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AQUIFER TRANSMISSIVITY DAR ZARROUK PARAMETERS AND GROUNDWATER FLOW DIRECTION IN ABUDU, EDO STATE, NIGERIA

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Abstract: A total of 14 Vertical Electrical Soundings (VES), using the Schlumberger configuration with a maximum current electrode separation of 300m were carried out in Abudu, Edo State, Nigeria, in order to investigate the aquifer transmissivity, Dar Zarrouk parameters and groundwater flow direction of the subsurface layers. The field data obtained were first analyzed by curve matching before computer iteration where the model parameters in terms of resistivity, thickness and lithology of the various layers were obtained. The aquifer hydraulic characteristics of the study area were established using the Zar Zarrouk parameters (transverse resistance, R and the longitudinal conductance, S in porous media). The hydraulic conductivity, kσ values and transmissivity of the layers were obtained for the various locations. Kσ values varies from 0.002 to 0.072 with a mean value of 0.023. The transmissivity value obtained at Abudu was T_{rmax} =288m^2/day (VES 6) T_{rmin} =133m^2/day (VES 14) with T_{rmean} = 241.143m^2/day while the direction of flow is towards the eastern region.
Keywords: Aquifer, Dar Zarrouk, parameters, Abudu, hydraulic conductivity, transmissivity.

INTRODUCTION

Abudu, the study area is the headquarter of Orhionwon local Government Area of Edo State, Nigeria. It is located within latitudes 06^0 15.265^{1}N and 06^0 21.145^{1}N and longitudes 006^0 1.241^{1}E and 006^0 4.109^{1}E.

The area is the equatorial climate made of two main seasons, the dry and wet season. The dry season begins from November and ends in March while the wet season begins from April and ends in October. The inhabitants practice subsistence farming. The area is prone to gully erosion due to the presence of hills and valleys.

High increases in industrial development, urbanization and agricultural production have resulted in freshwater shortages in many parts of the world. As a result of this increasing demand for portable water for these various purposes, there is need to have a planned and optimal utilization of water resources. The water resources of the Benin Owina basin and

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other basins remain almost constant while the demand for water continues to increase (Kumar, 2002).

Aquifer parameter is necessary for the management of groundwater resource. The parameters necessary for the description of the dynamics of aquifer, include, geometry of the pore space, geometry of the rock particles, secondary geologic processes such as faulting and folding and secondary deposition (Udoinyang & Igboekwu, 2012). These parameters jointly affect the rate and pattern of groundwater flow.

The relationships between electrical parameters and aquifer characteristics of the geoelectric layers have been reviewed and studied by many eminent geophysicists (Kelly, 1977; Niwas & Singhai, 1981; Onuoha & Mbazi, 1988, Egbai *et. al* , 2013).

There is the realization that the integration of aquifer parameters which have been calculated from existing borehole locations and subsurface resistivity values got from resistivity measurements can be highly effective since relationship between hydraulic and electrical aquifer properties can be possible as both properties are related to the pore space structure and heterogeneity (Kosinki and Kelly, 1981; Niwas *et. al*, 2006; Soupios *et. al* , 2007).

The transmissivity of an aquifer is a measure of its ability to transmit water over its entire saturated thickness. The higher the higher transmissivity, the more productive the aquifer and the less draw down is produced in a well during pumping. Similarly, well yield is a measure of the quantity of water that can be pumped continuously from a well and delivered per unit of time. The magnitude of both transmissivity and well yield are dependent on the characteristics of the geologic formation or aquifer storing the groundwater.

The aim of this study is to carry out a detailed geophysical and hydrogeological survey in the determination of aquifer transmissivity, groundwater flow direction and to propose, design criteria to enhance the likelihood of successful boreholes. It will also enable us develop a conceptual model for Dar Zarrouk parameters and the direction of groundwater flow in the study areas. The Dar Zarrouk parameters S and T may be of direct use in aquifer protection studies and evaluation of hydrologic properties of aquifers. The geology of the area could be seen from the work of Egbai.

