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Aquifer Transmissivity from Surface Geo-electrical Data: A Case Study of Owerri and Environs, Southeastern Nigeria

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Abstract: The combination of layer resistivity and thickness in the so called Da-zarrouk parameters S (longitudinal conductance) and R (transverse resistance) have proved useful in the evaluation of the transmissivities of the aquifers around Owerri and environs. The area is underlain by the unconsolidated to semi-consolidated coastal Benin Formation. The surface direct current electrical resistivity method was used in the study. Seven Vertical Electrical Soundings (VES) data by the Schlumberger array was acquired in the area. A maximum current electrode spacing (AB) of 1000 m was used for data acquisition. Four of the soundings were carried out near existing boreholes. Computer modelled interpretative methods was utilized in processing the data. Results show that the depth to the water level is shallow around Ife and Egbu areas with a mean depth of 30 m. Semi- deep aquifers were encountered around Okpalla and AVU areas with a mean depth of 90 m while very deep aquifers were sensed around Owerri and Obinze areas with a mean depth of 125 m. Aquifer thicknesses in the study area range from 8 m at Ife and 117 m at Owerri. The diagnostic $K\sigma$ = constant value have proved so useful in calculating transmisivities and hydraulic conductivities of all the sounding locations including areas where no boreholes exist. Hydraulic conductivity varies between 6.19m/day at Ife and 24.7 m/day at Obinze. Transmissivity values also very between 51.39 m^2/day at Ife and 1379.56 m^2/day at Owerri. It is hoped that the results would help in long term planning of groundwater exploitation schemes within the study area.

Keywords: Transmissivity, Porous media, Da-zarrouk Parameters, Owerri, Southeastern Nigeria.

INTRODUCTION

The electrical resistivity method is utilized in diverse ways for groundwater exploration (Zohdy, 1976; Young et al. 1988; Choudhury et al. 2001; Sumanovac and Weisser, 2001; Kaya, 2001; Frohlich and Urish, 2002). Computer modelled direct interpretation techniques are used to resolve the true thicknesses and resistivities of the aquiferous zones from surface resistivity measurements (Johnson, 1977; Niwas and Singhal, 1981; Onuoha and Ezeh, 1988; Onu, 1995; Ekwe, et al. 2006). When the thickness and resistivity of an aquifer is known, its transverse unit resistance (R) and longitudinal conductance (S) can be calculated easily. Malliet (1947) was the first to give the concept of these parameters and subsequently called them the Da-zarrouk variable (R) and Dar-zarrouk function (S). Da-zarrouk parameters have since been used in the estimation of the hydraulic characteristics of aquifers. Onuoha and Ezeh (1988) used the concept of Da-zarrouk parameters to estimate the transmissivity of Ajali sandstone aquifers in Southeastern Nigeria. Ekwe et al. (2006) applied the concept of Da-zarrouk parameters to estimate aquifer transmissivities within the middle Imo River basin. Uma (1989) carried out a study on the groundwater resources of the Imo River Basin using hydrogeological data from existing boreholes. He concluded that three aquifer systems exist in the area:

a) A shallow discontinuous unconfined aquifer, with average transmissivity value of about 30 m^2/day.
b) A middle semi-confined to confined aquifer, with spatial variation in groundwater potential.
c) A confined aquifer with transmissivity value ranging from 284 m^2 /day to 702 m^2/day.

Onu (1995) carried out a hydro-geophysical study of the Njaba River sub-basin using the Electrical resistivity method. He estimated aquifer hydraulic parameters such as storativity, transmissivity and hydraulic conductivity from surface geo-electrical data. In this study, we have applied the concept of using Da-zarrouk parameters to estimate the transmissivities of the aquifers in Owerri and environs.

FORMULAE

Niwas and Singhal (1981) have combined the Darcy's equation and the differential form of Ohm's law to establish an analytical relationship between aquifer transmissivity and transverse resistance on one hand, and transmissivity and aquifer longitudinal conductance on the other.

From Darcy's law, $Q = KIA$ 1

From Ohm's law, $J = \sigma E$ 2

where Q = fluid discharge, K= hydraulic conductivity, I= hydraulic gradient, A = area of cross–section perpendicular to the direction of current flow, J = current density and σ = electrical conductivity

Niwas and Singhal (1981) combined equations (1) and (2) to get.

$$T = K\sigma R \quad 3$$

and $$T = K/\sigma C \quad 4$$

where T = transmissivity (Aquifer thickness x hydraulic conductivity). R = Transverse resistance (Aquifer thickness x resistivity). C = longitudinal conductance (Aquifer thickness x conductivity).

