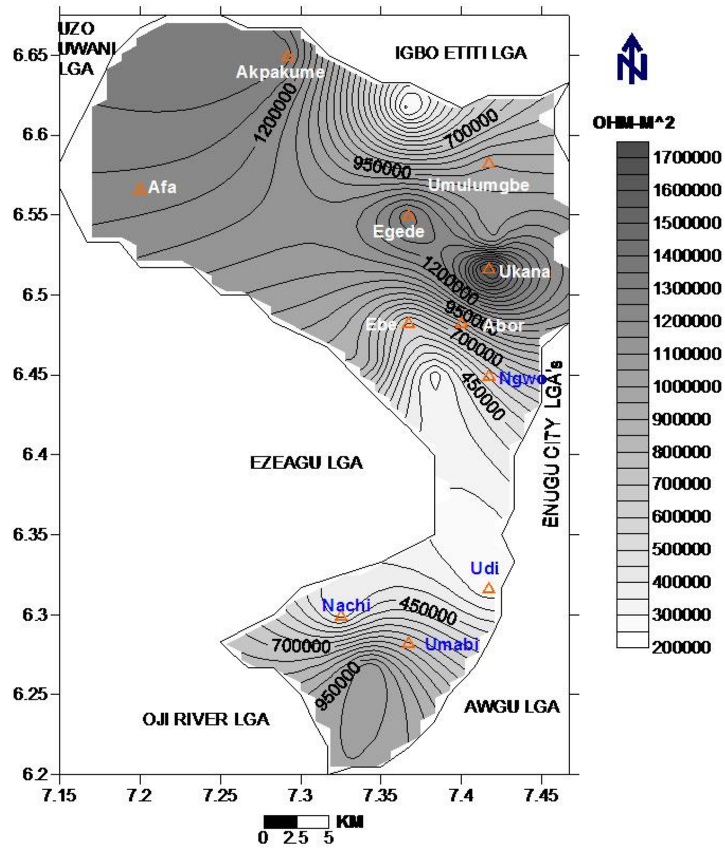

Figure 6. Transverse resistance map of the study area

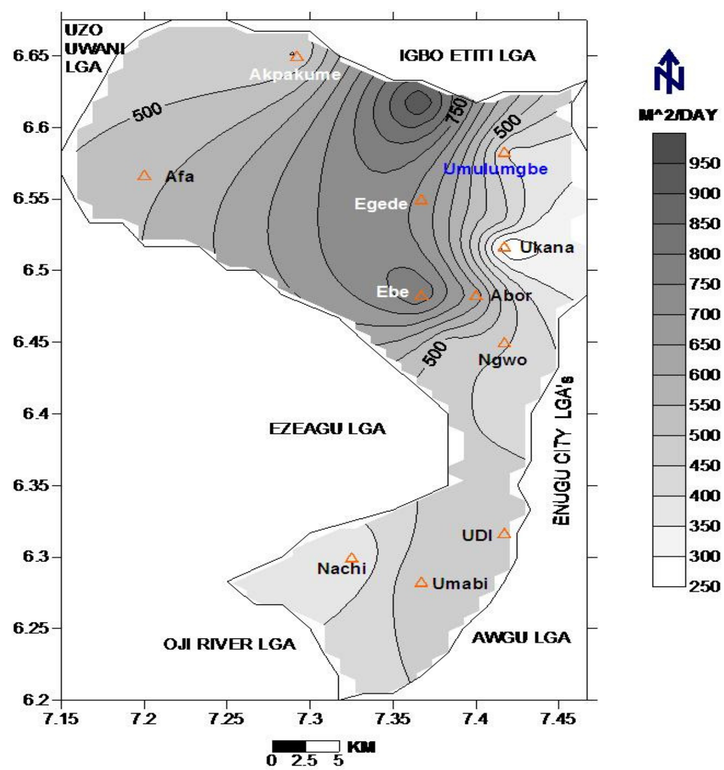

Figure 7. Transmissivity map of the study area (estimated from dar zarrouk parameters)