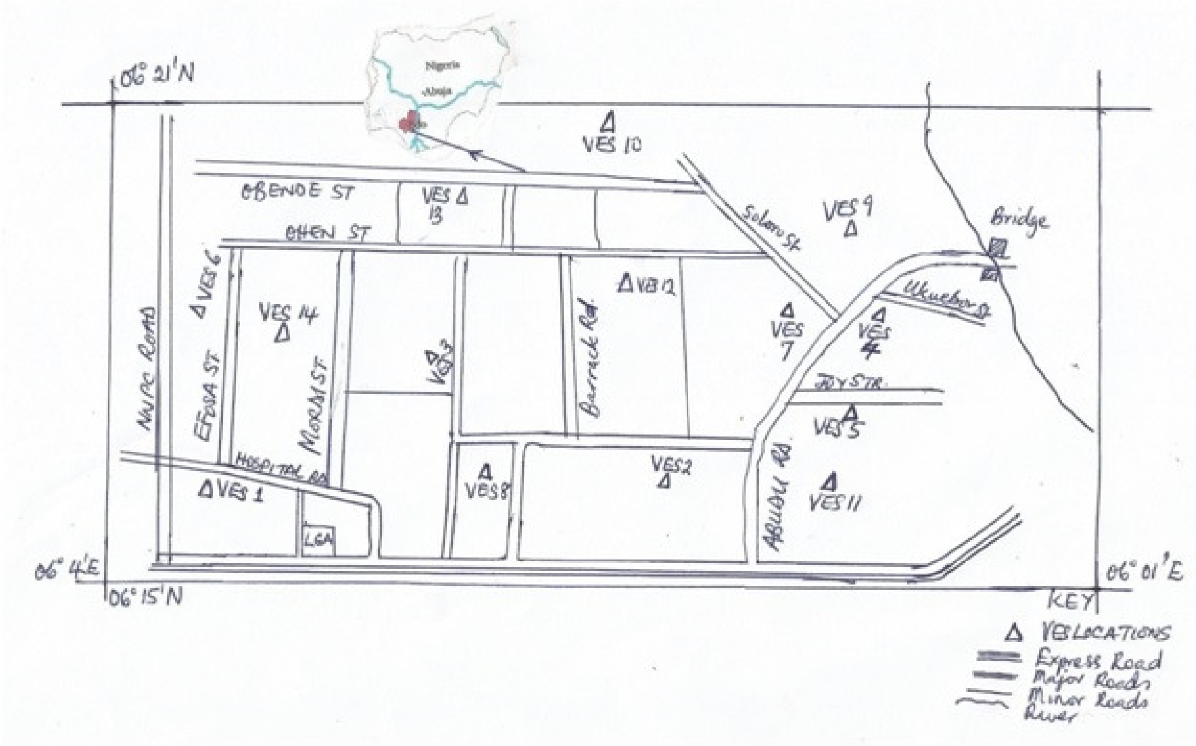

Figure 1: Sketched map of the studied area showing VES locations

METHODOLOGY AND DATA OF ACQUISITION

The Schlumberger configuration with a maximum current electrode (AB/2) separation of 300m was adopted. Fourteen vertical electrical soundings (VES) were carried out to evaluate the aquifer characteristics and groundwater flow directions in the area of the research. The VES locations are as shown in figure 1. The potential electrode (MN/2) was increased several times during the sounding from 1.0m to 20m. The Abem Terrameter SAS 100 was used for data acquisition in the field as shown in figure 3. The apparent resistivity is given by:

$$e_a = \frac{\pi\left(\frac{L}{2}\right)^2 \left(\frac{b}{2}\right)^2}{b}\frac{\Delta V}{I} = \pi\left\{\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right\}\frac{\Delta V}{I}$$

where L= distance between the two current electrodes

b= distance between the two potential electrodes

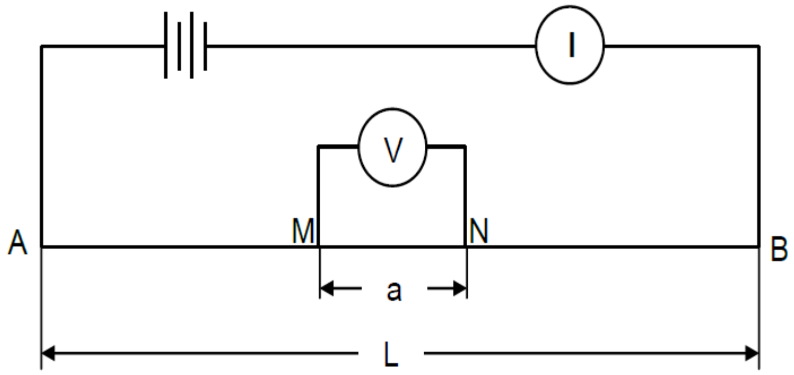

Figure 2: Schlumberger Configuration

A corresponding of apparent resistivity was plotted against current electrode spacing for the various VES location. The curve was smoothened by partial curve matching. The curved matched data was used for computer iteration using WinResist software (Vander Velpen, 2004).