In this study, we have used equation 3 to estimate the transmissivity of the aquifers in Owerri and its environs since the product ks have remained fairly constant within the area of study.

STUDY AREA

The study area (Fig. 1.0) lies between latitudes (5°20'N-5°32'N) and longitudes (6°50'N-7°20'N). It lies within the southwestern section of the middle Imo River Basin. A good network of motorized and track roads made data acquisition is the area feasible. Seven Vertical Electrical Soundings (VES) were carried out in the area. Four of the soundings were carried out near already drilled boreholes.

GEOLOGY OF THE STUDY AREA

The study area is underlain by the coastal plain sands of the Benin Formation (Fig.1.0). The Formation consists of unconsolidated yellow to white sandstones. The sandstones are occasionally pebbly with lens of grey sandy clay. The age is from Miocene to Recent and the maximum approximate thickness is 200 m (Uma, 1989).

DATA ACQUISITION

The locations of the sounding stations are shown in Fig. 1.1. Seven Schlumberger soundings were made in the study area with a maximum current electrode separation (AB) of 1000 m.The instrument used was the ABEM 300B Terrameter, a digital averaging instrument for Direct current resistivity work. Four of the sounding was made at the sites of existing boreholes for comparative purposes to explore the interrelation between lithological sequences with geo-electrical layer sequences. Existing boreholes beside which soundings were conducted are located at Owerri, Ihiagwa, Egbu and Ife. The respective VES stations at these borehole locations are 1, 4, 5, and 6.

DATA PROCESSING

The measured resistance values obtained from different conducting horizons was converted to apparent resistivity values by multiplying it with the geometric factor. The sounding curve for each site is obtained by plotting the apparent resistivity on the ordinate against the half electrode spacing on a bilogarithmic transparent paper. Parameters such as true resistivity and thickness obtained from both partial curve matching and the method of asymptotes were used as input data for computer iterative modeling (Zohdy, 1976). An inspection of such curves and preliminary interpreted layer parameters gives an idea of the relative resistivities of the layers and its areal extension. Detailed quantitative interpretation was done with the IP12Win Software.

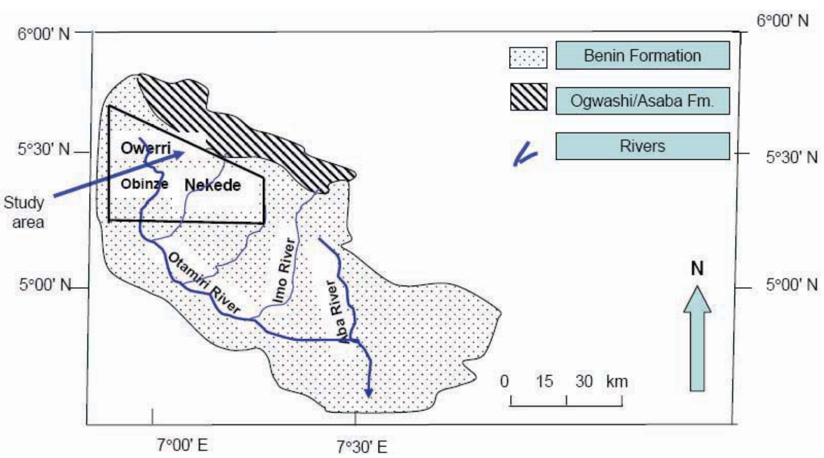

Fig.1. Geological map of the middle Imo River Basin showing the stratigraphical succession of the study area (modified from Uma, 1989).

RESULTS AND INTERPRETATION

The following format was adopted in presenting the results:

a) Comparison of VES curve results and drill hole logs of boreholes at Owerri and Ihiagwa.

