Determination of Dar Zarouk Parameters for the Assessment of Groundwater Resources Potential: Case Study of Imo State, South Eastern Nigeria

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Abstract

The vertical electrical soundings (VES) method of geophysical survey using the Schlumberger configuration with a maximum electrode spread of 900m were carried out in parts of Imo State of Nigeria in order to determine the aquifer Dar Zarouk parameters. Using the estimated value of hydraulic conductivity from drilled boreholes and interpreted electrical sounding data around the borehole, the transmissivity variation within the area were determined. The values obtained are moderate and fairly uniform, ranging from 551.695 m^2/day to 556.607 m^2/day and are consistent with the geology of the area. The transverse resistance values ranged from 4366 Ω measured at Okohia (VES 12) to 953310 Ω obtained at Anara (VES 11). Similarly the isoresistivity map for L/2 = 150m shows that the area is generally underlain by fairly high resistivity materials with the Western half being more resistive than the eastern part. Separating these two regions is a very narrow low resistivity area in the central part around Okohia with value of 200 Ωm. The variation in resistivity could be linked to differences in geology, topography, drainage system, water quality and degree of saturation. The low resistivity observed in the central part could be associated with the presence of Oramiriukwa River. On the basis of longitudinal conductance, three major zones are identified. Zone A which covers the western and North-eastern parts is underlain by relatively low resistive aquifer materials. This zone is more promising for siting productive boreholes. The central area makes up Zone B while the third zone (Zone C) is underlain by high resistivity (low longitudinal conductance) aquifer materials. This zone may not be good enough for drilling boreholes with high yield expectation.

Key Words: Dar Zarouk, Isoresistivity, transverse resistance, longitudinal

conductance.

1. Introduction

Dar Zarouk parameters - the tranverse resistance and the longitudinal conductance derived from layer resisivity and thickness obtained during Vertical Electrical Sounding (VES) survey have been proved to be very useful in enhancing the interpretation of groundwater survey (Zhody et al. 1974; Ekwe et al. 2006). Niwas & Singhal (1981) derived analytically the relationship between aquifer transmissivity and transverse

resistance and that between transmissivity and longitudinal conductance and showed that in areas where the geologic setting and water quality do not vary greatly, the conductivity product $K\sigma$, remains fairly constant. Thus if the value of hydraulic conductivity K, from the existing boreholes and the electrical conductivity from the sounding interpretation around the boreholes are available, it is possible to estimate the transmissivity and its variation from place to place by determining the transverse resistance or longitudinal conductance for the aquifer. This is the basis of this geophysical survey.

The study area, Mbano, is located between latitude $5^o35\ ^1$N to $5^o48\ ^1$N and longitude $7^o02\ ^1$E to $7^o18\ ^1$E (Fig. 1). The area is within the central part of Imo State in the South Eastern Nigeria and is characterized by equatorial climate with abundant rainfall that feeds an extensive hydrological system. However, the inhabitants of the area do not have access to portable water. The streams and river channels have become polluted due to poor waste management, agricultural and commercial activities since the area is rapidly becoming urbanized. A number of drilled boreholes in the area such as the one located at Ibeme have been unproductive. This could be linked to inadequate or non availability of geophysical data of the area (Ekine &Iheonunekwu 2007; Nwosu et al. 2011). It could also be linked to the complex nature of the depositional environment as the area lies within the transition zone between Imo, Benin and Ogwashi Formations

(Fig. 2). This study therefore aimed at using Dar Zarouk parameters to provide information on the groundwater resources potential of the area.

2. Summary of Geology of the Study Area

The major sedimentary sequences of the study area (Fig. 2) are the Benin Formation, the Ogwashi-Asaba Formation, the Bende – Ameki Formation, the Imo Shale and the Nsukka Formation. The Benin Formation is overlain by lateritic overburden and underlain by the Ogwashi – Asaba Formation which is in turn underlain by the Ameki Formation of Eocene to Oligocene age (Mbonu et al. 1990). The Benin Formation consists of coarse – grained gravelly sandstones with minor intercalations of shales and clay. The sand units which are mostly coarse grained, pepply and poorly sorted, contains lenses of fine grained sands (Onyeaguocha 1980; Ehirim & Nwankwo 2010). The formation which forms parts of the stratigraphic unit of study area is a continental deposit of Miocene to Recent age and has a thickness greater than 1820m. It has typical outcrops around Benin, Onitsha and Owerri. The Ogwashi -- Asaba Formation is made up of variable succession of clays, sands and grits with streaks of lignite. It also forms part of the stratigraphic unit of the study area. The Ameki Formation consists of greenish- grey clayey sandstones, shales and mudstones with interbedded limestones. This formation in turn over lies the impervious Imo Shale group characterised by lateral and vertical variations in lithology. The Imo Shale of Paleocene age is laid down during the transgressive period that followed the Cretaceous. It is underlain in succession by the Nsukka Formation, Ajali Sandstones and Nkporo Shales.

Due to the porous and permeable nature of the Benin Formation coupled with the overlying lateritic earth and the weathered top of this formation as well as the underlying clay/shale member of the Bende-Ameki series, this geologic zone provides the hydrologic conditions that favour aquifer formation (Mbonu et al. 1990). However, the fact that the study area lies within the transition zone of the Benin Formation and the

Ogwashi -Asaba Formation makes groundwater prospecting difficult. Siting of productive borehole depends largely on proper preliminary geophysical survey.

2.1 *Theoretical Background*

Dar Zarouk Parameters equations are derived by considering a column of unit square cross-sectional area cut out of group of layers of infinite extent. The total transverse unit resistance R, and total longitudinal unit conductance S, are respectively given as:

$$R = \sum_{i=1}^{n} h_i\rho_i, \quad i = 1,2,3, ---n \qquad 1$$

and,

$$S = \sum_{i=1}^{n} h_i/\rho_i, \quad i = 1,2,3, ---n \qquad 2$$

where ρ_i and h_i are the resistivities and thickness of the ith layer. The average longitudinal resistivity is expressed as,

$$\rho_L = H/S \qquad 3$$

$$\text{where } H = \sum_{i=1}^{n} h_i, \quad i = 1,2,3, ---n \qquad 4$$

and the average transverse resistivity is given by

$$\rho_t = R/H$$

The coefficient of anisotropy is defined as the square root of the ratio of ρ_t to ρ_L

The longitudinal conductance S_i can also be represented as:

$$S_i = \sigma_i h_i \qquad 5$$

where σ_i is the layer conductivity which is analogous to the layer transmissivity, Tr used in groundwater hydrology (Mbonu et al., 1990). It is given by:

$$Tri = Ki\ hi \qquad 6$$

where Ki is the hydraulic conductitivty of the ith layer of thickness hi.