Some parameters are generally very important in the understanding and interpretations of geological model hence the lithological condition, hydraulic and electrical conductivities are generally controlled by the same physical parameters. These parameters are related to different combination of the thickness and resistivity of each geoelectric layers in the model (Zohdy, 1974, Orella, 1972, Braga *et al,* 2006).

For a sequence of horizontal, homogeneous and isotropic layers of resistivity and e_1 thickness h_i, the Dar Zarrouk parameters (longitudinal conductance S and transverse resistance T_R are respectively defined as :

$$S = \frac{h_1}{e_1} + \frac{h_2}{e_2} + \frac{h_3}{e_3} + ---\frac{h_n}{e_n} = \sum_{i=1}^{n} \frac{h_i}{e_i}$$

$$T_R = e_1h_1 + e_2h_2 + ---e_nh_n = \sum_{i=1}^{n} e_ih_i$$

The relationship between aquifer transmissivity, and longitudinal conductance could be written as $Tr = K\delta R = \frac{KS}{\sigma}$

where Tr= aquifer transmissivity, K= hydraulic conductivity, σ = electrical conductivity (reciprocal of resistivity), R = transverse resistance and S = longitudinal conductance.

K value is taken as 10m/day (MNT, 1974) for calculating transmissivity at Abudu, the area of the study.

The determination of the direction of groundwater flow of an aquifer in the study area, Abudu was carried out by the groundwater level measurement, relative geographic position of the wells and elevation were collected and contoured using Sulphur 8 software, thereby generating groundwater surface map. The direction of groundwater movement can be understood in the fact that groundwater level is typically highest to the discharge areas where groundwater level is lowest (Egbai & Efeya, 2013).

The knowledge of the direction of flow of groundwater is important so as to know where refuse dump could be sited since water contaminants move generally in the direction of groundwater flow.

Table 1 shows the Geoelectric parameters and lithologic delineation at Abudu while Table 2 is the Dar Zarrouk parameters at Abudu. Table 1 model parameters which indicates the total number of layers, resistivity of various layers, thickness, depth, lithology and curve types for the 14 locations in Abudu.

Model Parameters

Table 1: Geoelectric Parameters and lithologic delineation at Abudu

VES	Layers	Resistivity Ωm	Thickness M	Depth M	Lithology	Curve Type	Rms % Error
1	1	1536.3	0.8	0.8	Lateritic Topsoil	KHKQ $\rho_1<\rho_2>\rho_3<\rho_4>\rho_5>\rho_6$	2.5
	2	2950.5	3.6	4.4	Clayey sand		
	3	1010.0	14.8	19.2	Fine to medium sand		
	4	4410.6	28.1	47.3	Medium sand		
	5	3634.6	24.0	71.3	Medium to coarse sand		
	6	1330.9	-	-	Coarse sand		
2	1	120.7	0.9	0.9	Lateritic Topsoil	HKHK $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5>\rho_6$	7.2
	2	29.6	1.7	2.6	Clay sand		
	3	989.8	8.8	11.4	Fine to medium sand		
	4	52.9	33.3	44.7	Clay sand		
	5	1211.9	20.3	65.0	Medium to coarse sand		
	6	1432.7	-	-	Coarse sand		
3	1	577.5	1.0	1.0	Lateritic Topsoil	QHKQ $\rho_1>\rho_2<\rho_3<\rho_4>\rho_5>\rho_6$	2.3
	2	272.0	5.5	6.5	Clayey sand		
	3	72.7	15.9	22.4	Clay sand		
	4	293.0	25.9	48.3	medium sand		
	5	255.6	29.6	77.9	Medium to coarse sand		
	6	47.5	-	-	Clay sand		
4	1	269.2	1.0	1.0	Lateritic Topsoil	HAKQ $\rho_1>\rho_2<\rho_3<\rho_4>\rho_5>\rho_6$	2.3
	2	171.4	5.1	6.1	Clayey sand		
	3	382.5	15.7	21.8	Fine to medium sand		
	4	499.3	25.2	47.0	medium sand		
	5	421.1	29.2	76.2	Medium to coarse sand		
	6	222.3	-	-			

