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Estimation of the Aquifer Hydraulic Characteristics from Electrical Sounding Data in Imo River Basin, South Eastern Nigeria: The Case of Benin Formation

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Abstract: Eight vertical electrical sounding data sets were obtained from various parts of the study area, located within latitudes 5°05"N and 5°37"N and longitudes 7°00"E and 7°30"E in the middle Imo River Basin. The litho-stratigraphic unit of Benin formation was investigated. The sounding data were analyzed with the RESIST Software to delineate the sub-surface layering. The concept of Da-Zarrouk parameters (transverse unit resistance and longitudinal conductance in porous media) was used to determine aquifer hydraulic characteristics. The following values of hydraulic conductivity and transmissivity were obtained for the Benin formation, K_{mean} = 23.07 m day^{-1}; T_{mean} = 704.72 m^2 day^{-1}; K_{max} = 46.97 m day^{-1}; T_{max} = 2036.21 m^2 day^{-1}; K_{min} = 7.02 m day^{-1}; T_{min} = 87.05 m^2 day^{-1}. It was established from the study that thick productive aquifers are located in the Benin formation.

Key words: Imo River Basin, Da-Zarrouk parameters, aquifer hydraulic characteristics, sounding, software

INTRODUCTION

The Imo River Basin is based on a bedrock of a sequence of sedimentary rocks of about 5480 m thick and with ages ranging from Upper Cretaceous to Recent (Uma, 1989). It is known to contain several aquiferous units. The characteristics of these aquifers such as transmissivity, hydraulic conductivity and storage potentials are not clearly understood. Since the mid 1980's, some researchers from the academia have carried out geological/geochemical investigations. Uma (1989) carried out a study on the groundwater resources of the Imo River Basin using hydro-geological data from existing boreholes. He concluded that three aquifer systems (shallow, middle and deep) exist in the area. His data were however too sparse to make any general statement on the hydraulic characteristics of the middle Imo River Basin aquifers. Geophysical investigations on groundwater resources in the Imo River Basin were also carried out in different sections of the basin. While the contributions made by these workers are remarkable, more work still needs to be done, particularly in the area of geophysical studies which so far have covered only a small fraction of the area of the basin. The present study is aimed at the estimation of hydraulic conductivity and transmissivity of the aquifers within Benin formation of the Imo River Basin using the electrical resistivity method. Eight electrical soundings (VES) were obtained at various locations within the study area.

The study area: Figure 1 shows the location map of the Imo River Basin where the study area is situated. The study area (Fig. 2) lies between latitudes 5°05'N and 5°37' and longitudes 7°00' and 7°30'. The Benin formation (Miocene to Recent) covers more than half of the area of the Imo River Basin. It consists of sands, sandstones and gravels with intercalations of clay and sandy clay. The sands are fine medium coarse grained and poorly sorted (Whiteman, 1982; Uma and Egboka, 1985). Petrographic study on several thin sections (Onyeagocha, 1980) show that quartz makes up >95% of all grains but Asseez (1976) and Avbovbo (1978) indicated a possible presence of more percentage of other skeletal materials including feldspar. This formation has very low dip to the South and South-West. The youngest deposits in the basin are alluvium of Recent age found mainly at the estuary of the Imo River at the Atlantic Ocean and on the flood plains of the river.

The Imo River Basin has a large amount of recharge; estimated at 2.5 billion m^3 per annum, coming mainly from direct infiltration of precipitation. Average annual rainfall is about 2000 mm. The Benin formation is by far the most aquiferous unit consisting mainly of massive continental sands, sandstones and gravels. It has a very extensive deep unconfined aquifer which covers more than half of the Imo River Basin. The aquifer consists of thick complex interbedded units of fine, medium and coarse-grained quartz sands and gravels (Uma, 1989).