The relationship between aquifer transmissivity Tr and transverse resistance R and that between Tr and S derived analytically by Niwas and Singhal (1981) is represented as:

$$Tr = K\sigma R = KS/\sigma = Kh \qquad 7$$

Thus, it is possible to estimate the transmissivity and its variation from place to place from the determinations of R or S for the aquifer.

3. Method of Data Acquisition

Field data was acquired using a portable resistivity meter, the "R – Plus". It is self averaging digital equipment capable of automatically compensating for the polarization of the electrodes, induced polarization of the earth materials and the drift effects (Nwosu et al. 2011). It displays on the screen the apparent resistivity for each electrode spacing.

The Schlumberger electrode array were used to carry out a total of seventeen vertical electrical soundings, utilizing a maximum electrode spread of 900 m. Four of the stations were sited near existing boreholes to enhance interpretation. The current electrode spacing was increased symmetrically along a straight line about the station point while the potential electrodes were kept fixed but increased only when the measured signal became very small. The measured apparent resistivity values were plotted against half of current electrode spacing ($L/_2$) on a log-log graph scale to obtain the field curves which were subjected to partial curve matching using the Rijks Waterstaat (1988) standard curves to obtain the initial model parameters. The model parameters were then used for computer aided interpretation using the soft-ware package - the Schlumberger automatic analysis version 0.92 by Hemker (1985).

4. Data Analysis and Discussion of Results

The field and modeled curves obtained reveal multilayered earth in the study area which ranged from 4 to 6 geoelectric layers. Fig. 3 shows typical field and model curve obtained from the VES result. Table 1 compares aquifer characteristics obtained from pumping test data from boreholes in the area with the corresponding values obtained from VES data near them. Parameters 1 to 3 were calculated from pumping test data while parameters 4 to 11 are calculated using the VES data. Little variation is observed between parameters 2 and 11 for Amaraku, Osuama and Umuelemai, indicating the reliability of the VES result. The summary of aquifer characteristics for all the sounding stations is presented in Table 2. It shows the geoelectric parameters obtained from VES results. The resistivity and thickness of the aquiferous zones as revealed by the geoelectric interpretative cross section (ICGS) along profile lines AB and GH varied over the entire area (Fig. 4). The layer resistivity also varied with depth and lithology as shown by the geoelectric section of the station near the sample boreholes (Fig. 5). Figure 6 gives the distribution of the transverse resistance over the entire area and shows that the entire area is highly resistive ranging from the least value of 4266 Ω measured at Okohia (VES 12) to 95331 Ω at Anara (VES 11) with the Southern part being more resistive.

Similarly, the Isoresistivity map for L/2 – 150m (Fig. 7) shows that the area is generally underlain by fairly high resistive materials especially at the western half, with values ranging from 1992 Ωm as recorded at Abajah (VES 10) to 5618 Ωm at Umuopara (VES 16). The eastern half values ranges from 200 Ωm recorded at Ezumoha (VES 15) to 3218Ωm at Umuneke (VES 13). Separating these two regions is a very narrow low resistivity zone around the central part of the study area with resistivity value range of 200 Ωm at Okohia to about 1,000 Ωm at Ezumoha and the area bordering Eziama.

The variation in resistivity at the depth probed with the electrode spacing could be linked to differences in geology, topography, drainage system, lithology, water quality and degree of saturation (Ekine & Osobonye 1996). The very low resistivity value of the central part of the area could be associated with the presence of the Oramiriukwa River which flows southwards from Osuama through Okohia (VES 12).

Transmissivity of the aquiferous zones and its variation from place to place were determined using the analytical relationship between aquifer transmissivity and transverse resistance and between transmissivity and longitudinal conductance. Figure 8 shows the distribution of transmissivity values which are moderate and fairly uniform, ranging from 551.695 m^2/day to 556.607 m^2/day.

The distribution of longitudinal conductance values across the study area is shown in figure 9. Three major zones can be identified by this distribution. The Western and the North-Eastern areas make up zone A. This zone is underlain by relatively low resistive (higher conductivity) aquifer materials. Separating this zone into two is a central zone (zone B) covering VES stations 4, *5, 7,* 9, 10, 11, 13 and 14. The third zone *(*zone C) lies in the Southern part covering VES *5, 6 and* 16. This zone is underlain by high resistive (lower longitudinal conductance) aquifer materials. This area may not be good for drilling of boreholes with high yield expectations (Mbonu et al. 1991). Areas within this zone are Amaraku, Ibeme and Umuopara. This could explain the failure of the borehole located at Ibeme. Another reason may be the effect of topography. Ibeme is located on a topographical high area between the Mbaa and Oramiriukwa rivers and the aquifer may have drained into these rivers. Zone A is therefore more promising for sitting boreholes. The distribution of transverse resistance (Fig. 6) reveals similar result.

5. Conclusion

Dar Zarouk parameters of transverse resistance and longitudinal conductance have been applied successfully in this study to assess the groundwater resources potential of the study area. On the basis of longitudinal conductance, three aquifer systems have been identified for the area. The distribution of transverse resistance for the area gave similar result. The results of this study are reliable and consistent with the geology of the area. The western and northeastern parts of the study area are more viable for sitting productive boreholes than the other parts.