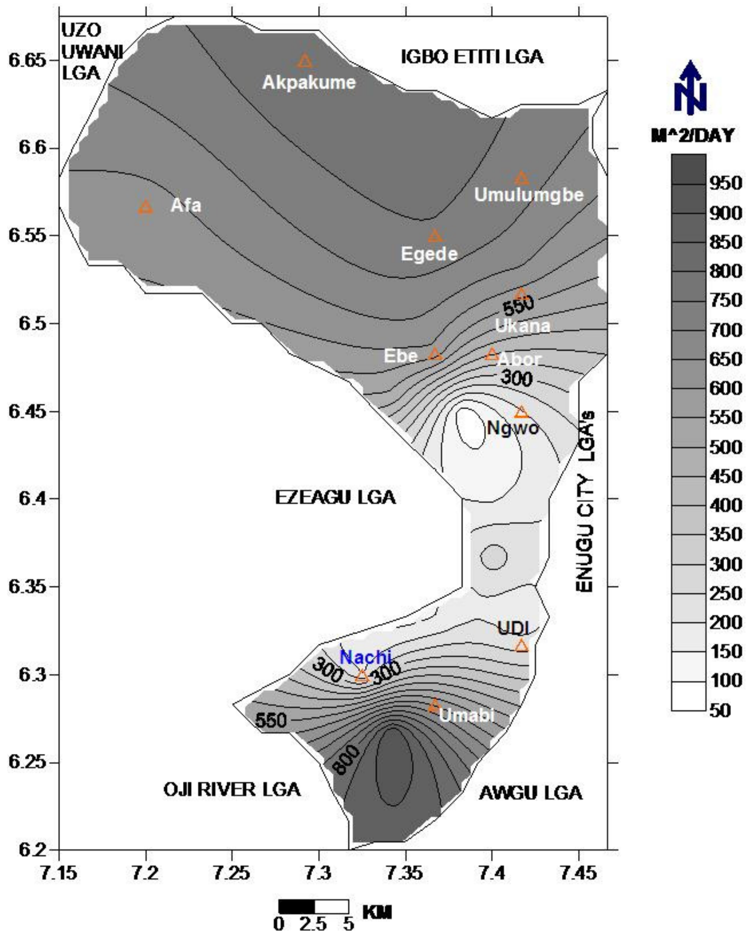

Figure 8. Transmissivity map of the study area (estimated from specific capacity)

points for computer-assisted interpretation. The computer program OFFIX, was used to interpret all the data sets obtained.

From the interpretation of the resistivity data, it was possible to compute, for every VES station, the longitudinal conductance and Transverse resistance using equations 5.6 and 5.7 respectively

RESULTS AND DISCUSSIONS

Figures 4-7 show contour maps of the apparent resistivity, thickness, transverse resistance and transmissivity of the aquiferous layer constructed from the results of the vertical electric sounding interpretation.

The resistivity map that shows the potential of the aquifer in the whole study area is presented in Figure 4. The distribution of resistivity values indicates that two distinct zones can be identified within the study area. The north- eastern part (Umulumgbe - Abor axis) of the map underlain mostly by the Nsukka Formations reveals the existence of very high resistive materials, with apparent resistivities ranging from 5721.6 Ohm-m at Abor to 10,730.83 ohm-m at Umulumgbe while the southern part, (Udi-Nachi axis) underlain mostly by the Ajali Formation shows the existence of fairly high resistive material with resistivities ranging from 2608.07Ohm-m at Udi to 5108.67 Ohm-m at Nachi.

An isopach map of the aquiferous layer has also been prepared from the interpreted VES data (figure 5). Aquifer thickness is highly variable in the study area, ranging from 48.2m at Ukana to158.8 at Ebe in the central part of the study area underlain by the Ajali Formation.

Figure 6 show the distribution of the aquifer raw transverse resistance (TR) computed from the resistivity sounding interpretation. Maximum transverse resistance values were observed in the eastern part of the study area, underlain mostly by the Nsukka Formation. Transverse resistance values range from 249154 Ohm-m^2 at Udi to 1777333 Ohm-m^2 at Ukana.