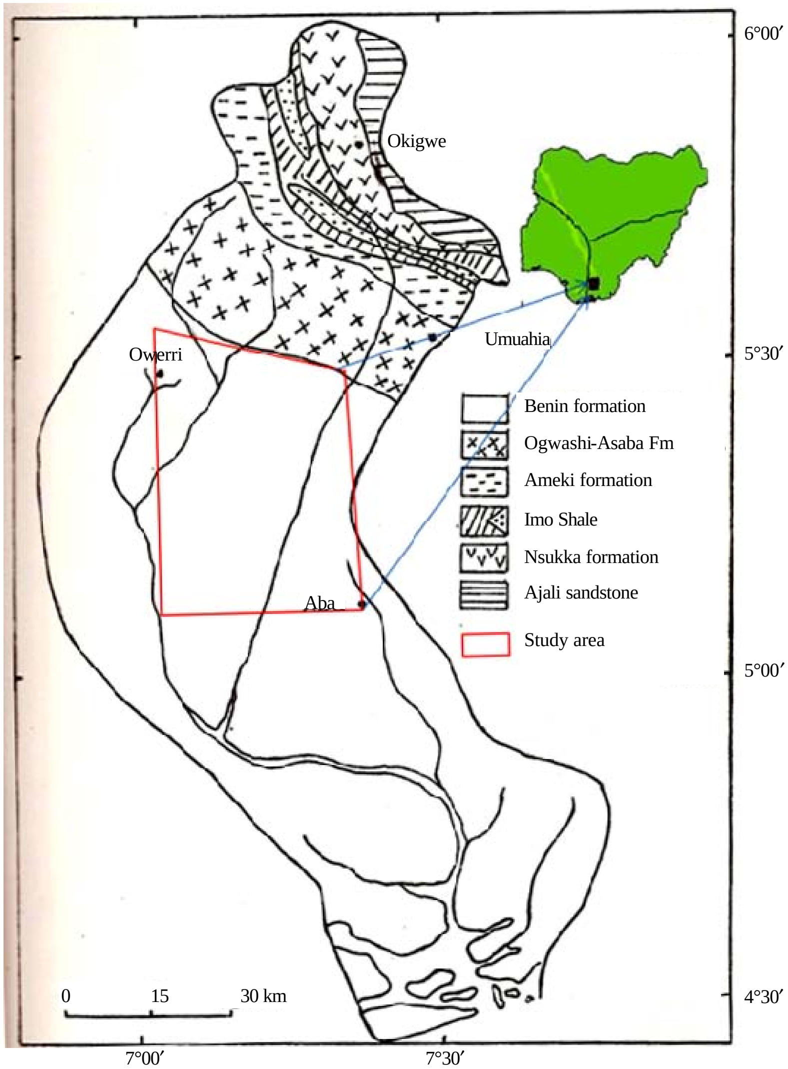

Fig. 1: Geology map of the Imo river Basin (Uma, 1989)

MATERIALS AND METHODS

Geoelectrical investigations were employed to delineate formations, distinguish between sandy, shale, clay and other layers and determine the nature of the overburden (Fig. 1). Schlumberger resistivity sounding method was used in this research. Eight vertical electrical soundings were carried out to establish the characteristics of the aquifers in the study area. Modeling of VES results was done using the RESIST Software which is an iterative inversion-modeling program. Analysis of the resulting apparent resistivity versus the half-current electrode separations yielded layered earth models composed of individual layers of specified thickness and apparent resistivity. The ABEM Terrameter SAS 4000 was used to obtain VES data from the field (Fig. 2).

Aquifer hydraulic characteristics from vertical electrical sounding data: To obtain a layer parameter, a unit square cross sectional area is cut out of a group of n-layers of infinite lateral extent. The total transverse resistance R is given by:

$$R = \sum_{i=1}^{n} h_i \rho_i \tag{1}$$

For a horizontal, homogeneous and isotropic medium:

$$\rho = \frac{(R_1 - R_2)}{(h_i - h_2)} \tag{2}$$

where, h_i and ρ_i are respectively the thickness and resistivity of the ith layer in the section. The total longitudinal conductance S is:

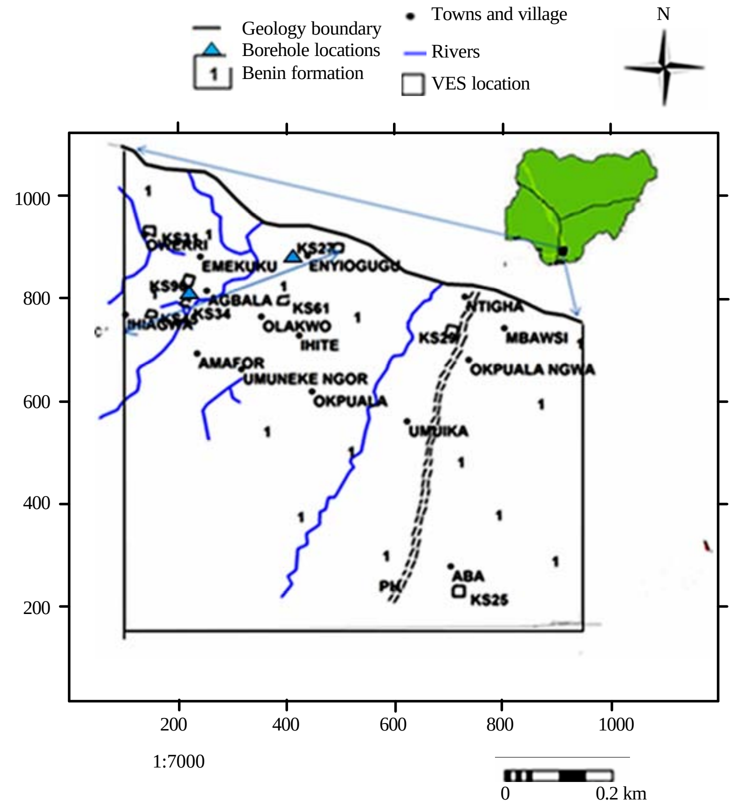

Fig. 2: Map of the study area showing VES locations

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$$

The longitudinal layer conductance S_i can also be expressed by:

$$S_i = \sigma_i h_i \quad (4)$$

where, σ_i is the layer conductivity. Conductivity in this case is analogous to the layer transmissivity, T, given by:

$$T = K_i h_i \quad (5)$$

K_i is the hydraulic conductivity of the ith layer of thickness h_i. R and S of Eq. 1 and 3 are called the Dar Zarrouk parameters which have been shown to be powerful interpretational aids in groundwater surveys (Zohdy *et al*., 1974). According to the fundamental Darcy's law, the fluid discharge 'Q' is given by:

$$Q = KIA \quad (6)$$

Where:

K = The hydraulic conductivity
I = The hydraulic gradient
A = The cross-sectional area perpendicular to the direction of flow

The differential form of Ohm's law gives:

$$j = \sigma E \quad (7)$$

Where:

j = The current density
σ = The electrical conductivity which is the reciprocal of the resistivity, ρ

For aquifer material having unit cross-sectional and thickness h, the two fundamental laws can be combined to give, according to Niwas and Singhal (1981):

$$T = K\sigma R = \frac{KS}{\sigma} = Kh$$

Where:

T = The transmissivity
R = The transverse resistance of the aquifer
K = The hydraulic conductivity
S = The longitudinal conductance

It has also been shown by Niwas and Singhal (1981) that in areas of similar geologic setting and water quality the product Kσ remains fairly constant. Thus, knowledge of K from some existing boreholes and of σ from VES sounding can be used to estimate Kσ for the same geologic zone. Hence, the aquifer hydraulic conductivity and transmissivity for the entire area can be estimated. This relationship forms the basis for the determination of aquifer hydraulic parameters used in this study.