Acknowledgment

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Table 1: Aquifer Characteristics calculated for some Boreholes located in the Study Area

S/NO.	PARAMETER	**AMARAKU BH VES 6**	**ANARA BH VES 11**	**UGIRI BH VES 8**	OSUAMA BH VES 14
1.	Screen length (m)	15.850	54.72	15.000	54.00
2.	Average filled hydraulic conductivity K (m^2/day)	10.127	32.304	28.806	5.515
3.	Transmissivity Tr (m^2/day)	161.045	1767.675	432.050	297.80
4.	Resistivity of aquifer(Ωm)	1500.0	12900	14600	2760
5.	Aquifer thickness (m)	36.000	73.9	44.5	38.3
6.	Longitudinal conductance S	0.00240	0.00573	0.00305	0.01388
7.	Transverse resistance (Ωm)	540000	953310	649700	105708
8.	K/σ value	14925.37	95897.44	182500.00	39834.65
9.	Kσ value	0.00103	0.00058	0.00084	0.00522
10.	Transmissivity of auriferous zone (m^2/day)	555.001	556.199	548.269	551.780
11.	Hydraulic conductivity (m^2/day)	15.34	7.48	12.41	14.42

Table 2: Aquifer Characteristics calculated for all the Stations

STATION NO	Resistivity p (Ωm)	Thickness h (m)	Conductivity σ (Ω^{-1})	Transverse Resistance R (Ωm)	Longitudinal Conductant S	Hydraulic Conductivity K (m/day)	Transmissivity Tr (m^2/day)
1	1820	61.9	0.000549	112658	0.034011	8.92	551.695
2	1680	56.6	0.000595	95088	0.033690	9.76	552.195
3	850.0	30.9	0.001176	26265	0.036353	17.88	552.271
4	4850	64.1	0.000206	311526	0.013189	8.62	553.183
5	4700	55.7	0.000213	261720	0.011851	9.98	556.349
6	15000	36.0	0.000067	540000	0.002400	15.34	555.001
7	6020	72.0	0.000166	433440	0.011960	7.67	551.864
8	14600	44.5	0.000068	649700	0.003048	12.41	548.269

9	9700	90.7	0.000103	879790	0.009351	6.09	551.866
10	4200	57.3	0.000238	240660	0.013643	9.64	552.151
11	12900	73.9	0.000078	953310	0.005729	7.48	556.199
12	236	18.4	0.004237	4366	0.077966	30.02	555.332
13	4140	78.4	0.000242	324576	0.018937	7.05	553.759
14	2760	38.3	0.000362	105708	0.013877	14.42	551.780
15	4310	97.8	0.000232	421518	0.022691	5.65	552.526
16	16000	57.7	0.000063	923200	0.003606	9.57	556.607
17	1480	56.3	0.000676	83324	0.038041	9.81	552.669

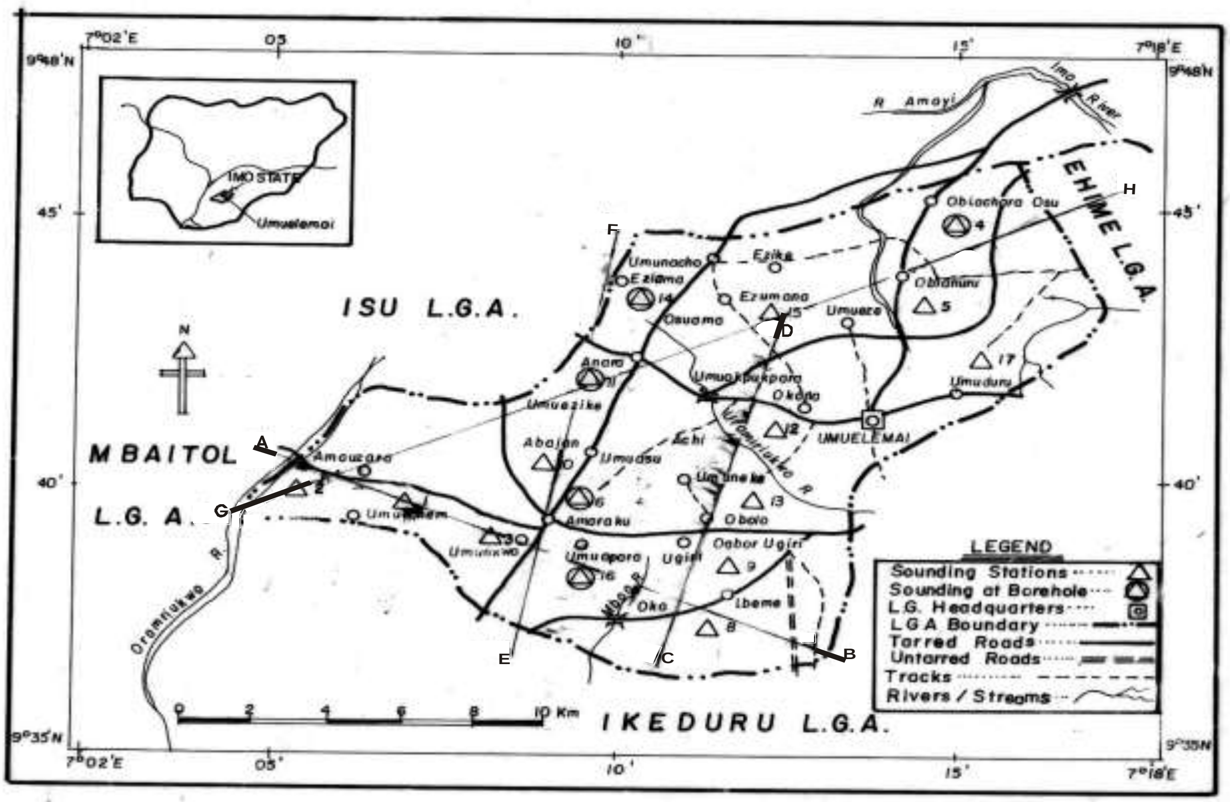


Figure 1: Map of study area showing location of sounding stations and IGCS traverse