Figures 7 and 8 show transmissivity contour maps derived Dar Zarrouk Parameters and Specific capacity respectively. The average transmissivity value derived

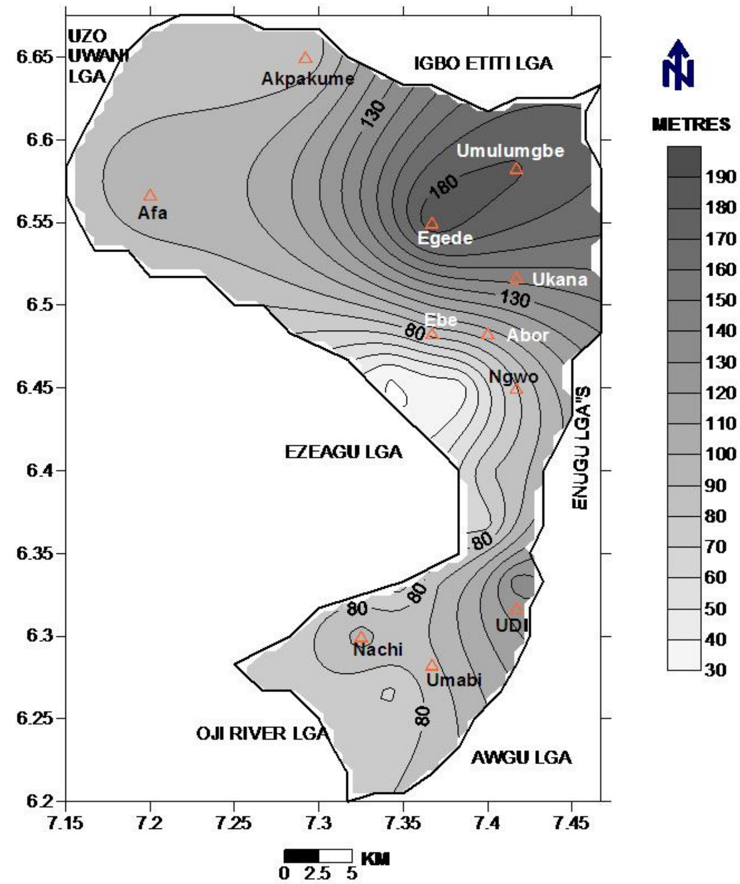

Figure 9. Static water level map of the study area

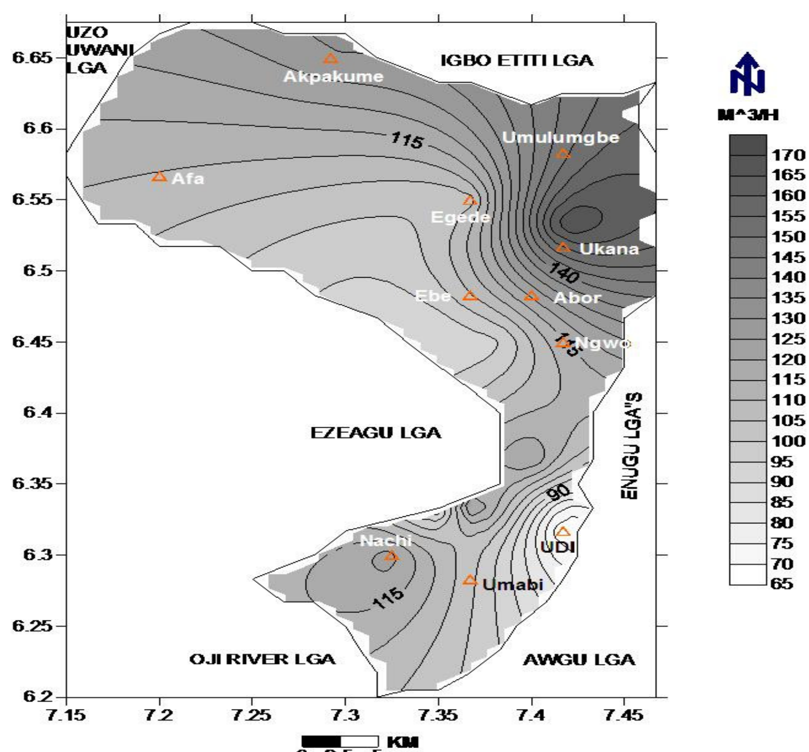

Figure 10. Borehole yield map of the study area

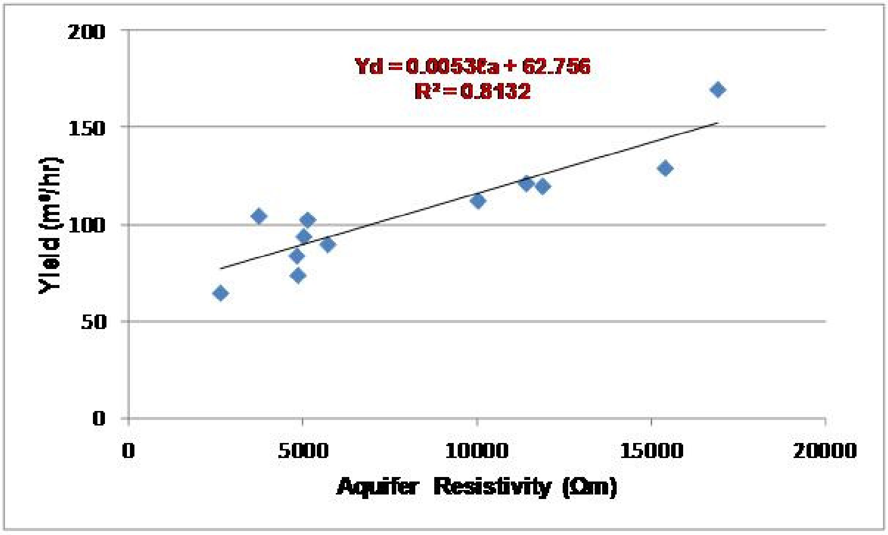

Figure 11. Borehole yield vs aquifer resistivity

from D-Z parameters (509.68m^2/day) is however slightly higher than the average value obtained from the specific capacity method (412.35m^2/day). The lower estimates may not necessarily be attributed to the model used, but could be due to recorded low specific capacity values arising from possibly poor well completion and development in some of the boreholes.

Static water level map (figure 9) indicates depth to water ranging from 30.8m at Eke to over 189 m at Egede in areas underlain by Nsukka/Ajali Formations. There is also a correlation between depth to water table and the thickness of the weathered red earth and lateritic overburden. Deeper water tables are found where thick layers of the weathered zone occur (Figure 2)

The contour map of borehole yield is shown in figure 10. Yield of water from the wells varies from 24 m^3/hr at Umulumgbe to 169.93 m^3/hr at Awhum. The figure also shows that there is a correlation between zones of high yielding wells and geology. Most high yielding wells are located in the eastern part of the study area, underlain the weathered red earth and lateritic overburden of the Nsukka Formation.