					Clayey sand		
5	1 2 3 4 5 6	754.2 587.3 875.5 369.6 943.6 4836.3	0.9 4.6 19.4 28.7 23.0 -	0.9 5.5 24.9 53.6 76.6 -	Lateritic Topsoil Clayey sand Fine to medium sand Medium sand Medium to coarse sand Coarse sand	HKHA $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	2.5
6	1 2 3 4 5 6	2889.3 1131.4 5006.4 1248.2 2363.4 5389.1	1.5 4.5 16.0 28.8 27.6 -	1.5 6.0 22.0 50.8 78.4 -	Lateritic Topsoil Clayey sand Fine to medium sand Medium sand Medium to coarse sand Coarse sand	HKHA $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	2.5
7	1 2 3 4 5 6	174.4 23.3 1143.4 65.4 138.6 1181.2	0.4 1.4 7.7 22.4 25.3 -	0.4 1.8 9.5 31.9 57.2 -	Lateritic Topsoil Clay sand Fine to medium sand Clay sand Clayey sand Coarse sand	HKHA $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	7.2
8	1 2 3 4 5 6	1605.9 1049.5 2293.7 374.4 938.0 4254.8	0.8 3.2 8.0 22.6 21.3 -	0.8 4.0 12.0 34.6 55.9 -	Lateritic Topsoil Clayey sand Fine to medium sand Clayey sand Medium to coarse sand Coarse sand	HKHA $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	2.5
9	1 2 3 4 5 6	959.1 422.2 2793.2 675.6 1491.2 5214.8	0.9 2.8 8.2 19.4 19.8 -	0.9 3.7 11.9 31.3 51.1 -	Lateritic Topsoil Clayey sand Coarse sand Medium sand Medium to coarse sand Coarse sand	HKHA $\rho_1>\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	3.6
10	1 2 3 4 5 6	2058.8 2884.6 1786.7 3444.0 3085.9 1832.6	0.9 5.1 14.0 27.5 29.0 -	0.9 6.0 20.0 47.5 76.5 -	Lateritic Topsoil Medium sand Clayey sand Medium sand Medium to coarse sand Fine sand	KHKQ $\rho_1<\rho_2<\rho_3<\rho_4<\rho_5<\rho_6$	2.4
11	1 2 3 4 5 6	113.4 246.2 117.4 529.3 778.7 1009.1	0.8 3.8 12.8 26.7 14.6 -	0.8 4.6 17.4 44.1 58.7 -	Lateritic Topsoil Clayey sand Fine to medium sand Medium sand Medium to coarse sand Coarse sand	KHAA $\rho_1<\rho_2>\rho_3<\rho_4<\rho_5<\rho_6$	2.5

12	1	87.7	1.0	1.0	Lateritic Topsoil	AKHA $\rho_1<\rho_2<\rho_3>\rho_4<\rho_5<\rho_6$	3.1
	2	498.2	3.8	4.8	Clayey sand		
	3	1737.7	10.8	15.6	Fine to medium sand		
	4	392.5	22.8	38.4	Medium sand		
	5	1258.4	20.1	58.5	Medium to coarse sand		
	6	5214.3	-	-	Coarse sand		
13	1	7631.1	0.5	0.5	Lateritic Topsoil	QHKQ $\rho_1>\rho_2>\rho_3>\rho_4>\rho_5>\rho_6$	2.5
	2	2974.2	2.9	3.4	Medium sand		
	3	1251.7	9.4	12.8	Fine to medium sand		
	4	4471.7	23.0	35.8	Medium sand		
	5	1791.4	26.0	61.8	Medium to coarse sand		
	6	1391.3	-	-	Coarse sand		
14	1	16.4	0.5	0.5	Lateritic Topsoil	KHAK $\rho_1<\rho_2>\rho_3<\rho_4<\rho_5>\rho_6$	5.7
	2	214.6	2.6	3.1	Clayey sand		
	3	19.7	14.2	17.3	Clay sand		
	4	170.9	13.3	30.6	Medium sand		
	5	2742.1	18.0	48.6	Medium to coarse sand		
	6	2416.9	-	-	Coarse sand		