RESULTS AND DISCUSSION

Aquifer characterization of the study area: The various aquifer characteristics obtained from the study area are shown in Table 1. The profile, CC', Fig. 3, located along SW-NE direction of the study area traverses Umuoma (KS45), Obibiezena (KS34), Obokwu Nguru (KS27) in Benin formation. There is obviously a thick aquifer underlying these locations. The borehole litholog at Enyiogugu (BH1), Fig. 4, is close to VES location KS27 (Obokwu-Nguru). There is a correlation between the VES result and the litholog. They both show fine-medium and coarse-grained sand. The depth to the water table is 20.3 m. The average aquifer thickness is 93.2 m. The hydrogeology of the area indicates that it has shallow unconfined aquifers with thickness mostly <30 m thick (Uma, 1989).

Hydraulic characteristics of the aquifer systems: The hydraulic characteristics of the several aquifer types within the study area were established using the concept of Dar-Zarrouk parameters (transverse unit Resistance (R)) and longitudinal Conductance (C) in porous media dicussed in Section 3.7. According to Ekwe *et al.* (2006), the Kσ product for Owerri-Egbu-Ihiagwa-Ife areas are hydrologically homogenous with Kσ values varying between 0.0061 and 0.0093. These may represent the Benin formation. From these values, the hydraulic conductivities of the various VES locations were estimated. From the analysis of Table 1, for the aquifers within the Benin formation, K_{mean} = 23.07 m day^{-1}; T_{mean} = 704.72 m^2 day^{-1}; K_{max} = 46.97 m day^{-1}; T_{max} = 2036.21 m^2 day^{-1}; K_{min} = 7.02 m day^{-1}; T_{min} = 87.05 m^2 day^{-1}. Uma (1989) obtained K values for the Benin formation that range from a minimum of 4.90 m day^{-1} to a maximum of 43.99 m day^{-1} with a mean of 19.71 m day^{-1}. These appear to be consistent with the values obtained in this study. Figure 5 shows the contour map of the hydraulic conductivity obtained for the

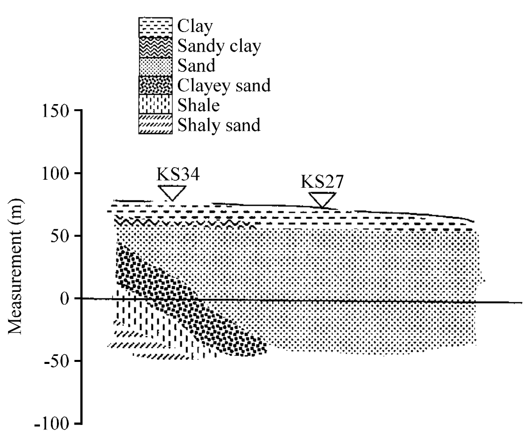

Fig. 3: Interpretative cross-section along CC'

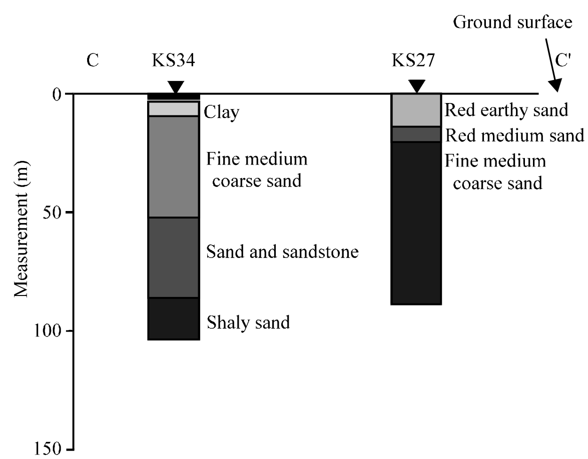

Fig. 4: Borehole lithologs along profile CC' (SW-NE)