An attempt has also been made to find a general functional relationship between the resistivity ℓ_a of the aquifer as interpreted from the Schumberger depth sounding curves and the yield of boreholes, Yd. The data on the boreholes produced a significant correlation coefficient of 0.81.32 between ℓ_a and borehole yield in m^3/h. Figure 11 show the plot of borehole yield versus aquifer resistivity. The least square regression fit between the two indicates the following empirical relationship:

Yd (m^3/h) = 0.0053ℓ_a + 62.76 -----------5.1

This relationship indicates that the yield of boreholes in the area has a direct bearing on the aquifer resistivity. Zones of high aquifer resistivity may generally correspond to zones of high yielding wells.

CONCLUSIONS

The geoelectrical method is an efficient tool for most of groundwater application and new approach is developed to estimate the yield of the aquifer from apparent resistivity in the study area. Zones of high aquifer resistivity may generally correspond to zones of high yielding wells. Thus the information obtained from resistivity data can be used for pre-drilling estimation of the yield of a prospective borehole in the area.

Trasnmissivity values have been estimated using Dar – Zarrouk parameters and specific capacity. The average transmissivity value derived from D-Z parameters (509.68m^2/day is however slightly higher than the average value obtained from the specific capacity method (412.35m^2/day. Hence from the above analysis, it is clear that there is a strong relationship between geoelectrical properties and hydraulic parameters of the aquifer.

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