Table 2: Dar Zarrouk Parameters at Abudu

VES	Aquifer Resistivity *e* (Ωm)	Aquifer Thickness h	Aquifer Conductivity σ = 1/*e*	Longitudinal Conductance S = σh	Transverse Resistance R=h*e*	Transmissivity Tr = kh	Quantity kσ
1	4410.6	28.1	0.0002	0.0056	123937.86	281.0	0.002
2	1211.9	20.3	0.0008	0.0162	24601.57	203.0	0.008
3	293.0	25.9	0.0034	0.0881	7588.70	259.0	0.034
4	499.3	25.2	0.0020	0.0504	12582.36	252.0	0.020
5	369.6	28.7	0.0027	0.0775	10607.52	287.0	0.008
6	1248.2	28.8	0.0008	0.0234	35946.16	288.0	0.072
7	138.6	25.3	0.00072	0.1822	3506.58	253.0	0.027
8	374.4	22.6	0.0027	0.06102	8461.44	226.0	0.015
9	675.6	19.4	0.0015	0.0291	13106.64	194.0	0.015
10	3444.0	27.5	0.0003	0.0087	94710.00	275.0	0.003
11	529.3	26.7	0.0019	0.0504	14132.31	267.0	0.019
12	392.5	22.8	0.0025	0.0581	8949.00	228.0	0.025
13	4471.7	23.0	0.0002	0.005	102849.10	230.0	0.002
14	170.9	13.3	0.0059	0.0778	2272.97	133.0	0.059