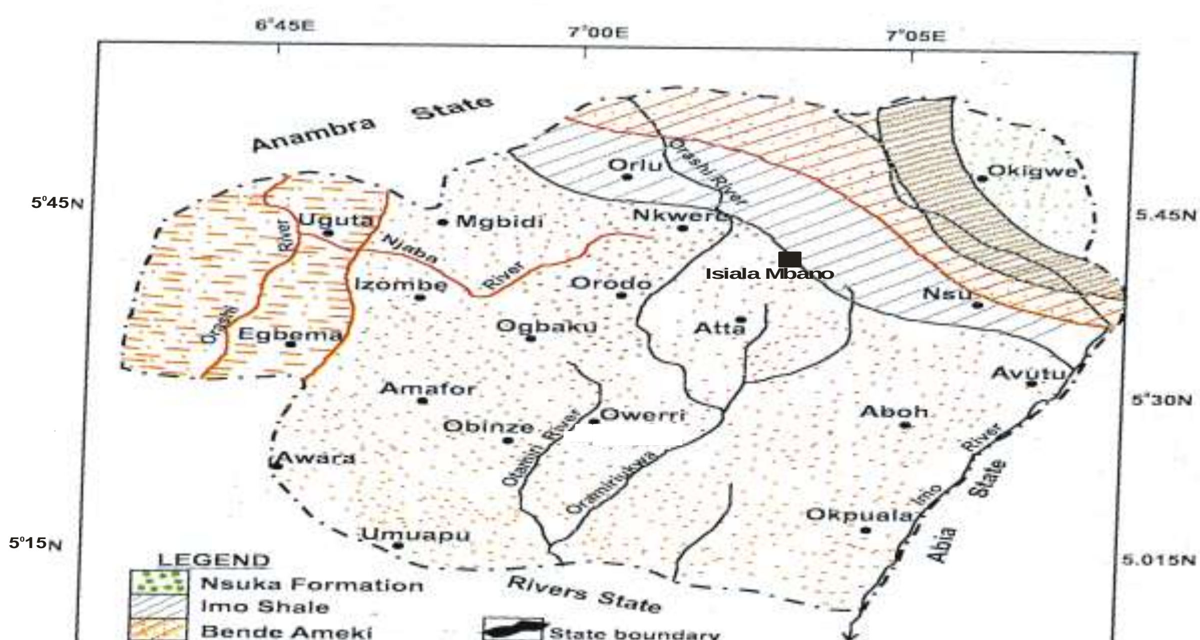
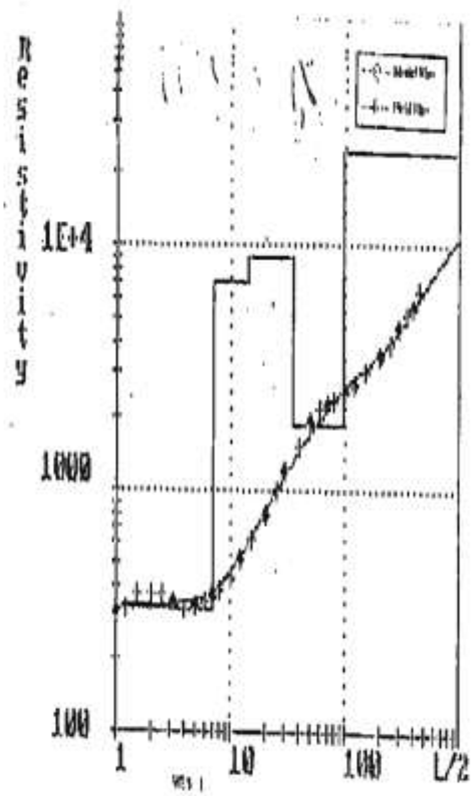
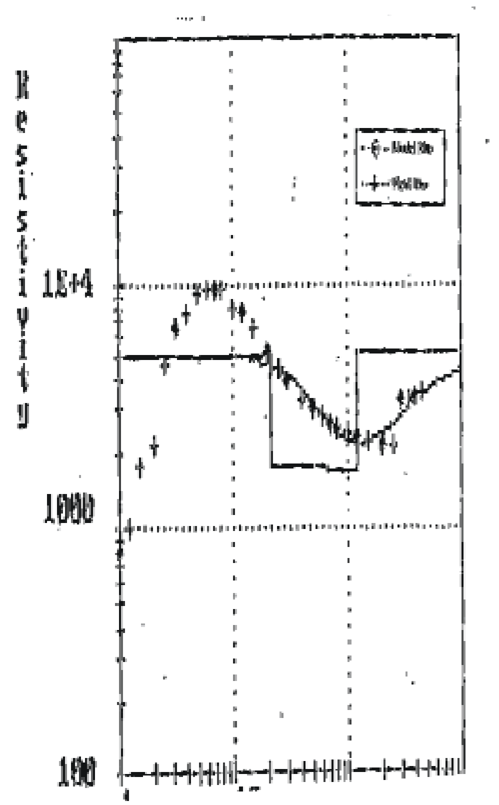


Figure 2: Geology map of Imo State showing the study area (After Akaolisa &Solomon 2009)