Table 1: Aquifer characteristics at the various VES locations in the study area

VES #	Location	Depth to water table (m)	Aquifer thickness h (m)	Apparent resistivity ρ (Ω-m)	Transverse resistance, R ρh (Ω-m^2)	Kσ	Hydraulic conductivity K (m day^{-1})	Transmissivity KσR (m^2 day^{-1})
KS25	Faulks RD, ABA	15.0	10.0	1949.8	19498	0.0077	15.01	150.13
KS27	Obokwu Nguru	20.3	93.2	2370.0	220884	0.0077	18.25	1700.81
KS29	Umuike Lowa	16.4	12.4	7800.0	96720	0.0009	7.02	87.05
KS31	100 Works L/O Owerri	12.0	33.8	7700.0	260260	0.0061	46.97	1587.57
KS34	Obibiezena	52.0	44.8	7451.0	333805	0.0061	45.45	2036.21
KS45	Umuoma	52.5	22.8	2040.0	46512	0.0061	12.44	283.72
KS61	Umuohiagu	52.4	32.9	1160.0	38164	0.0076	8.82	290.05
KS90	NAZE	10.5	20.1	8800.0	176880	0.0035	30.80	619.08

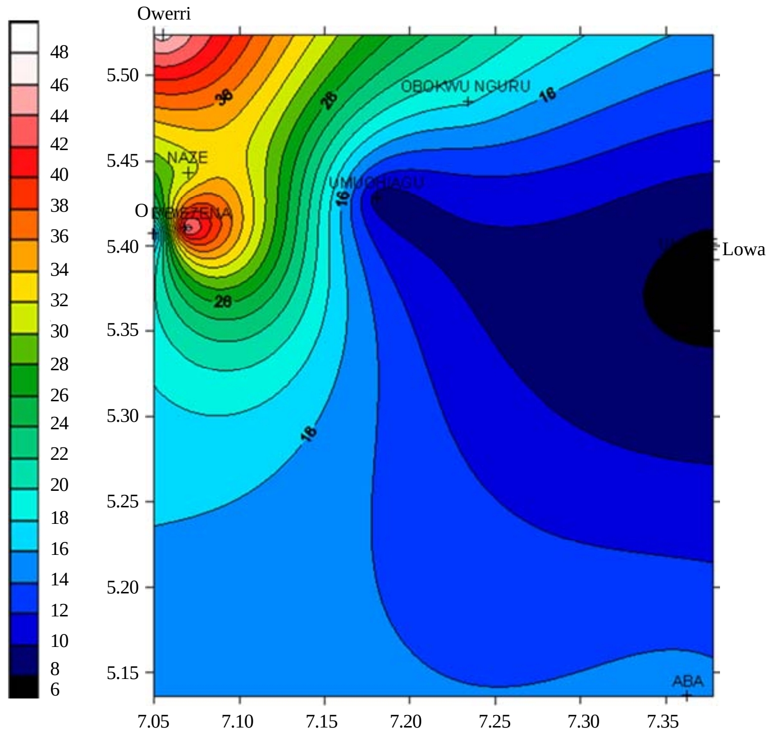

Fig. 5: Map of hydraulic conductivity for the study area

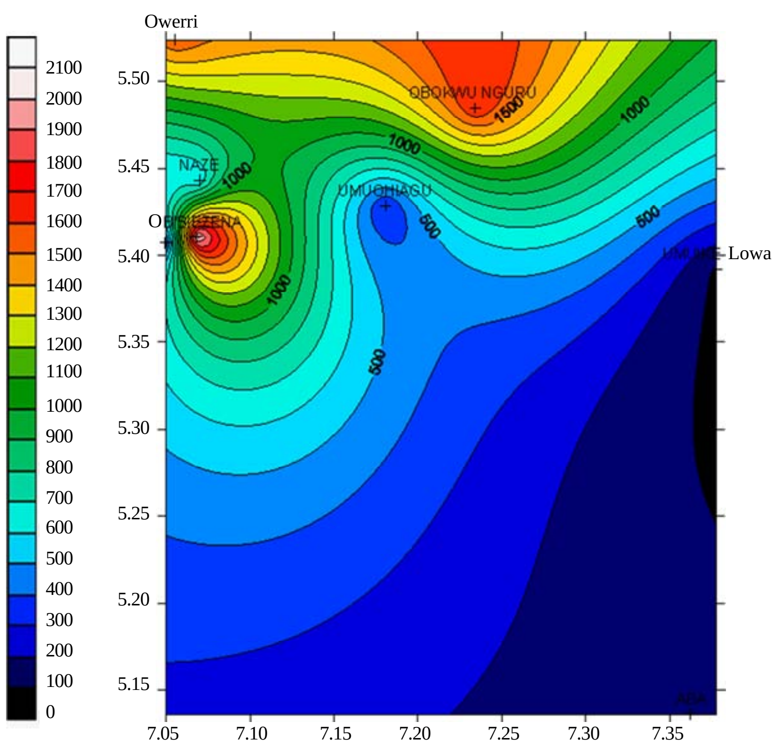

Fig. 6: Map of transmissivity for the study area

study area showing areas with high and low hydraulic conductivities. Figure 6 shows the contour map of transmissivity for the study area. These are indicative of the productive potential of the aquifers. Figure 7

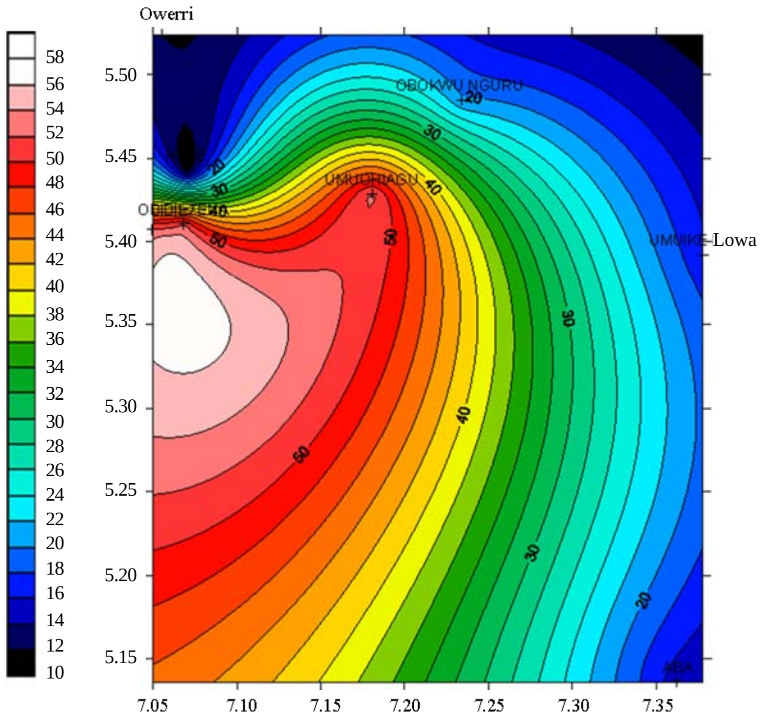

Fig. 7: Map showing depth to water table (m)