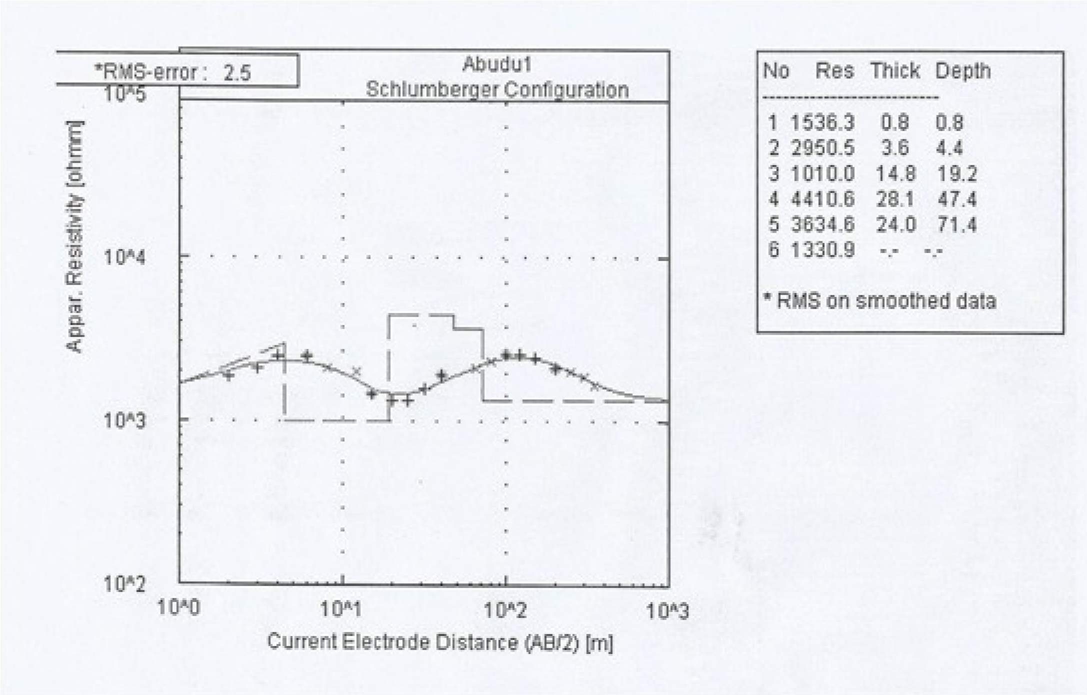

Figure 3: Sounding curve for VES 1 at Abudu

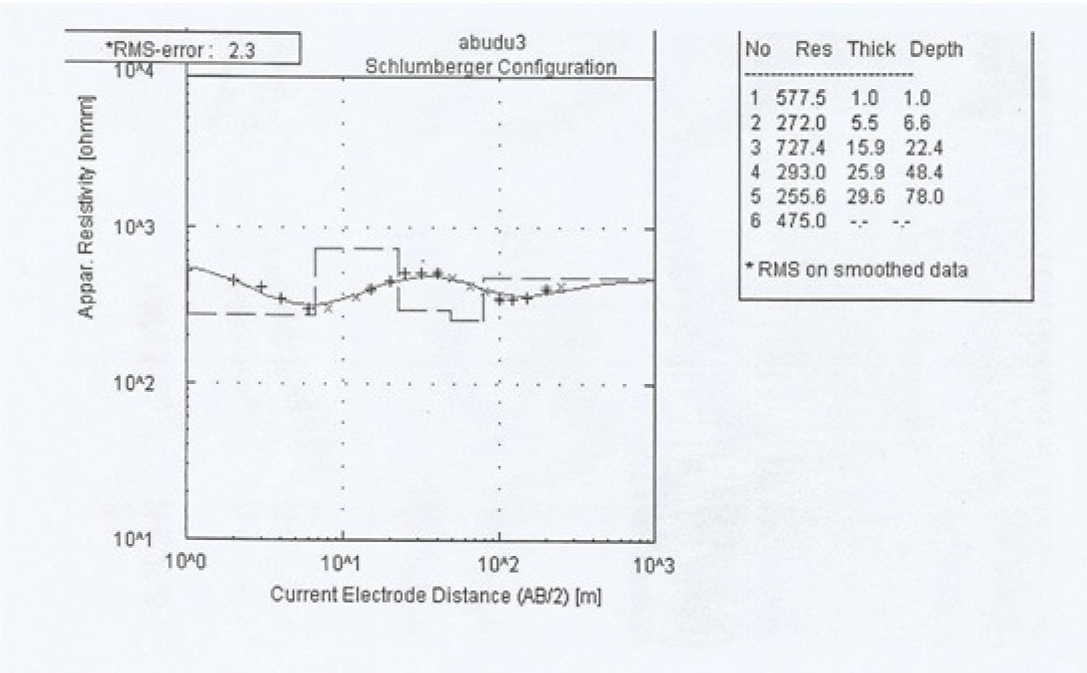

Figure 4: Sounding curve for VES 3 at Abudu

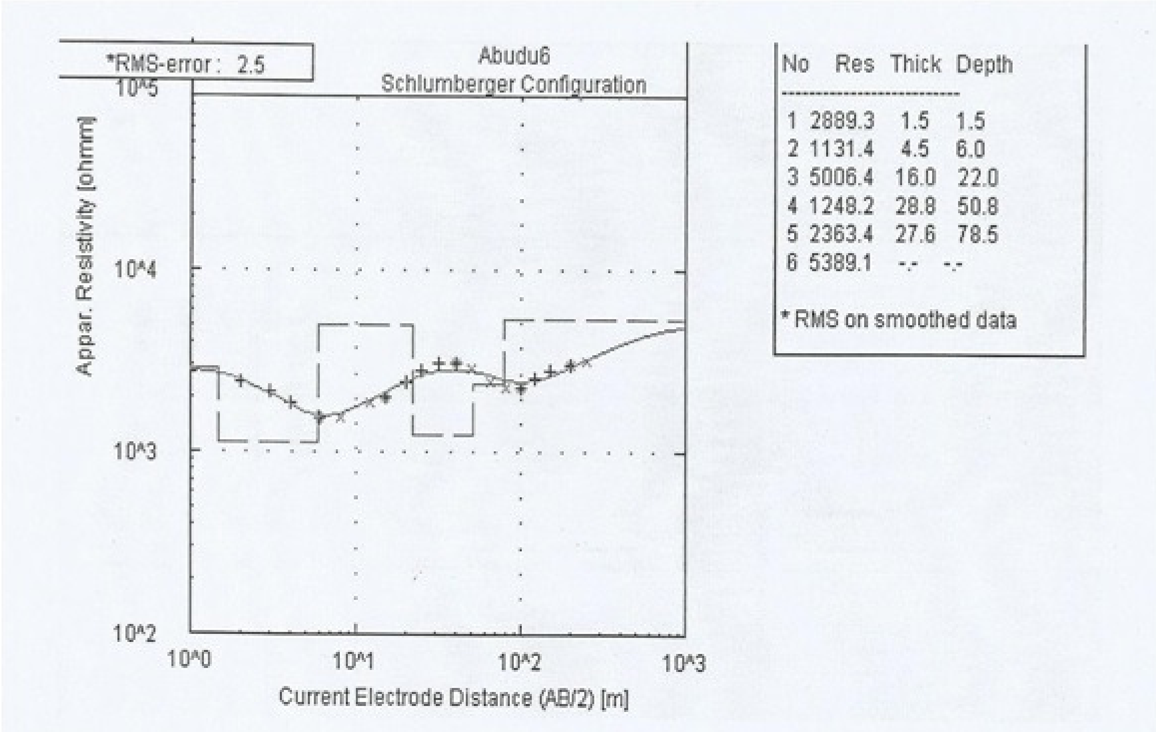

Figure 5: Sounding curve for VES 6 at Abudu

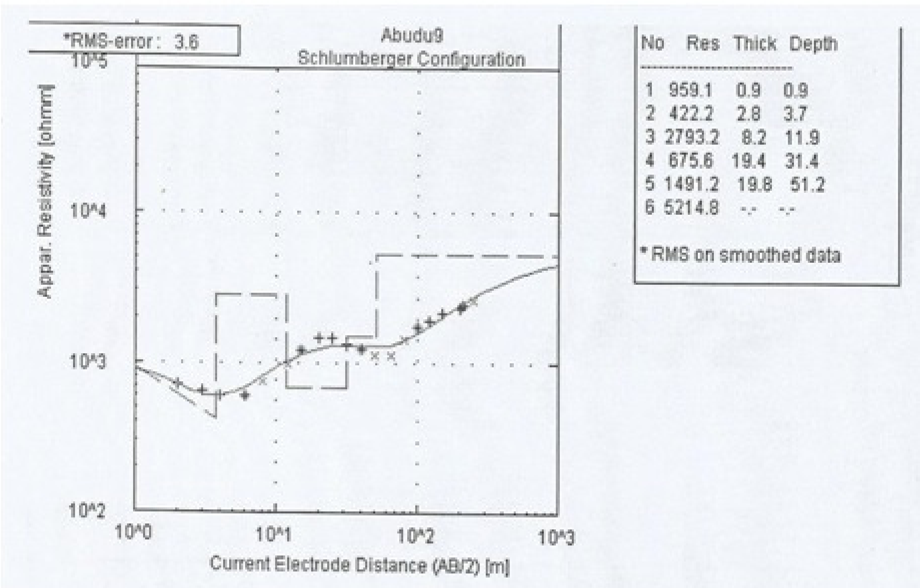

Figure 6: Sounding curve for VES 9 at Abudu

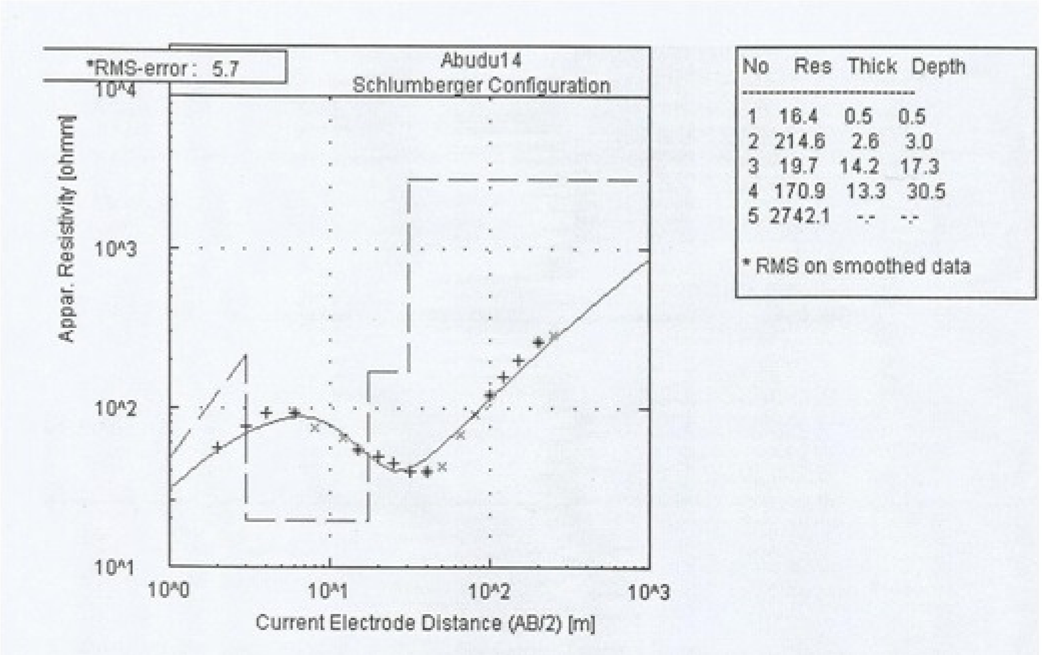

Figure 7: Sounding curve for VES 14 at Abudu

RESULTS AND DISCUSSION

The various aquifer characteristics of Abudu, the studied area are shown in Table 1 and 2. Fourteen VES were conducted at Abudu. The fourteen locations are made of six layers. The lithology consists of lateritic topsoil, clayey-sand, clay, fine-medium grained sand, medium sand, medium to coarse sand and coarse sand.

In Abudu, the topsoil is lateritic with resistivity ranging from 16.4Ωm to 2889.3 Ωm and the thickness ranging from 0.5 to 1.5m.

The second layer is mostly clayey sand except location 2 and 7 which is made up clay. This layer has resistivity ranging from 171.4 Ωm to 2950.5 Ωm with thickness varying from 2.6 m to 5.5m while location (VES) 2 has resistivity 29.6 Ωm and thickness 1.7m and location (VES) 7 has resistivity 23.3 Ωm with thickness 1.4m.

The third layer is made up of fine to medium sand except VES 3 and 14 made up of coarse sand and clay respectively. The third layer has resistivity ranging from 117.4 Ωm to 5006.4 Ωm and thickness varying from 7.7m to 19.4m. The resistivity for the third layer for VES 3 and 14 are 72.7 Ωm and 19.7 Ωm with thickness of 15.9m and 19.7m respectively.