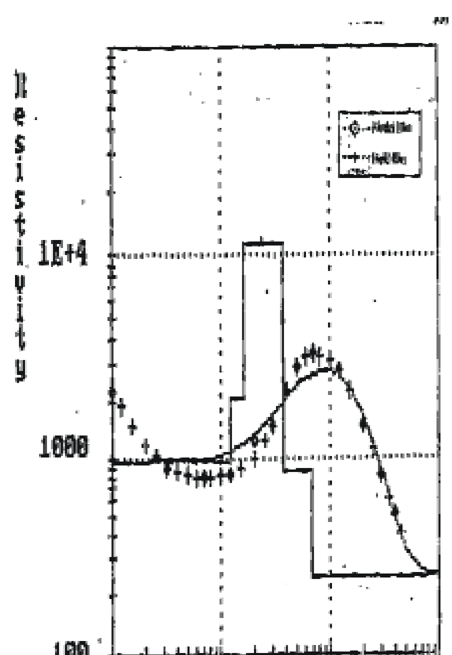
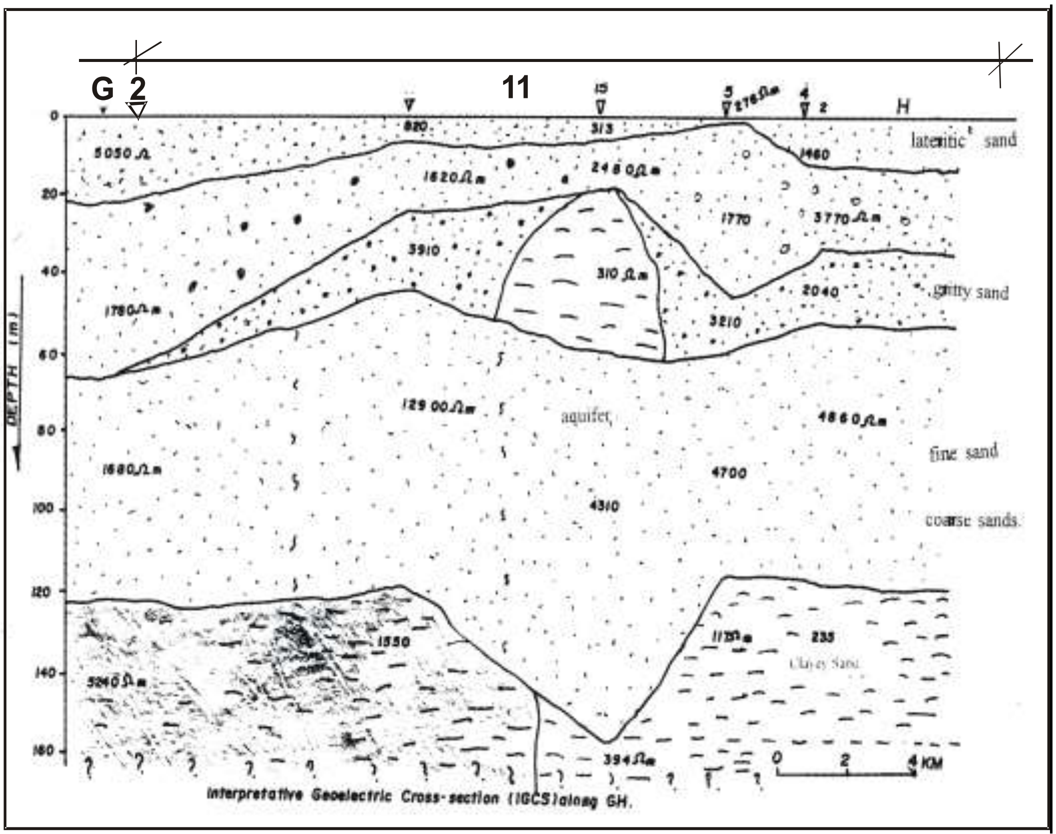
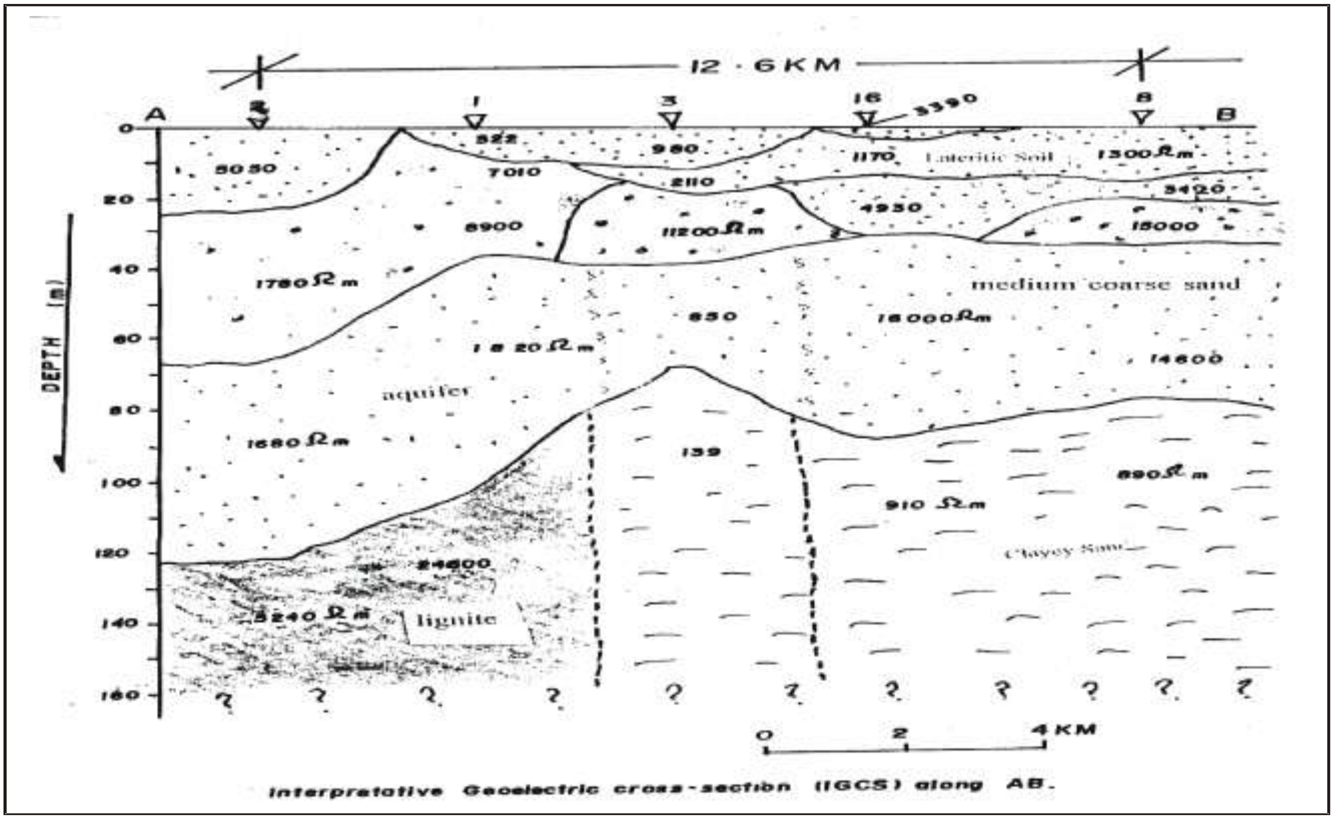