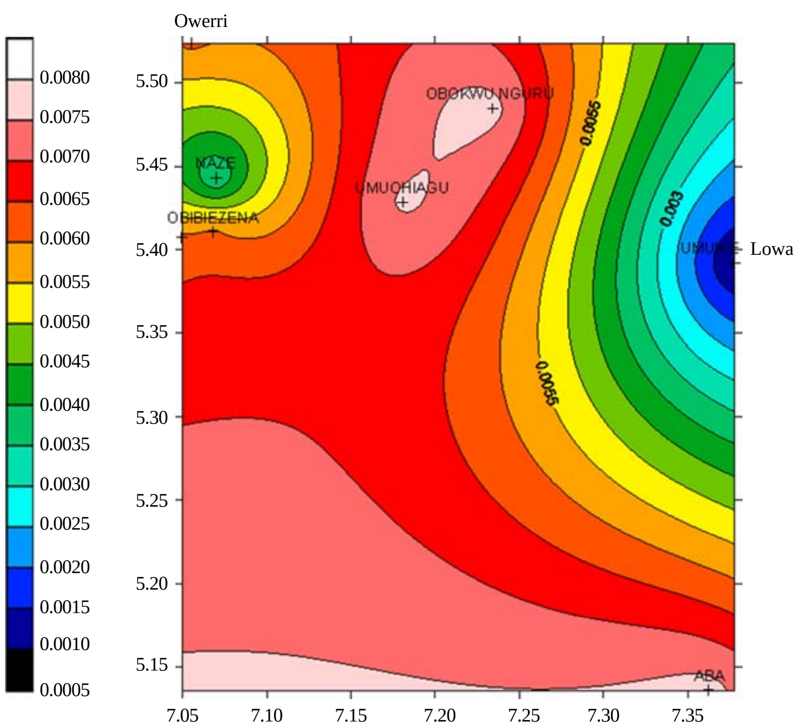

Fig. 8: Map of diagnostic prameter (kσ)

shows the contour map of the depth to the water table. Figure 8 shows the contour map of the aquifer thickness. Figure 9 shows the contour map of Kσ values estimated for the study area.

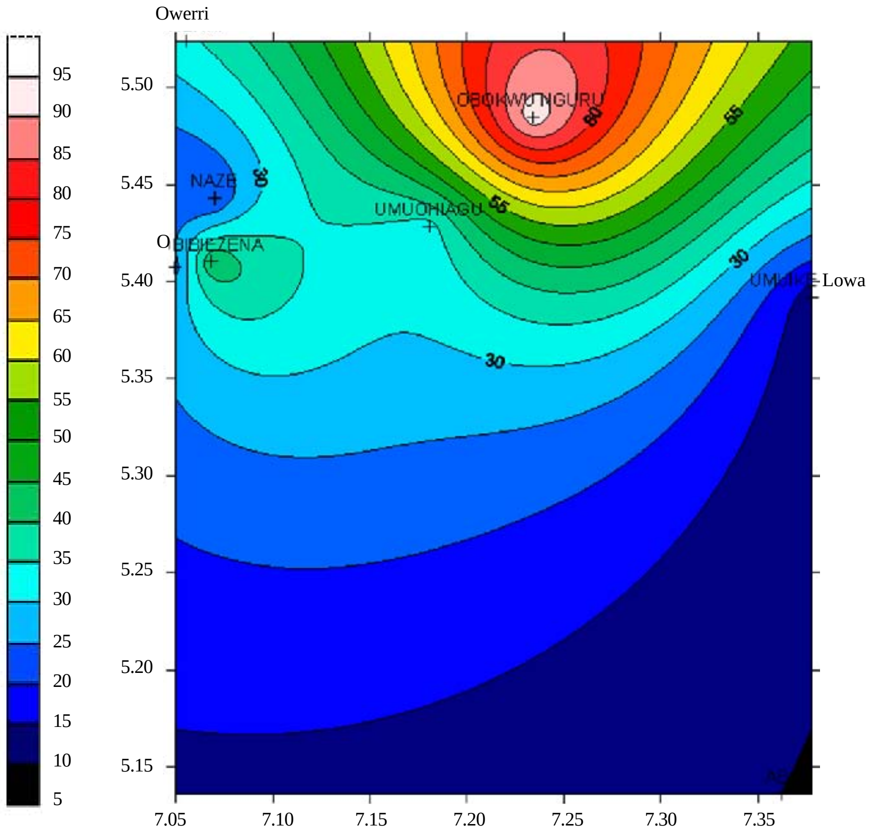

Fig. 9: Map of aquifer thikness (m) for the study area

CONCLUSION

The diagnostic features of the Kσ product proved useful in the study. It was used to estimate the hydraulic conductivity and the transmissivity for all the sounding locations across the study area. The hydraulic conductivity varies between 7.02 m day^{-1} (KS29) in Umuike-Lowa and 46.97 m day^{-1} in Owerri (KS31). The transmissivity varies from 87.05 m^2 day^{-1} at Umuike-Lowa to 2036.21 m^2 day^{-1} at Obibiezena. Areas with sufficiently high transmissivity and good aquifer thickness are most prospective for drilling productive boreholes. The productive potential for aquifers in the Benin Formaton is generally high.

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