The fourth layer is medium sand, except location 2, 7 and 8. VES 2 and 7 is made up of clay while VES 8 is clayey sand. The resistivity of this layer ranges from 52.9 Ωm to 4471.7 Ωm with thickness varying from 13.3 to 33.3m.

The fifth layer is medium to coarse sand except VES 7 which is made of clayey sand. The resistivity of this layer ranges from 138.6 to 3634.6 Ωm with thickness varying from 17.2 to 29.6m.

The sixth layer is made of coarse sand except VES 3, 4, 10 and 13 made of clay, clayey sand, fine sand and fine sand respectively. The resistivity of this layer ranges from 47.5 to 5389.1 Ωm. The thickness of the layer cannot be determined as the current electrode terminated in this layer. Figures 3 to 7 show the typical curves for Abudu geophysical investigation.

The aquifer hydraulic characteristics of the study area were established using the Dar-Zarrouk parameters (transverse resistance, R and longitudinal conductance, S in porous media).

The quantities Kσ and K/σ are taken to be fairly constant within the area of study. If the hydraulic conductivity and electrical conductivity of the existing boreholes at Abudu, the value of the transmissivity from one location to the other can be estimated using the Dar-Zarrouk parameter from each aquifer. Table 2 shows the values of hydraulic conductivities and