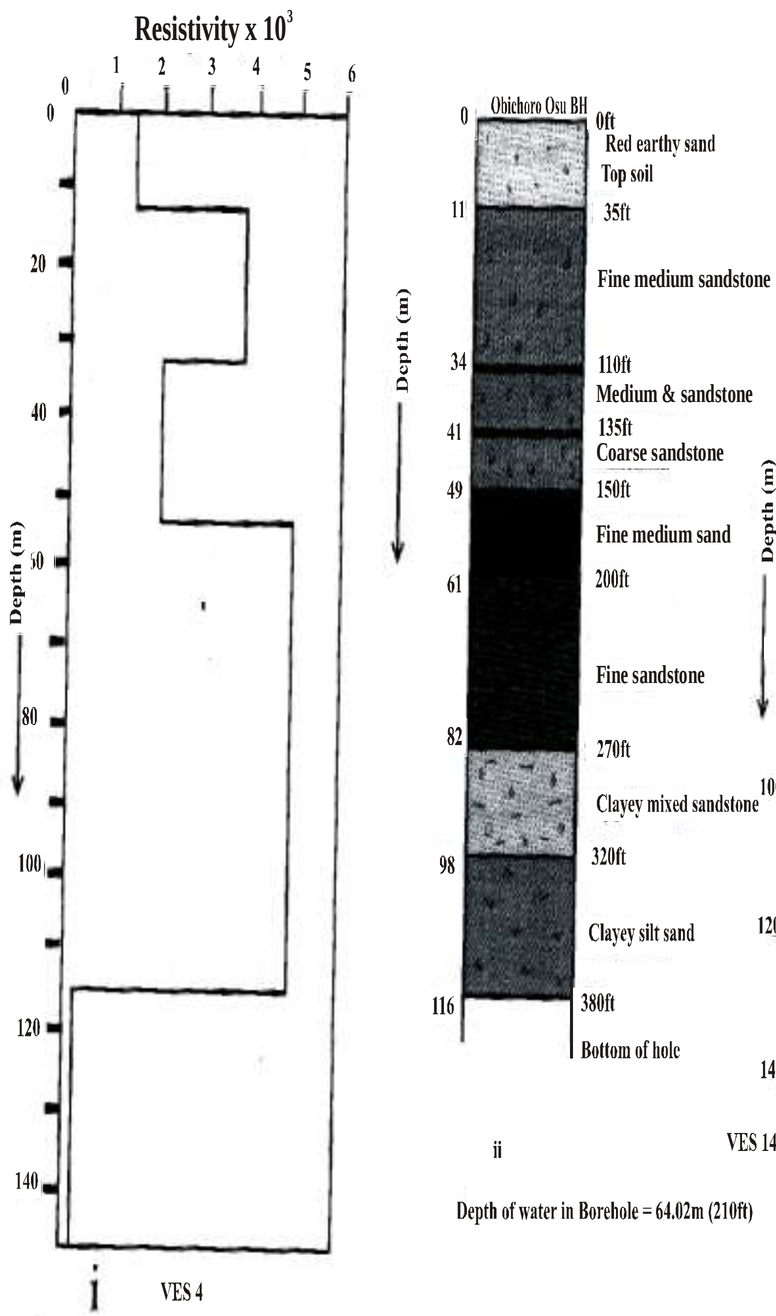
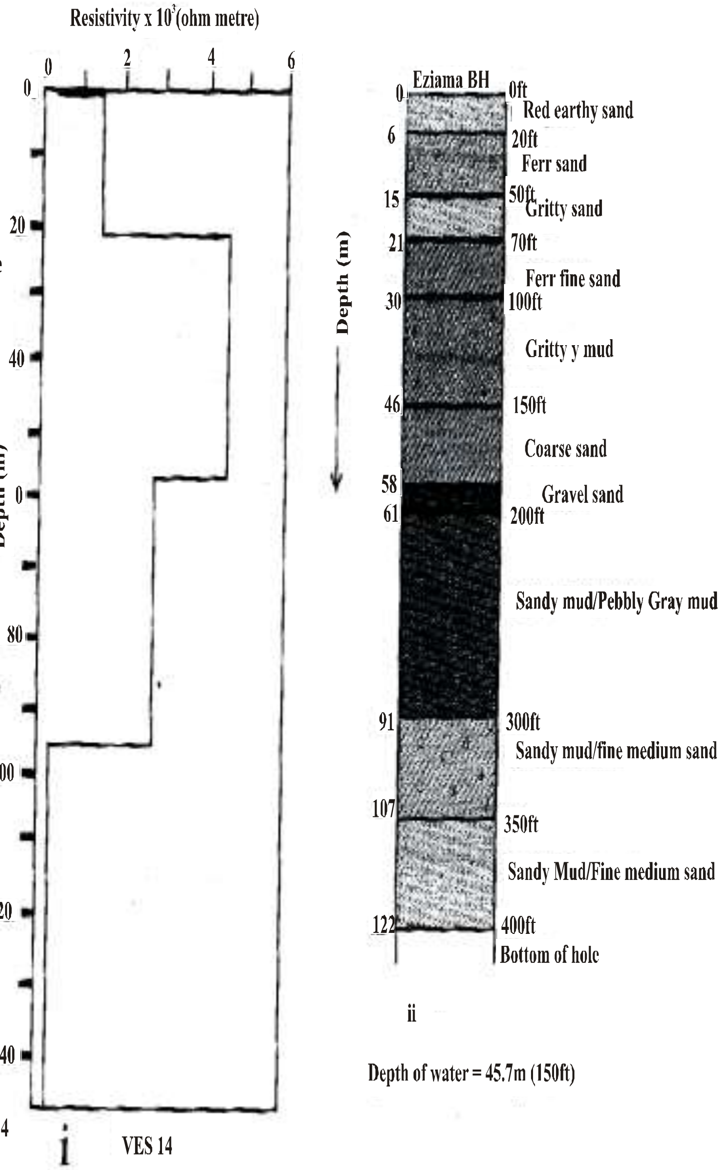