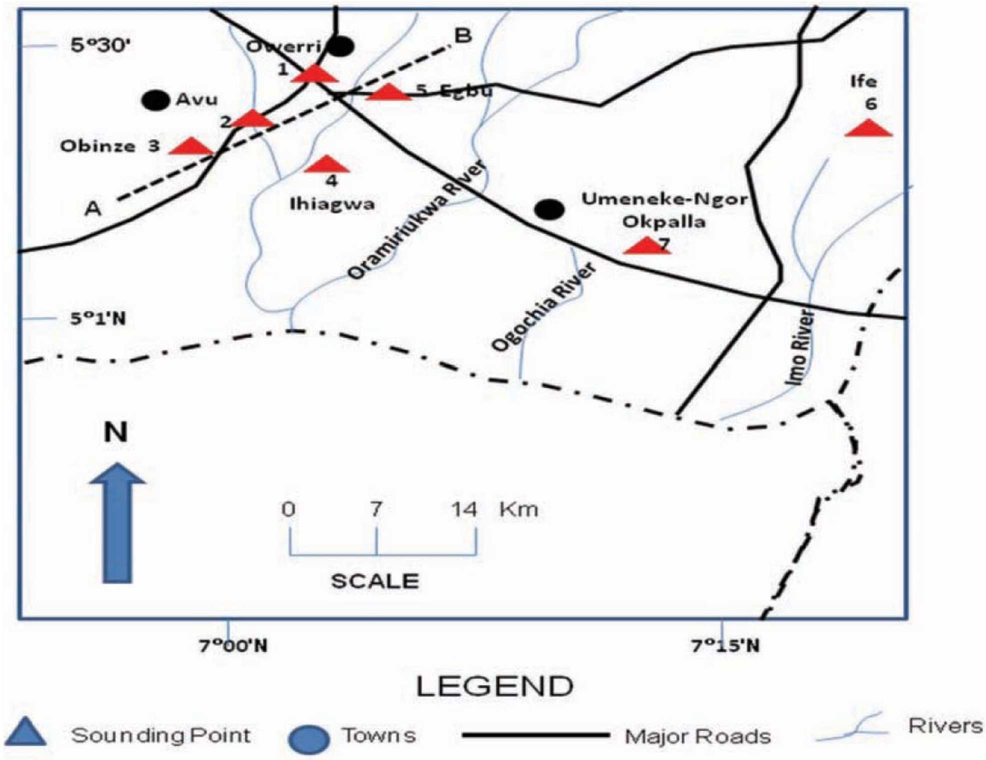

Fig.1.1. Map of the study area showing the sounding locations

b) Determination of the depth to the water table and Aquifer thickness.
c) Development of Ks (hydraulic conductivity x electrical conductivity) variation map across the study area. The variable in turn would be used to estimate Aquifer transmissivity for the area under study.

Comparison of VES Curve Results and Lithology Logs

VES 1 and borehole log at Owerri

The first geoelectic layer with a resistivity value of 2772 Wm is the top soil. The second layer consists of a reddish brown lateritic soil with clay admixtures. The third layer is sand and has a light brownish colour. The fourth geo-electric layer consists of gravel and whitish sand while the aquiferous layer consists of white sand with apparent resistivity of 1456 Ωm (Fig. 1.2).

VES 4 and borehole log at Ihiagwa

The first geoelectric layer with a resistivity of 4090 Ωm is lateritic topsoil. This layer is underlain by a reddish brown layer that is made up of dry clay and sand with grain diameter ranging between zero and one millimeter. The third layer consists of another mixture of sand and clay but the grain diameters are larger (1-2mm). They have been termed the lower lateritic soil. The fourth geoelectric layer has a resistivity value of 2917 Ωm. Lithologically, the layer contains white sand mixed with gravel and constitutes the aquiferous layer (Fig. 1.3).

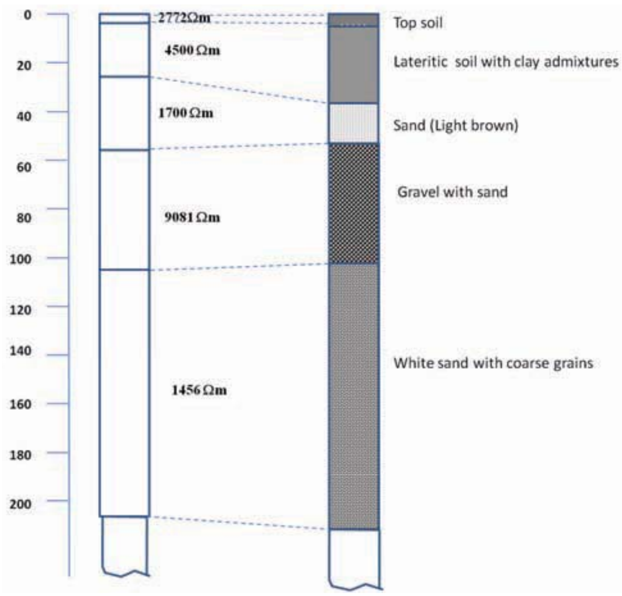

Fig.1.2. VES 1 and lithology log at Owerri borehole.