transmissivity for Abudu, the research area: Kσ values varies between 0.002 to 0.072 with a mean value of 0.023. The minimum value of Tr = 133m^2/day and maximum value of Tr = 288m^2/day and a mean of Tr = 241.143m^2/day. This shows that VES has the highest potential for productive aquifer since it has the transmissivity of 288m^2/day. This is followed by VES 5 and VES 1 of transmissivity of 287m^2/day and 281m^2/day respectively. The lowest aquifer transmissivity are VES 14 and VES 9 having 133m^2/day and 194m^2/day respectively. The area is good for productive boreholes having high transmissivity.

Figures 8 shows the groundwater flow direction which flows in the eastern direction while figure 9 shows contour map of equal elevation in Abudu.

CONCLUSION

Fourteen VES were conducted in Abudu with a view of studying the aquifer transmissivity, Dar-Zarrouk parameters and groundwater flow direction. The lithology shows that a lateritic topsoil, clayey soil, fine-medium grained sand, medium sand, medium to coarse sand and coarse sand.

The transmissivity value obtained at Abudu was Tr_{max} = 288m^2/day, Tr_{min} = 133m^2/day with Tr_{mean} = 241.143m^2/day. This is good for sedimentary basin of Abudu.

The direction of groundwater movement shows that it flows in the direction of decreasing head. The flow is in the eastern direction while the contor maps shows area of equal elevation.

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