Fig. 3: Typical field and model curves




12 · 6 KM
A
B
Lateritic Soil
medium coarse sand
aquifer
lignite
Clayey Sand
DEPTH (m)
0
2
4 KM
Interpretative Geoelectric cross-section (IGCS) along AB.





(I) Geoelectric Section of VES 14 near the borehole
(ii) Lithologylog from Eziama Osuama borehole

(i) Geoelectric Section of VES 4 near the borehole
(ii) Lithologylog from Obichoro Osu borehole

Figure 5: Geoelectric Section of some sounding stations near borehole and the corresponding lithology

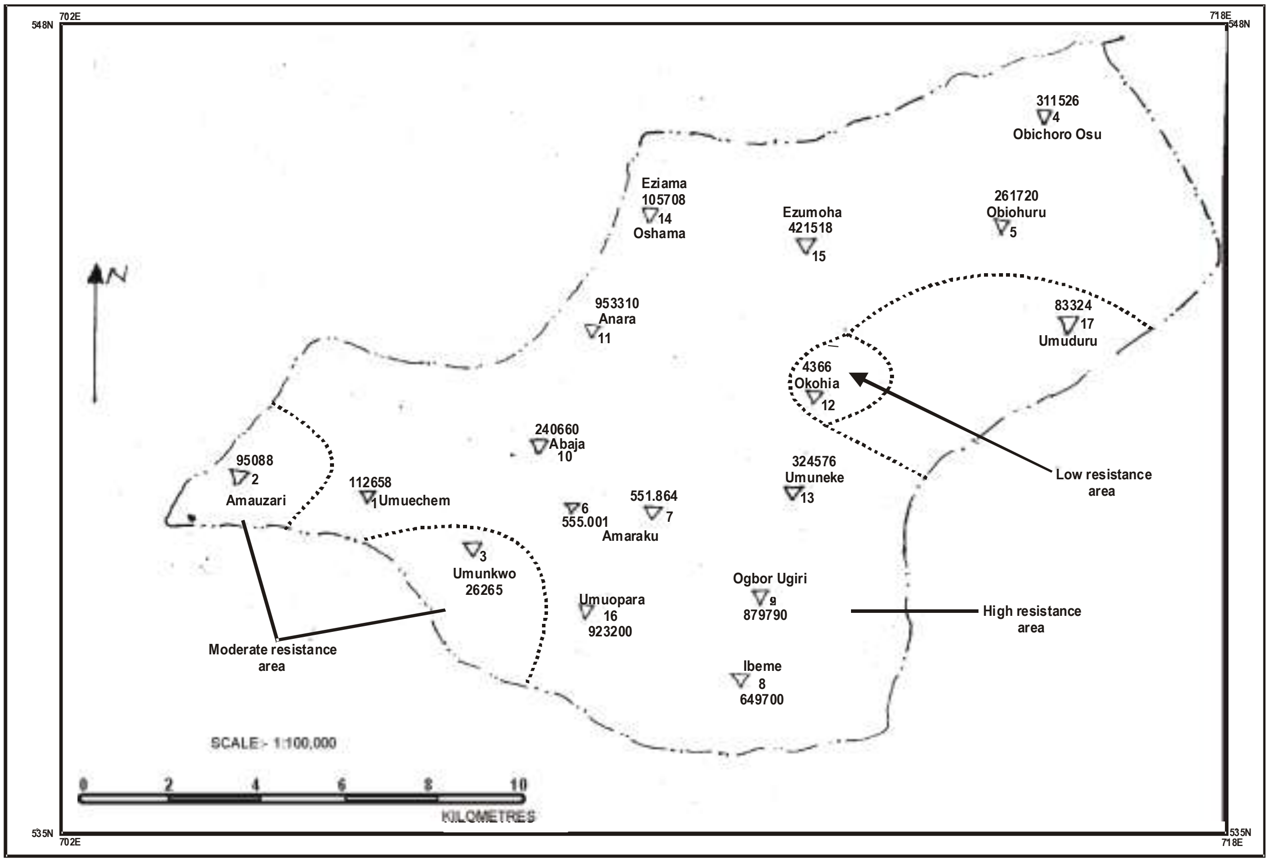


Fig. 6. Distribution of transverse resistance (in ohms)