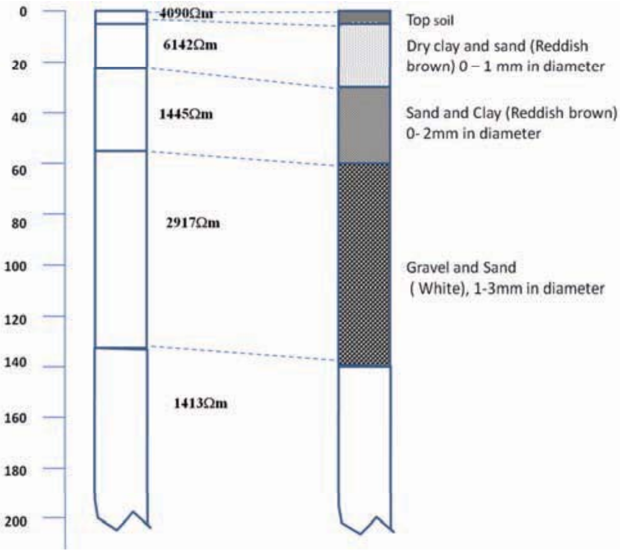

Fig.1.3. VES 4 and lithology log at Ihiagwa borehole

Depth to Water Table and Aquifer Thickness

The depths to the water table (Fig. 1.4) across the study area were deduced from the sounding result through a quantitative interpretation of the sounding curves. The deduction shows that shallow to semi-deep aquifers with

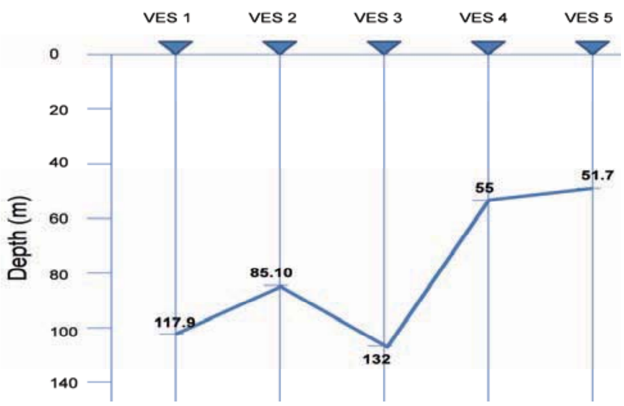

Fig.1.4. Cross-section along A-B showing the depth to water level

depths of 85.10 m, 55 m, 51.7 m and 11.2 m were encountered at Avu , Ihiagwa, Egbu and Ife areas respectively. Deep aquifers with an average depth of 125 m were encountered around Owerri and Obinze. Aquifer thickness range between 8 m at Ife and 117 m at Owerri (Fig. 1.5).

Kσ Variation across the Study Area

Niwas and Singhal (1981) have shown that in areas of similar geologic setting and water quality, the product Ks (hydraulic conductivity x electrical conductivity) remains fairly constant. Using K values at few borehole points in

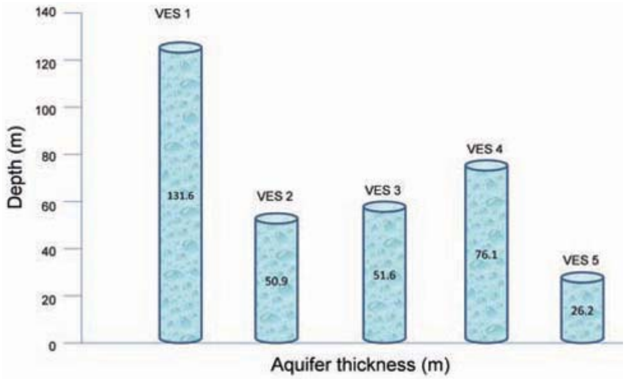

Fig.1.5. Cross-section along AB showing aquifer thickness.

the study area and σ values extracted from the sounding interpretation for the aquifer at borehole locations, it has been possible to determine transimissivity and its variation from place to place, including those areas where no boreholes exist (Fig 1.6).

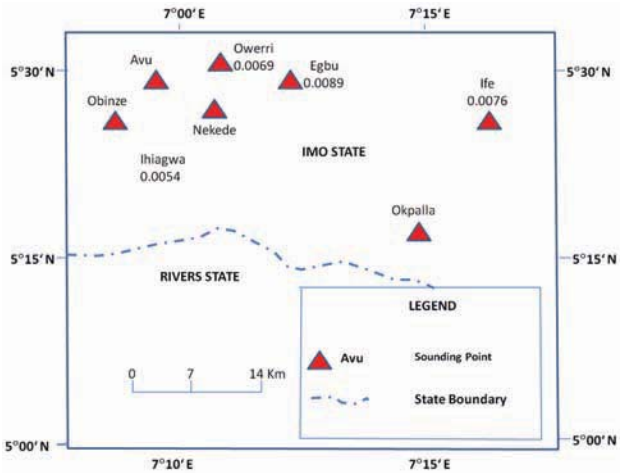

Fig.1.6. Kσ variation across the study area.

On the basis of the Kσ product, it can be concluded that Owerri – Egbu – Ihiagwa and Ife areas are homogenous hydrologically. They have K values that vary between 0.0054 and 0.0089 with a mean value of 0.0072. The area represents the Benin Formation which confirms the earlier statement by Niwas and Singhal (1981).

AQUIFER HYDRAULIC CONDUCTIVITY

By using K_{ave}= constant for the study area we have calculated hydraulic conductivity from the relation.

$$K = \frac{an\_average\_value}{\sigma}$$

The computed K values are shown in Table 1. It varies between 6.19 m/day at Ife and 24.70 m/day at Obinze.

Table 1. Aquifer parameters for the study area

VES No.	Location	Depth to water table (m)	Aqufer Thickness (b) (m)	Aquifer Apparent (r) (wm)	σ = 1/r) (seimens)	K-value from pumping tests	Kσ value	K (m/day)	T = K b (m2/day)
1	Owerri	117.9	131.6	1456	0.00069	10.02	0.0069	10.4832	1379.56
2	AVU	85.10	50.90	3120	0.00032			22.464	1143.42
3	Obinze	132.00	51.60	3430	0.00029			24.696	1274.31
4	Ihiagwa	55.00	76.1	2917	0.00034	15.74	0.0054	21.0024	1302.15
5	Egbu	51.70	26.20	1760	0.00057	15.72	0.0089	12.672	332.00
6	Ife	11.20	8.30	860	0.00116	6.57	0.0076	6.192	51.39
7	Okpalla	97.70	62.80	1050	0.00095			7.56	474.77

Transmissivity

The transmissivity for all the sounding locations in the study area including areas where no boreholes exist is computed with the relation below.

$$T = K\ b$$

K = hydraulic conductivity, b = aquifer thickness (obtained from sounding interpretation)

The estimated transmissivity values vary between 51.39 m^2/day at Ife and 1379.56 m^2/day at Owerri (Table 1).

DISCUSSION AND CONCLUSION

Analyses of the VES curves for the study area have revealed a succession of sounding layers with minor clay intercalations. Computer modeled direct interpretation techniques have also helped to resolve the true thicknesses and resistivities of the aquifer zones. The depth to the water layer is shallow around Ife and Egbu areas with a mean depth of 30 m. Semi-deep aquifers were encountered around Okpalla and AVU areas with a mean depth of 90 m, while very deep aquifers were sensed around Owerri and Obinze areas with a mean depth of 125 m.

The above results agrees closely with how Uma, 1989 delineated the aquiferous zones within the Imo River Basin. He concluded that the aquifers belong to three systems:

a) A shallow discontinuous aquifer
b) A thick regional unconfined aquifer system and
c) A confined aquifer system.

Most of the shallow aquifers are tapped using hand pumps. Some dry up at the peak of the dry season. The diagnostic Ks = constant parameter earlier derived by Niwas and Singhal, 1981 have proved very useful in this study. Based on a K_{ave} = 0.0072 derived for the study area we found out that hydraulic conductivity varies between 6.19 m/day at Ife and 24.7m/day at Obinze. Transmissivity values also vary between 51.39m^2/day at Ife and 1379.56m^2/day at Obinze.

It is however recommended that a thorough hydrochemical study be carried out to determine the potability of the water.

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Announcement

Geological Society of India

Annual General Meeting - 2012

and

National Seminar on "Mining and Community Welfare"

At the invitation of the Society of Geoscientists and Allied Technologists (SGAT), the Annual General Meeting (AGM) of the Geological Society of India for 2012 will be held on 23rd September 2012 at Bhubaneswar, Odisha. A National Seminar organized by SGAT on "**Mining and Community Welfare**" will be held during 22nd to 23rd September, 2012 at Bhubaneswar. The Seminar will cover the following focal broad aspects:

- Legislative Provisions
- Areas of concerns
- CSR and beyond
- Role of Mining Industry, Governments and other Stakeholders
- Cased studies and Action plan

Scientists interested in participating in the National Seminar may please contact: Shri **B.K. Mohanty**, D-20, BJB Nagar, Bhubaneswar – 751014, Odisha. **Phone:** +91-674-2431909, **Mobile:** +9437355664, **Email:** bkmohanty@mail.com or Shri **R.H. Sawkar**, Secretary, Geological Society of India, No.63, 12th Cross, Basappa Layout, Gavipuram P.O., P.B.No. 1922, Bangalore - 560 019; **Telefax:** 080-2661 3352, **Phone:** 080-2242 2943; **Email:** gsocind@gmail.com; **Website:** www.geosocindia.org.