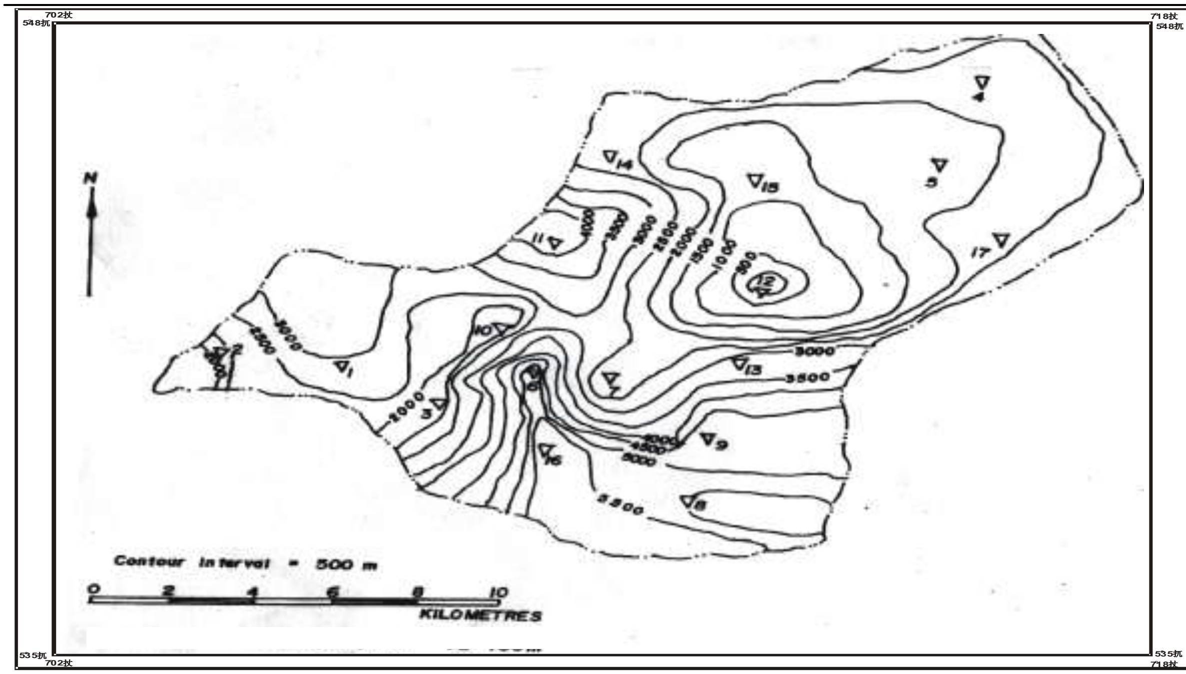


Fig. 7 Isoresistivity map forL/2 = 150m

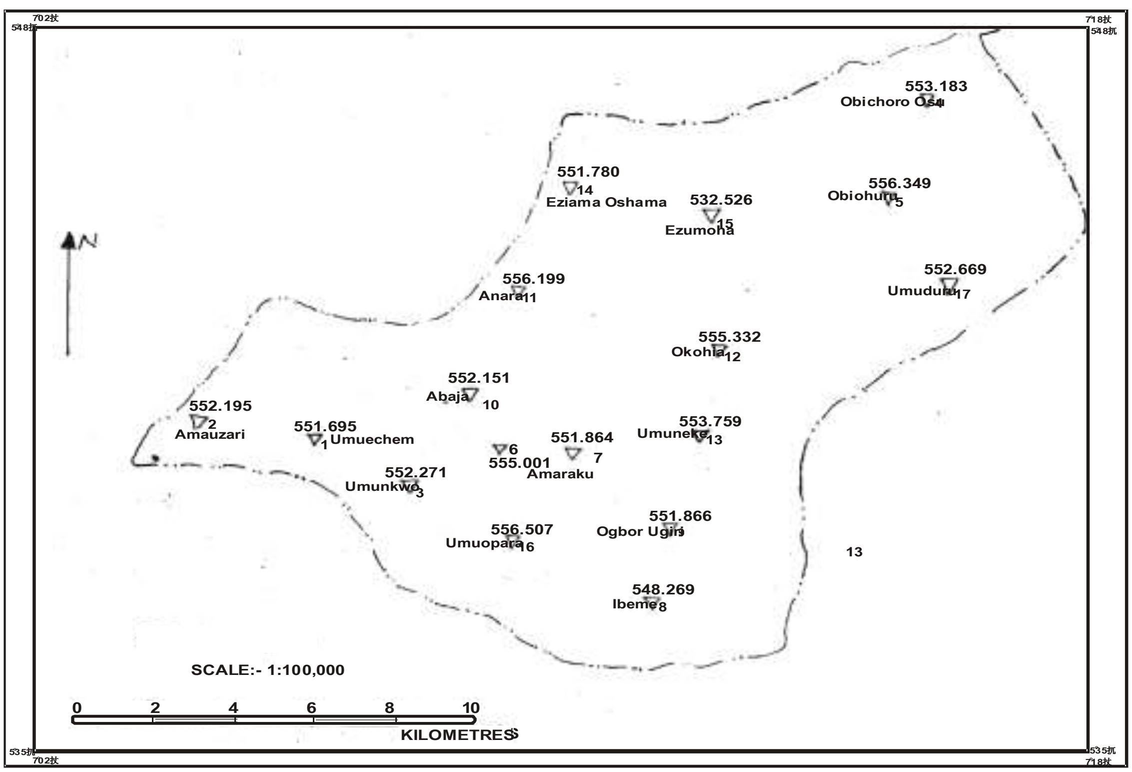


Figure 8. Distribution of Transmissivity values (m^2/day)

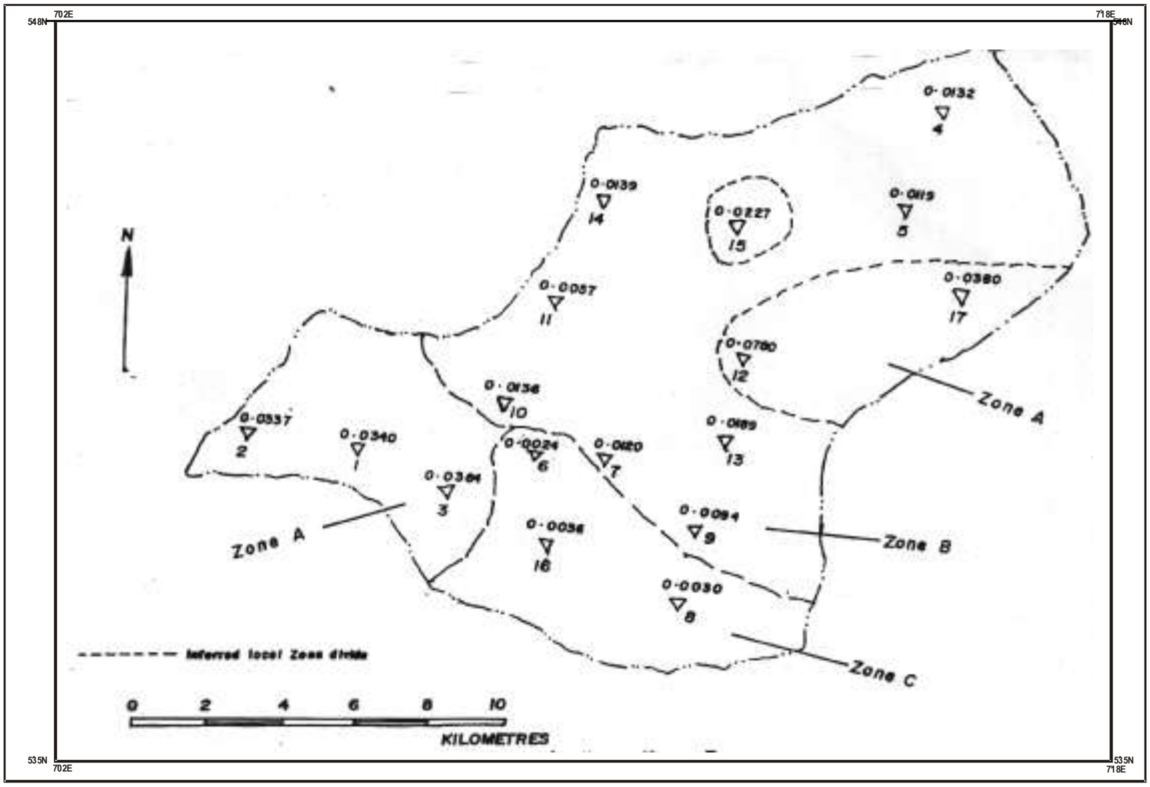


Fig.9. Distribution of longitudinal conductance for the auriferous Zone